COMPARISON OF LARGE SCALE RENEWABLE ENERGY PROJECTS FOR THE UNITED STATES AIR FORCE

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Abstract

This thesis focused on the performance of large-scale renewable energy projects for the United States Air Force. As global energy demands continue to rise, the need to find ways to save energy and produce alternative sources of energy will increase. The Federal Government has begun to address the challenge of energy production and energy security in recent years. In order to increase both the energy production and energy security for the Air Force, there is a trend to increase the amount of renewable energy produced on military installations. The goal of this research was to compare the estimated and actual performance of these large-scale on-site renewable energy projects at Air Force installations. The variables considered for this research were the execution methods and the renewable energy sources. The performance of each project was evaluated against factors identified in previous sustainable construction studies. The study found that actual performance of third party owned and operated projects differed from the expected performance by less than the Air Force owned and operated projects, and that performance of renewable energy projects differed from the expected performance by less than high performance buildings from previous studies. The study also found factors that contributed to the gap between the expected and actual performance including optimistic modeling, unusual weather, operational issues and higher than expected maintenance of the projects. The results of this research were an initial step in understanding the actual performance of large-scale renewable energy projects.

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1 Introduction

As global energy demands continue to rise, the need to find ways to save energy and produce alternative sources of energy will increase. The Federal Government has begun to address the challenge of energy production in recent years. With each new policy or executive order, the government has addressed a variety of sustainable energy areas including reducing energy intensity, pollution prevention and waste minimization, increasing renewable energy use, reducing green house gases, improving water use efficiency and management, and sustainable procurement (EPACT 2005, EISA 2007, EO 2007, EO 2009). The themes that appear repeatedly are the need to reduce energy use and to increase the current energy supply. These requirements are especially applicable to the Department of Defense, which is currently the largest energy user in the Federal Government (DoD 2010).

1.1 Increase Energy Supply

The commitment to increase energy supply is seen as necessary in order for the United States to enhance its energy security. The increase in energy can be separated into energy for aviation, vehicles, and infrastructure. There are technology developments toward alternative fuels for all of these categories. Although the energy for aviation is the largest portion of the DoD's energy consumption, this study focuses on the energy supply for infrastructure (USAF 2010). The alternative fuels for infrastructure include wind, water, and solar technologies. The North American Electric Reliability Corporation identified major technologies including:

- Wind Generation – Wind systems convert air movement into electricity through the rotary motion of wind turbines. Wind farms include on- and offshore projects with the capability of one turbine reaching 5 MWs and total capacity over a gigawatt.
- Solar Generation – Solar systems include solar thermal generation and solar photovoltaic generation. Solar thermal systems are comprised of a system that collects solar energy and converts the energy into heat and then converts the heat into electricity. Solar photovoltaic systems convert sunlight straight to electricity.
- Hydrokinetic Generation – Hydrokinetic systems include hydroelectric power, wave power and tidal power (NERC 2009).

Jacobson and Delucchi conducted research considering the potential of providing all of the necessary global energy through wind, water and solar power. In addition to the technologies listed in the NERC report, the Jacobson study considered geothermal technology. The geothermal power plants considered generate power through steam rotating turbines (Jacobson & Delucchi 2011). Additional opportunities that are being pursued include biomass, waste-to-energy and landfill gas-to-energy technologies.

1.2 Defense Renewable Energy Opportunities

In recognition of the need to increase the use of renewable energy, Congress requested the Department of Defense (DoD) conduct an assessment of renewable energy alternatives at or near military installations in 2004. The study evaluated the potential impact on energy security, developed purchasing strategies and developed a roadmap for future development. The study considered 900 installations covering 22 million acres. From the original pool of installations, the study detailed installation specific assessments including 18 geothermal assessments, 75 wind development assessments and 430 solar assessments. Three of the 18 assessments were favorable for the geothermal installations. The opportunities for wind generation were found to be 70 MWs. The potential for solar existed at all 430 sites inspected including grid-connected systems, hybrid PV/diesel for remote locations, solar hot water, transpired heat collectors, and daylighting opportunities. Table 1 summarizes the opportunities identified by the assessment in terms of renewable energy source and execution method. The Department of Defense report of this assessment was completed in 2005 and outlined the short- and long-term strategies to increase the DoD's renewable energy use (DoD 2005). The study found that the on-installation production of renewable energy should be pursued to gain energy savings, reduce dependence on fossil fuels and increase energy security. According to the report the installations assessed had the potential to produce between 1% and 6% of the DoD's electricity use. To construct these projects, the DoD would need to pay for projects through the Military Construction (MILCON) Energy Conservation Investment Program (ECIP) program or attract third party contractors willing to own, operate and maintain large-scale projects on federal property.

Table 1: Potential Renewable Energy Production for DoD (DoD 2005)

Finance Source	**Wind**		**Geothermal**		**Solar PV**		**Solar Thermal**	
	Sites	**MW**	**Sites**	**MW**	**Sites**	**MW**	**Sites**	**MW**
Third Party	2	60.9	4	40	38	56.5	N/A	N/A
MILCON (ECIP)	107	9.2	N/A	N/A	4	12.2	up to 430	25
Total	109	70.1	4	40	42	68.7	up to 430	25

The report also noted several challenges in the pursuit of these on-site renewable energy opportunities including access to third party funding, conflicts with electric utilities, possible conflicts with military operations, and higher cost of MILCON projects because the government cannot benefit from state and federal tax incentives (DoD 2005).

1.3 Energy Mandates

Over the last decade, the Federal Government has released several policies and mandates related to energy. The policies included provisions for reducing energy consumption, improving energy efficiency and increasing renewable energy. The following documents directly impact the current renewable energy requirements for agencies in the Federal Government.

1.3.1 Energy Policy Act 2005

The Energy Policy Act (EPACT) of 2005 addressed energy production in the United States including energy efficiency, renewable energy, Tribal Energy, electricity, energy tax incentives, and hydropower and geothermal energy. The EPACT 2005 required the increase of renewable energy production as a percentage of total electricity use by the Federal Government to the extent economically feasible (EPACT 2005). The EPACT of 2005 required the percentage of total energy the Federal Government consumed during the fiscal year from renewable energy be:

a) Not less than 3 percent in fiscal years 2007 through 2009
b) Not less than 5 percent in fiscal years 2010 through 2012
c) Not less than 7.5 percent in fiscal years 2013 and thereafter (DOE 2008)

1.3.2 Executive Order 13423

The Executive Order (EO) 13423, "Strengthening Federal Environmental, Energy, and Transportation Management," was signed on January 24, 2007 by President Bush. It set numerous federal energy requirements in several areas including the increased use of renewable energy. EO 13423 mandated that all federal agencies ensure a minimum of 50 percent of required renewable energy consumed by agencies to be from a new source. A new source was defined as energy produced from projects completed after 1999 (EO 2007). EO 13423 also required that federal agencies ensure to the greatest extent possible, implementation of renewable energy generation projects on agency property for agency use (DOE 2008).

1.3.3 Energy Independence and Security Act

The Energy Independence and Security Act (EISA) of 2007 focused on energy security, vehicle fuel economy and renewable fuel production. The Act required federal agencies to reduce energy intensity by 3 percent annually through FY 2015. Federal construction of new buildings and major renovations were required to reduce fossil fuel energy use by 55 percent in 2010 and 100 percent in 2030. The Act also mandated the design and construction of high-performance federal buildings. The EISA stated that a minimum of 30 percent of hot water demand for new construction and major renovations be met through the installation of solar hot water heaters if they are life-cycle cost effective. This life cycle cost can be calculated by using the Building Life Cycle Cost (BLCC) program, which conducts economic comparison of the cost effectiveness of building systems. By considering the life-cycle cost of a building or system BLCC can identify projects that might have a higher up front cost but still make sense over the life of the project. For example, although the solar water systems might have a higher initial cost, they should also have a lower operating cost. All of these provisions increased the emphasis on energy use and production; however, two provisions were removed from the final bill that would have impacted renewable energy production. First, the Senate removed a renewable portfolio standard requiring utilities to produce 15 percent of their power from renewable energy. Second, a tax provision repealing oil and gas tax breaks and using the money to fund renewable energy projects and research was also deleted from the bill (DOE 2007). The EISA requirements do not directly affect the projects in this study; however, the study does cover some state mandated renewable portfolio standards and their impact on the large-scale renewable energy projects. As of March 2009, 33 states had established renewable portfolio standards or goals. These states vary on the minimum requirements of renewable energy, timelines, and sources of renewable energy that count toward the standards (EPA 2009). Table 2 displays the renewable energy standards for states discussed in this study. The requirements in the state RPS encourage some energy companies to be more proactive in their development of renewable technologies. An example of this is the solar array project at Nellis AFB. The RPS, tax incentives and sale of RECs were enough of a driver that the energy company made an unsolicited offer to build a solar array on Nellis AFB.

Table 2: State RPS Requirements (EPA 2009)

State	Target (% of electric sales)	Specific Provisions (% of electric sales)
CO	IOUs 20% by 2020; electric cooperatives and municipal utilities 10% by 2020	IOUs: 0.4% solar by 2020
MA	Class I: 4% by 2009 (+1%/year after); Class II: 3.6% renewable, 3.5% waste energy by 2009; APS: 5% by 2020 increasing by 0.25% each year after	Class II: 3.6% renewable, 3.5% waste energy by 2009
NV	20% by 2015	1% solar by 2015
OH	25% by 2025 (12.5% renewable energy)	1% solar by 2025
VT	Goal of 20% by 2017; Total incremental energy growth between 2005-2012 to be met with new renewables (10% cap)	

1.3.4 Executive Order 13514

Executive Order 13514, "Federal Leadership in Environmental, Energy, and Economic Performance," recommended that agencies consider increasing the use of renewable energy and implementing renewable energy generation projects on agency property. Additionally, in response to E.O. 13514, every agency of the Federal Government was required to develop and implement a strategic sustainability performance plan (EO 2009). This study will discuss the strategic sustainability performance plans for 2010 and 2011.

1.3.5 United States Code Title 10 § 2911

The United States Code Title 10 outlines the role of the armed services in the United States Code. Section 2911 of Title 10 relates to the energy performance goals and master plan for the Department of Defense. It requires the Department of Defense to produce or procure 25 percent of total energy consumed by its facilities from renewable energy sources by 2025. This goal is important when considering the long-term planning of the renewable energy projects because the requirement is significantly higher than the earlier mandates (10 U.S.C § 2911 2010). This includes all renewable energy used for electricity and thermal energy. This study will only consider the electricity portion of this mandate.

1.3.6 Summary of Mandates

The Energy Policy Act of 2005 required the percentage of total energy the Federal Government consumed during the fiscal year from renewable energy to be at least 7.5 percent in fiscal years 2013 and thereafter. EO 13423 mandated that all federal agencies ensure a minimum of 50 percent of required renewable energy consumed by agencies to be from a new source. The EISA stated that a minimum of 30 percent of hot water demand for new construction and major renovations be met through the installation of solar hot water heaters if they are cost effective. E.O. 13514 required every agency of the Federal Government to develop and implement a strategic sustainability performance plan. The United States Code Title 10 Section 2911 required the Department of Defense to produce or procure 25 percent of total energy consumed by its facilities from renewable energy sources by 2025. The trend of the policies from 2005 through 2011 has been to continually raise the target of renewable energy production as part of electrical consumption from three percent in 2009 to 25 percent by 2025.

1.4 Current Policy and Goals for DoD

The Department of Defense's Installations Energy Management Program developed a core strategy to improve facilities management (DoD 2009). This strategy seeks to reduce energy demand, increase energy supply, support technology innovation and improve energy security.

In response to Executive Order 13514, the Department of Defense's first Strategic Sustainability Performance Plan was released in 2010 (DoD 2010). Objective 1 of the plan focused on ensuring continued availability of resources critical to the DoD mission, and goal 1: Reducing the use of fossil fuels. The plan reinforced the path for increased renewable energy in order to meet the department's sustainability goals (DoD 2010). Goal 1 was separated into 3 sub-goals as seen in Table 3. The second sub-goal in Table 3 displays the milestones needed to reach the 20 percent goal for renewable energy by 2020. If the DoD met these milestones, it would be on track to meet the 25 percent goal for renewable energy by 2025.

Table 3: DoD SSPP Goal 1 - The Percent Use of Fossil Fuels Reduced (DoD 2010)

Sub-Goal	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
1.1: Energy Intensity of Facilities Reduced by 30% from FY 2003 by FY 2015 and 37.5% by FY 2020	11.4	18	21	24	27	30	31.5	33	34.5	36	37.5
1.2: By FY 2020, Produce or Procure Energy from Renewable Sources to at Least 20% of Electricity Consumed by Facilities	9.6	11	12	13	14	15	16	17	18	19	20
1.3: Use of Petroleum Products by Vehicle Fleets Reduced 30% from FY 2005 by FY 2020	5.3	12	14	16	18	20	22	24	26	28	30

The portion of the plan regarding energy intensity reiterated the need for increased renewable energy use. The energy intensity of the Department of Defense was reduced by 11.4 percent between 2003 and 2010; however, the total energy consumption has increased by 3.1 percent over the same timeframe (DoD 2010). The rise in total consumption was attributed to enhanced training requirements, growing troop levels, and increased facility activity supporting contingency operations. This trend supports the need to increase renewable energy production in order to offset the growing energy requirements.

1.5 Status Reports

Several documents have measured the DoD's progress toward meeting the renewable energy goals. After implementing the plan in 2010 each agency was evaluated by the Office of Management and Budget (OMB). The OMB released a scorecard in April 2011 rating the performance of the each federal agency in terms of meeting seven sustainable goal areas. The goal areas include energy and water intensity reductions, vehicle fuel reduction, greenhouse gas emissions, green building practices and renewable energy use. Table 4 displays the goals of each of the areas used in the OMB scorecard.

Table 4: Sustainability/Energy Scorecard Goals (OMB 2011)

Area	Goal
Scope 1 & 2 Greenhouse Gas (GHG) Emission Reduction	Reduce scope 1 & 2 GHG emissions by 34% by 2020
Scope 3 GHG Emission Reduction Target	Reduce scope 3 GHG emissions by 13.5% by 2020
Reduction in Energy Intensity	Reduce energy intensity in EISA goal-subject facilities by at least 18 % compared with 2003 and on track for 30% reduction by 2030
Use of Renewable Energy	Use at least 5% electricity from renewable sources as a percentage of facility electricity use & at least 2.5% of facility electricity comes from new sources (post-1999)
Reduction in Potable Water Intensity	Reduce water intensity by at least 8 percent from 2007 baseline and on track for 26% reduction by 2015
Reduction in Fleet Petroleum Use	Reduce petroleum use in vehicle fleet compared to 2005 by 20 percent by 2015.
Green Buildings	Implement Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings for new, existing and leased buildings for 15% of buildings >5,000 GSF

The results showed that the DoD was behind schedule in four of the seven areas including the use of renewable energy. According to the scorecard, the DoD consumed 4.1 percent of its energy from renewable sources compared to the EPACT 2005 target of 5 percent (OMB 2011). The results from the OMB scorecard support a Government Accounting Office report (GAO 2009), in which the Government Accounting Office (GAO) reviewed the DOD's renewable energy initiatives and challenges in meeting federal renewable energy goal. The GAO report found that the DoD lacked the methodology to calculate its progress toward meeting the energy mandates. It also noted the need to develop information systems or processes that will enable the services to monitor and coordinate their consumption of renewable energy and aid in achieving their renewable energy goals.

In addition, the Department of Defense produced annual energy reports for 2009 and 2010 that measured its progress toward the renewable energy goals. The reports for the DoD are a function of the three military branches, Army, Air Force and Navy, which comprise it. For each branch of the military, the renewable energy total includes the renewable energy generated onsite, renewable energy purchases from the local utilities, and the purchase of renewable energy certificates. The bases that generate renewable energy on-site and retain the renewable energy certificates receive bonus credit toward the mandates. This bonus is equal to the amount of the certificates that are retained. During fiscal year 2009, the DoD spent $3.6 billion on facility energy. Electricity use accounted for about 45 percent, and the DoD used renewable energy for 3.6 percent of its electricity. This renewable energy included self-generated renewable energy, purchased renewable energy and renewable energy certificates. Figure 1 displays the DoD trend for meeting the EPACT 2005 renewable energy goal (DoD 2011). As discussed in the OMB scorecard, the DoD fell short of the 5 percent goal despite the Air Force buying a significant number of renewable energy certificates.

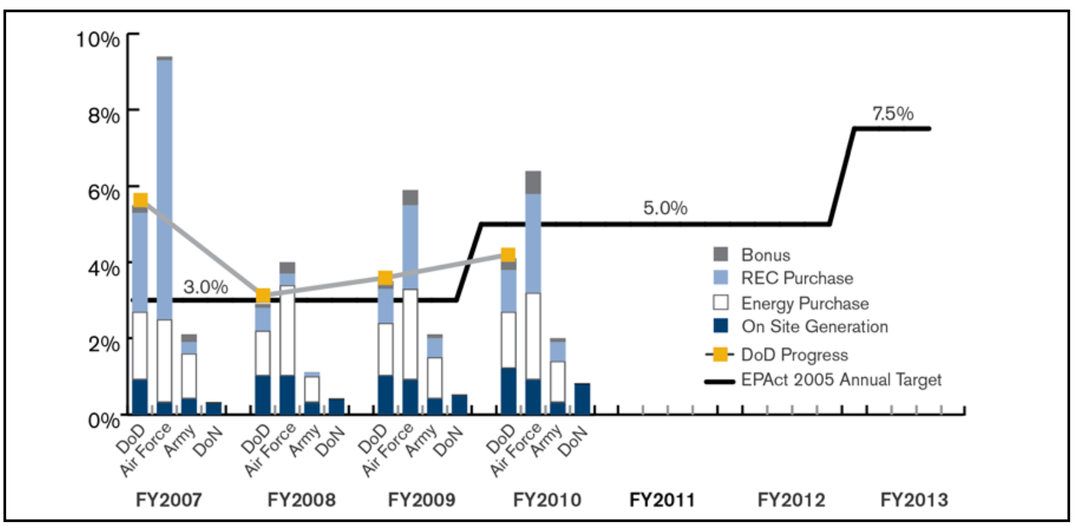

Figure 1: DoD Renewable Energy Trend Towards EPACT 2005 Goal FY 2010 (DoD 2011) (http://denix.osd.mil/sustainability/upload/DoD-SSPP-FY11-FINAL_Oct11.pdf) (public domain)

Renewable Energy Certificates (RECs) represent the environmental and non-power attributes of renewable electricity generation. RECs are generated for each MWh of electricity a renewable energy source produces. By purchasing RECs, the buyer is able to make environmental claims about how their electricity was generated. Each REC includes the type of renewable energy source that produced the electricity, the date the REC was created, the location of the generation, eligibility for renewable portfolio compliance and any green house gases associated with the generation of the electricity. It is important to note that RECs are not electricity; they are certificates that allow a buyer to claim the electricity they used from the grid was produced by a renewable source. In order to claim the environmental benefits of the REC, a buyer must retire the certificate in order to prevent two claims for the same renewable production (EPA 2008).

As the largest energy user in the Federal Government, the Department of Defense is an integral part of how the country achieves its renewable energy goals (USAF 2010). By utilizing the feasibility studies completed in 2005, the DoD has started to pursue large-scale renewable energy projects. However, the federal mandates call for continued increase in the amount of renewable energy the DoD produces. Although the DoD exceeded the goals in from 2007 to 2009, it failed to meet the goals in 2010. This emphasized the need to keep pursuing renewable energy projects now and in the future. It is important to see how the Department of Defense will address the gap between the mandated and actual renewable energy production.

2 Background

The Department of Defense is the largest consumer of energy in the Federal Government (Figure 2). As the largest consumer of energy in the Department of Defense, Figure 3, and the Federal Government overall, the Air Force needs to be a leader in measures of energy reduction and renewable energy production (USAF 2010). The Air Force accounts for 64 percent of all energy consumed by the DoD. Flight operations account for 84 percent of the Air Force's energy consumption, facility operations account for 12 percent and vehicles account for 4 percent (USAF 2010). The Air Force has focused on energy reduction for almost thirty years, reducing energy by 30% between 1985 and 2005 and with goals to reduce it by another 30% by 2015 (AFFEC 2011). However, the Air Force still has a challenging road ahead in order to achieve the 25 percent renewable energy goal by 2025. The Air Force has created a renewable energy project development process in an attempt to streamline the project execution process (AFCESA 2011a). This development process includes four avenues to increase renewable energy use including Air Force owned projects, third party owned projects on installations, renewable energy purchases from off-site sources, and purchases of renewable energy certificates. The Air Force is currently pursuing projects for biomass, landfill gas, and waste to energy opportunities in addition to solar, wind and geothermal. As these projects begin to operate, the Air Force will need to compare actual performance with the expected performance.

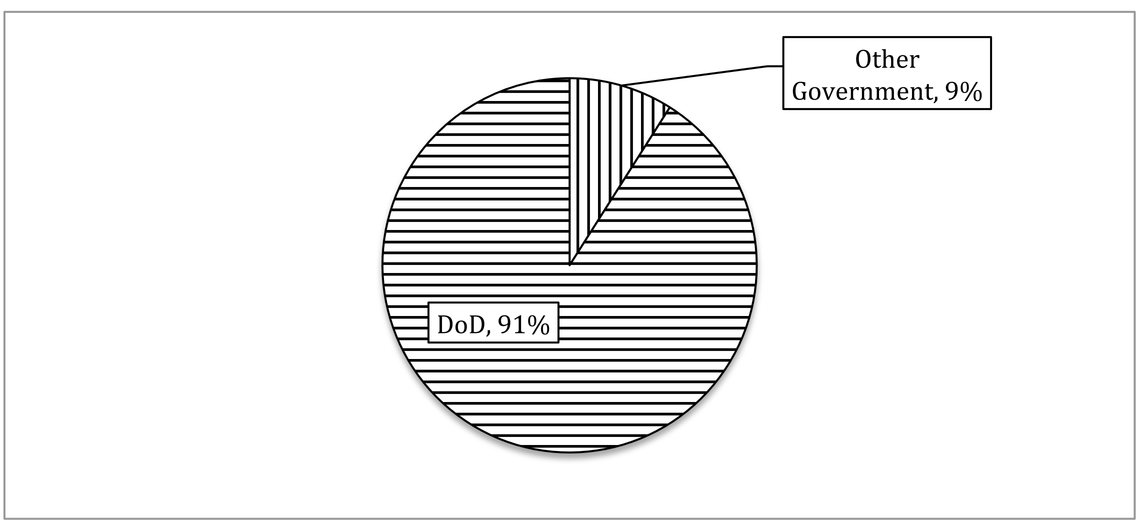

Figure 2: Federal Government Energy Consumption FY 2008 (USAF 2010)

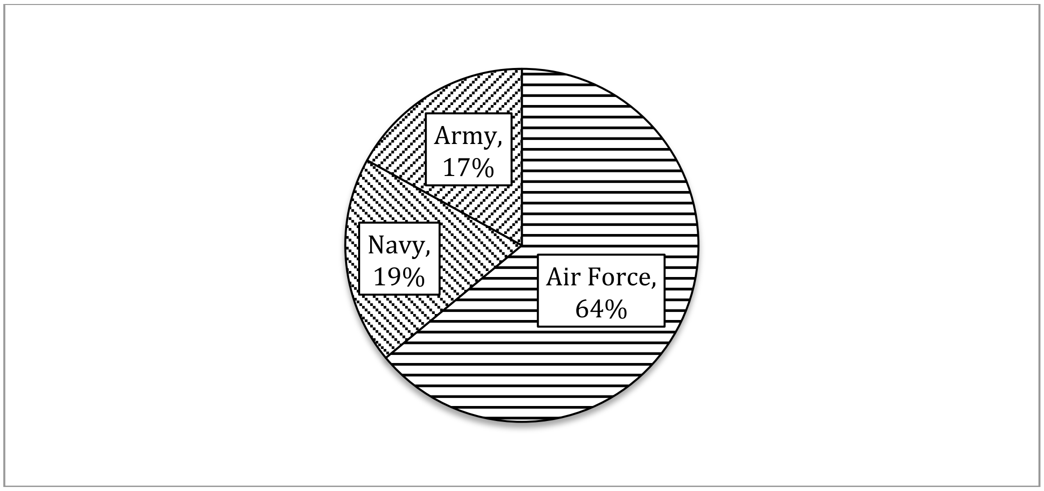

Figure 3: DoD Energy Consumption FY 2008 (USAF 2010)

2.1 Project Development Process

The Air Force's Renewable Energy Playbook describes the project development process for executing potential renewable energy projects at the installation level (AFCESA 2011b). The playbook is a nine-step process to identify requirements, feasibility and construction of renewable projects. The first step is to assess renewable resources. Bases evaluate renewable energy project concepts at their locations. This process includes assessing renewable resources, tracking and evaluating new technology, assessing mission impacts and assessing state laws. Following this process, each base will have a prioritized list of possible projects. Each installation's list is then consolidated by the Air Force Facility Energy Center to form a prioritized list based on the projects providing the most benefit to the Air Force. The next step involves studying and evaluating each opportunity to determine which will make viable projects. The main portions of this process are conducting a feasibility study, opportunity assessment and business case analysis. The factors that the Air Force Civil Engineer Support Agency (AFCESA) considers for evaluating projects are the renewable energy source availability, economics, land availability, mission impact and support from the local utility company (AFFEC 2011). The project viability is dependent on the resource availability and economics. The economics of each project considered the life-cycle cost, which takes into account the resource quality, energy costs, taxes and incentives of a project. This process was streamlined by AFCESA in 2010, by completing feasibility studies at every stateside Air Force installation. This allowed every site to be considered based on the greatest benefit for the Air Force.

Following the 2010 feasibility studies, AFCESA conducted opportunity assessments at the most attractive sites in 2011. The results from the opportunity assessment allowed the Air Force to further narrow the pool of potential projects. Once the business case analysis is done and a project is considered viable, the execution method will be determined. The Infrastructure Energy Implementation Plan defines the development of on-site renewable energy resources to the extent economically and technically feasible as the first step in meeting the 25% renewable goal by 2025 (AFFEC 2011).

2.2 Project Execution Methods

All projects that are feasible for on-site energy generation will be either Air Force owned and operated or owned and operated by a third party. Third party owned projects are typically executed as a Power Purchase Agreement (PPA) (AFFEC 2011). As seen in Figure 1, the Air Force has been unable to meet the renewable energy goals completely with on-site renewable energy production, relying on purchases of off-site renewable credits to meet policy requirements. Thus more options have been pursued since 2007 in order for the Air Force to meet energy goals (DoD 2011). The second option the Air Force pursues is the procurement of power from off-site resources delivered over the power grid. This is possible in states that allow for competitive purchases of electricity and has accounted for about 15 percent of the Air Force electricity requirements. The last option that the Air Force pursues is the purchase of renewable energy certificates. Table 5 displays the goal to limit the amount of off-site renewable energy purchases and renewable energy certificates the Air Force purchases while continuing to increase the overall amount of renewable energy the Air Force uses (AFFEC 2011).

Table 5: Execution Method for Renewable Energy Purchases (AFFEC 2011) (https://newafpims.afnews.af.mil/shared/media/document/AFD-120113-017.pdf) (public domain)

	FY11	FY12	FY13	FY14	FY15	FY16
On-base Government owned RE Projects (elec +thermal)	212,701	223,788	410,569	417,621	422,489	422,489
Direct Bundled RE Purchases	141,055	141,055	161,305	161,305	161,305	161,305
Utility/Third Party On-base RE Projects	33,933	95,428	208,082	646,301	859,475	987,371
EUL RE Project On-base	-	-	47,304	440,704	671,704	1,254,104
Purchase RECs to meet goals	643,382	654,495	369,422	-	-	-

There are several reasons that the Air Force is trying to limit purchases of off-site renewable energy and renewable energy certificates. First, on-site energy projects increase the energy security for its installations including the physical security of infrastructure and supply. Energy security is a challenge discussed from the National Security Strategy to all of the military branches energy programs. The National Security Strategy (NSS) states that energy security is a necessary component of national security. The NSS calls for a diversification of the nation's energy supply and an increase of renewable energy sources (NSS 2010). The National Defense Strategy (NDS) stated, "The Department is examining its own energy demands and is taking action to reduce fuel demand where it will not negatively affect operational capability (DoD 2008)." The Army Energy Security Implementation Strategy stated, "Energy security for the Army means preventing loss of access to power and fuel sources (surety), ensuring resilience in energy systems (survivability), accessing alternative and renewable energy sources available on installations (supply), providing adequate power for critical missions (sufficiency), and promoting support for the Army's mission, its community, and the environment (sustainability) (USA 2009)." The Department of the Navy's Energy Program for Security and Independence stated, "Energy Security is achieved by utilizing sustainable sources that meet tactical, expeditionary, and shore operational requirements and force sustainment functions, and having the ability to protect and deliver sufficient energy to meet operational needs (USN 2010)." The Air Force's Energy Plan states, "Energy security drives the goals and objectives of the Air Force Energy Plan. Energy security includes physical security of infrastructure and supply, and continuity of operations (USAF 2010)." The Air Force is pursing the concept of energy security by reducing dependence on oil, reducing energy demand and developing alternative and renewable energy supply chains. This will insulate the Air Force from grid failure or supply chain disruptions. With 99 percent of current electricity consumed by the DoD originating outside the installations, there is not sufficient reliability to sustain operations during a long-term outage (USAF 2010). Second, renewable energy certificates are not actual energy, and when the Air Force purchases them, they are an expense that does not contribute to the energy security posture. For this reason, the other military branches are moving away from REC purchases to pursue third-party investments for on-site generation.

2.3 Renewable Energy Sources

Previous research (Duke 2004) completed by the Air Force Institute of Technology confined the feasibility of renewable energy sources to solar, wind and geothermal opportunities. However, there is an increased emphasis on researching renewable energy projects that provide a constant source of energy as opposed to the intermittent production of solar and wind (Gray 2010). The Department of Defense has widened the definition to include: solar, wind, biomass, landfill gas, ocean, geothermal, municipal solid waste, and new hydroelectric generation (DoD 2009). The Air Force is currently pursuing projects focusing on grid-connected generation of electricity from solar, wind, geothermal, biomass, and waste resources. It is also pursuing thermal energy projects from biomass and waste resources. The feasibility of implementing various renewable energy sources varies from base to base according to a nation-wide feasibility study completed by the Air Force (AFCESA 2010). However, each base is not required to meet a particular renewable energy goal because overall policy requirements apply to the Air Force as a whole and not each base specifically (Gray 2011). This idea is important because some installations might have the ability to exceed the requirements, while other bases lack the ability to meet the goals with on-site energy. This idea is supported by the nation-wide feasibility study in 2010 and the opportunity assessments in 2011, which allowed the Air Force to pursue projects that will have the largest benefit to the Air Force in meeting its overall energy goals.

2.4 Current Status

Despite the need to focus on on-site generation for energy security and other reasons, there are relatively few large-scale renewable energy projects currently operating on Air Force installations. The Air Force installations that generate more than two percent of the electrical consumption at that installation from on-site renewable energy are listed in Table 6.

Table 6: Air Force Bases with Largest Percent On-Site Renewable Energy (DoD 2011) (http://denix.osd.mil/sustainability/upload/DoD-SSPP-FY11-FINAL_Oct11.pdf) (public domain)

Installation Name	Renewable Production (million Btu)	Total Consumption (million Btu)	% Consumption Produced On-site
Nellis AFB, NV	115,814	609,351	18%
F.E. Warren AFB, WY	29,778	385,920	7.7%
Charleston AFB, SC	19,171	326,619	5.9%
Offut AFB, NB	45,404	913,838	5.0%
Hill AFB, UT	51,580	2,230,315	2.3%

As the Air Force moves forward with its goal of on-site renewable energy, projections of progress vary widely based on the level of performance expected from on-site renewable energy systems (Figure 4). There will be a need to assess the actual performance of these projects compared with the projected performance in order to give an accurate depiction of progress toward service renewable energy goals and build adequate buffer to meet policy requirements. Figure 4 displays how the current planned renewable energy projects will contribute to the long-range energy goals of the Air Force (AFCESA 2010). Even if all of the projects are 100% successful, the higher of the two lines per year, more projects will be needed to achieve the 25 percent goal by 2025. The Air Force is in the process of identifying these future projects, but accurate prediction of system performance will be essential to planning how resources should be allocated to these projects.

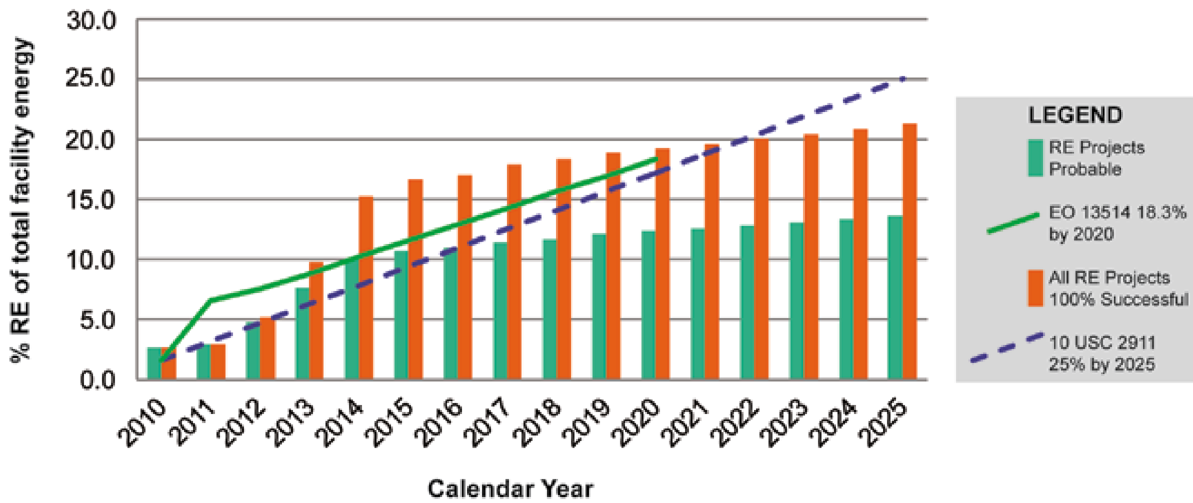

Figure 4: Projected Renewable Energy Percentage (AFCESA 2010) (http://www.afcesa.af.mil/shared/media/document//AFD-110803-041.pdf) (public domain)

2.5 Analysis of Performance

Analysis of a system or structure is a critical step in the life cycle of a project. The monitoring and feedback portion of the process allows for verification of best practices and lessons learned used to improve the next round of the process. The Commission for Architecture and the Built Environment (CABE) identified three distinct elements for the feedback phase of the building design process:

- Review of project performance
- Feedback during one year or more after completion

- Assessing the complete building and its performance in use (CABE 2011)

The benefits of post-occupancy evaluation have been identified in several studies since the 'Probe' studies in 1995. Post-occupancy evaluations are continually used to identify successes and failures in any given project. The CABE cited that a critical step of post-occupancy evaluation is to share these lessons with the relevant professions associated with building systems.

A case study approach was used to conduct a post-occupancy evaluation of an office building in an attempt to close the gap between the predicted and actual performance of non-domestic buildings (Menezes 2011). This study divided POE into three categories:

- Feedback: A management aid aimed at measuring building performance
- Feed-forward: Aimed at improving building procurement by using data as feedback to design teams
- Benchmarking: Aimed at measuring progress toward increasing sustainable construction and stricter targets of energy consumption (Menezes 2011)

Post-occupancy evaluations can be used to verify the facility is performing as designed. Differences can be used to improve future designs and modeling estimates. Although there has not been extensive studies on the post-occupancy evaluation of there have been several studies that examined the actual performance of high performance buildings compared to the expected performance.

2.5.1 Evaluation of High Performance Buildings

The performance of the high performance buildings has been the topic of several studies in the last ten years. These include a study for the National Renewable Energy Laboratory comparing the performance of six high-performance buildings (Torcellini 2004); a post occupancy evaluation report on 10 LEED buildings in the Cascadia Region (Turner 2006); a study conducted by the New Buildings Institute analyzing the energy performance of 121 LEED buildings (Turner 2008); a study examining how LEED buildings maintain their sustainable integrities over time (Cotera 2011); a post-occupancy evaluation of 12 GSA buildings (Fowler & Rauch 2008); a study examining the yearly energy flow of six certified buildings (Newsham, Mancini, and Birt 2009); a study examining the causes of discrepancies between energy modeling predictions and in-use performance of occupied buildings (Menezes 2011); and a study examining the performance of LEED office buildings compared to baseline performance (Scofield 2009).

2.5.1.1 Actual Energy Compared to Design

The 2004 Torcellini study evaluated the energy performance of six high performance buildings across the country. The design goals for the buildings ranged from 40 percent over standard practice to net-zero energy performance. Simulations were used to calculate the design performance for every building, but it was not explained when each simulation was completed. The study did state that none of the design estimates were based on the construction plans for the building. All of the buildings performed better that the baseline buildings; however, none of the buildings performed as well as expected. Table 7 displays the actual and design energy savings for each building. The study did find that the design teams that set the highest energy saving goals resulted in the buildings that had the best performance (Torcellini 2004).

Table 7: Ratio Actual vs Design Energy Savings Compared to Baseline (Torcellini 2004) (http://www.nrel.gov/docs/fy05osti/38080.pdf) (public domain)

Building Name	Actual/Design
Oberlin College	45%
Zion Visitor Center	84%
Big Horn Improvement Center	73%
NREL Thermal Test Facility	24%
Cambria Office Building	67%
Chesapeake Bay Foundation Merrill Center	88%

The 2006 study by Turner examined the actual performance of 11 buildings in the Cascadia. The design estimates were from the LEED Design Energy Cost or Water Use Design Case based on the energy efficiency features in the initial design. The design calculations were not updated to mirror the as-built construction of the buildings. The study found that six of the ten buildings used less energy than their design estimates. The average performance of the buildings was 10 percent worse than the designed estimates. Additionally, none of the building's actual performance was within 20 percent of the design performance. This study also showed how one building could distort the results of a small population. For example if the one removed the building that used 300 percent of the design estimate, the remaining 9 buildings performed 11 percent better than the design estimates (Turner 2006). The results from the 2006 Turner study are summarized in Table 8.

Table 8: Ratio of Actual Versus Designed Energy Use Intensities (Turner 2006) (fair use)

Building Name	Actual/Design
Balfour Guthrie Office	73%
Hillsdale Branch, Multnomah County Library	73%
Jean Vollum National Capitol Center	127%
Anonymous	300%
Seattle Public Library	58%
Viridian Place	124%
PSU Broadway Building	72%
PSU Epler hall	79%
The Henry	63%
Traugott Terrace	129%

The 2008 Turner study compared the Energy Use Intensity (EUI) for the 121 LEED buildings by their certification level. EUI is a measurement that describes a facility's energy use relative to its size. It is calculated by dividing the total energy use of a building by the floor area, usually square footage, of the building. Figure 5 displays the ratio of the design EUI to the measured EUI for all of the buildings. The average ratio for certified, silver, and gold buildings were 0.93, 0.83 and 1.12 respectively. Although these averages show an actual level close to the expected level, Figure 5 displays a wide range of performance for all three certification levels (Turner 2008).

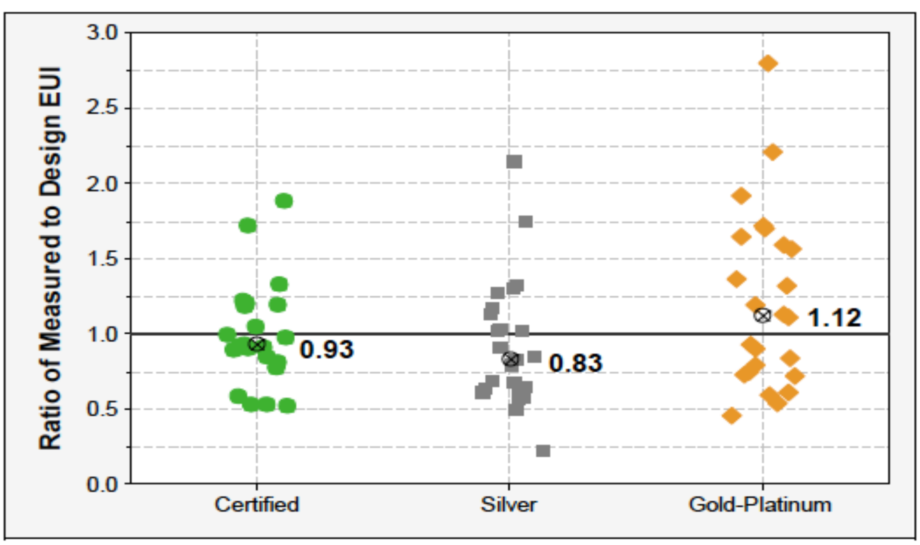

Figure 5: Energy Performance LEED Buildings (Turner 2008) (fair use)

A comparison of the energy savings for these buildings showed a similar range of performance. Turner suggested that the large degree of scatter for these projects indicate opportunities for improvements in the programs and procedures for developing design projections. More than half of the 121 projects exhibited performance more than 25% more or less than the design estimates. Some of the buildings even performed worse the baseline for the project. Further study was recommended for the best and worst performing buildings to identify lessons learned for both. The wide range of performance also indicated a need to improve feedback between the actual performances and the designers who develop the estimated performance for each project. The author also recommended improvements for advanced commissioning and measurement and verification to reach better energy performance (Turner 2008).

In 2009, Newsham, Mancini and Birt reevaluated the data from 100 LEED buildings from the New Building Institute. Similar to the Turner study, the 21 high-energy use buildings from the total 121 buildings were not examined. Newsham found that the LEED buildings save an average of 18-39 percent on energy depending on the parameters of comparison. However, the study also found that 28-35 percent of the LEED buildings used more energy per area than the baseline projects (Newsham, Mancini, Birt 2009).

In 2011, the General Services Administration (GSA) conducted a post occupancy evaluation of 22 sustainably designed buildings across the country. The study identified that the operational cost for buildings in the study was 19 percent lower than the baseline. The buildings in the study also exhibited better energy performance and lower water usage than the baseline. Although the study found that the buildings were outperforming the average building, there was no mention on how the buildings perform compared to expectations (GSA 2011).

The 2011 study by Menezes conducted a post-occupancy evaluation of an office building in central London. The assessment utilized an in-depth monitoring of lighting, small power and catering equipment. Occupant patterns were also monitored by half-hourly inspections. The data collected was used to develop predictive models of energy use. Five models were developed that ranged from 33 percent to 97 percent of actual consumption. A validation of the model achieved predictions within six percent of actual energy consumption. The main issue with this study is that the predictions are developed after the building was built and occupied followed by extensive monitoring of occupant behavior to develop the future prediction of performance. This is impossible to accomplish during the design phase of a building because the occupancy behavior is unknown.

In summary, the Torcellini and Turner studies comparisons between predicted and actual performance for high performance buildings. The Torcellini study found that the actual performance saving was 63 percent of the predicted performance. Only two of the projects were within 20 percent of the expected performance. The 2006 Tuner study found the actual energy use was 110 percent of the projected design. However, none of the building performances were within 20 percent of the predicted performance. The 2008 Turner study found that the actual savings for the buildings was 28 percent compared to the expected 25 percent, or approximately a 12 percent better performance. However, the 2008 study had less than 50 percent of the projects within 25 percent of the predicted performance.

2.6 Factors Impacting Performance

The idea of utilizing a post-occupancy evaluation to reduce the difference between predicted and actual performance by identifying factors that affect the actual performance of the building was supported by a 2011 study (Menezes 2011). Table 9 displays causes of differences between the predicted and actual energy performance of the buildings identified in the Menezes study.

Table 9: Causes of Gap between Predicted and Actual Energy Performance (Menezes 2011) (fair use)

	Causal Factors
Predicted Performance	Design Assumptions
	Modeling Tools
Actual Performance	Management and Controls
	Occupancy Behavior
	Built Quality

The accuracy of the modeling software will have a significant impact on the accuracy of the predicted energy performance of a technology. Software commonly used for predicting performance of solar arrays is the PVWATTS calculator developed by the National Renewable Energy Laboratory. PVWATTS determines the energy production and cost-savings of grid-connected photovoltaic (PV) arrays across the country. The calculator simulates hourly performance to create monthly energy performance in terms of kWs.   The calculation is based on location, size of array, local electricity cost, array type, tilt angle, and azimuth angle. Although many factors are considered in the calculation of solar array performance, NREL found that PVWATTS calculations have an error rate of 10% to 12% compared to long-term performance of solar arrays (Marion 2001). One study collected data from 480 residential and commercial PV installations in Austin Texas (Gostein 2009). Most of the systems were residential systems rated under 4kW. The goal of the study was to compare the actual performance of the systems in Austin to the PVWATTS estimating tool. The Gostein study found that the PV systems underperformed the PVWATTS estimates by an average of eight percent. Another study compared the performance of Enphase microinverter systems to PVWATTS estimates. The study collected performance of 143 Enphase installations and found that Enphase systems outperform PVWATTS estimates by and average of eight percent (Briggs 2011). Both of the studies discussed had results within the expected 10 percent error rate of PVWATTS. However, the Gostein cited expected underperformance and the Briggs found an expected higher performance for the Enphase systems. Two other studies compared the PVWATTS estimates to actual performance and found that PVWATTS over estimated performance by six percent (Dean 2010) and nine percent (Pepper 2006). However neither of these studies examined large-scale renewable projects. The Pepper study examined performance of arrays between 10 and 100 kW and the Dean study performed its analysis on a theoretical model.

On a smaller scale, there have been numerous studies assessing the actual energy performance of green[1] buildings vs. their expected performance. These studies suggested that the actual performance of a facility could differ from the projected performance due to several factors including optimistic modeling, changes in design, commissioning issues and the operation and maintenance of the buildings. The 2004 study examined six green buildings across the US and found that none of them performed as well as predicted. The authors suggested that the difference in performance was due to higher than expected occupant loads, systems not performing together as designed, and optimistic expectations of occupant behavior (Torcellini 2004). Turner found that six of the eleven buildings performed better than the design

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[1] Many of these studies utilize the Leadership in Energy and Environmental Design (LEED) rating system as a means to define what constitutes a green building.

and suggested that the operational variables might have differed from the baseline models to account for this (Turner 2006). The author's subsequent study (Turner 2008) found that although the average performance of the LEED projects was close to the expected performance, more than half of the projects differed by more than 25 percent from the design projections. Some of the common key factors explaining the difference between predicted vs. actual energy performance was summarized in a 2009 study (Newsham 2009). This study found in LEED studies of buildings include the following:

- Occupancy hours can differ from the initial design assumptions
- Final as-built project can differ from the initial design or model
- Experimental technologies may not perform as predicted
- Project might not be commissioned properly

2.7 Point of Departure

Little research has been done to assess the expected and actual performance of large-scale renewable energy projects. In order to assess the success of renewable energy projects, a post-occupancy evaluation (POE) needs to be performed to determine a project's performance (Newsham 2009). Some of the factors from the sustainable building studies may also apply to large scale on-site renewable energy projects to explain performance discrepancies, but to date, no systematic study has been conducted to evaluate the measured actual vs. predicted performance of for USAF renewable energy projects. Although data exists for projected and actual performance for many Air Force renewable projects, there has not been a post occupancy evaluation for these Air Force projects. There is a need to better understand what factors influence actual system performance of renewables when planning projects and allocating scarce funding to meet renewable energy policy mandates and goals.

3 Problem Statement

The usage of renewable energy has increased in the public and the private sector recently. Some companies or agencies purchase enough electricity to account for their entire electricity use. Table 10 lists some of largest purchasers of renewable energy in the United States as of July 2012. Although the Air Force is one of the largest purchasers of renewable energy in the United States, the percentage of total electricity use for the Air Force still lags compared to the other purchasers.

Table 10: Top purchaser of green power (EPA 2012) (http://www.epa.gov/greenpower/toplists/partner100.htm) (public domain)

Organization	Annual Green Power Usage (kWh)	GP % of Total Electricity Use	Green Power Resources
1. Intel Corporation	2,798,660,169	89%	Biogas, Biomass, Small-hydro, Solar, Wind
2. Kohl's Department Store	1,528,378,000	101%	Solar, Wind
3. Microsoft Corporation	1,120,000,000	46%	Biomass, Small-hydro, Wind
4. Wal-Mart Stores	872,382,088	28%	Biogas, Solar, Wind
5. Whole Foods Market	800,257,623	107%	Solar, Wind
6. Lockheed Martin Corporation	546,399,457	30%	Biogas, Small-hydro, Solar, Wind
7. Staples	516,713,408	78%	Biogas, Solar, Wind
8. City of Houston, TX	438,000,000	35%	Wind
9. Starbucks	414,560,000	46%	Biogas, Geothermal, Small-hydro, Wind
10. City of Austin, TX	370,464,066	100%	Wind
18. U.S. Air Force	265,777,826	3%	Biogas, Biomass, Solar, Wind

In order to be successful in its pursuit of renewable energy, each installation to succeed, and in turn the Air Force to succeed in reaching its goals for renewable energy and energy security, it is important to continue to move toward on-site generation of renewable energy (Gray 2010). The main methods for accomplishing renewable energy projects on Air Force bases are through the Energy Conservation Investment Program ECIP program and power purchase agreements (AFCESA 2010). As shown in Figure 6, currently the Air Force was short of the 10% goal of set by Title 10 U.S.C. section 2911 for fiscal year 2010 (DoD 2011).

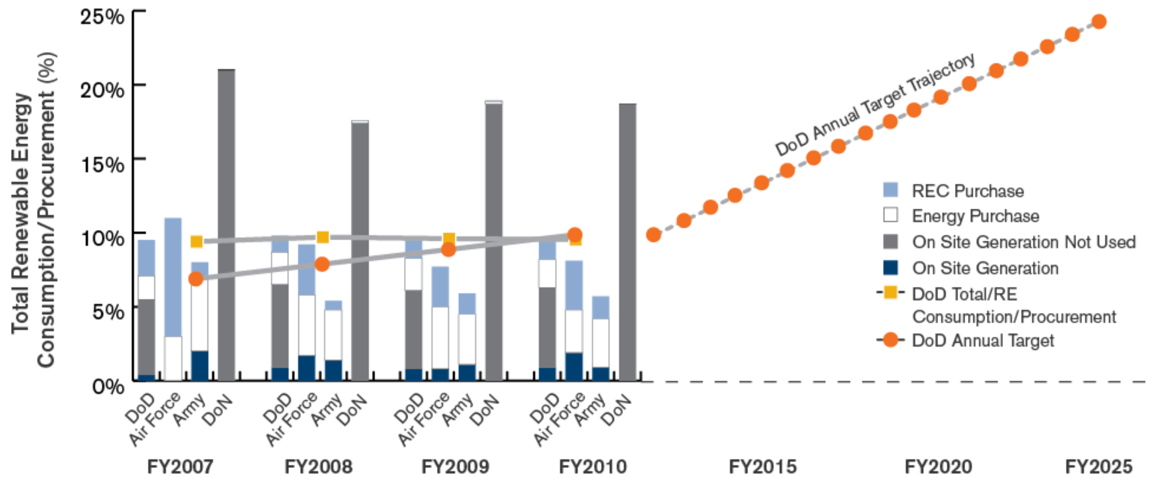

Figure 6: Renewable Energy Trends Toward §2911(DoD 2011)
(http://denix.osd.mil/sustainability/upload/DoD-SSPP-FY11-FINAL_Oct11.pdf) (public domain)

Although there are benefits from both off-site renewable energy purchases and renewable energy credits, increasing the amount of energy produced on base will increase the energy security for the military operations (AFCESA 2010). Thus there is a need to continue to increase the amount of renewable energy produced and consumed on Air Force installations. In order to accurately predict the progress of on-site renewable energy projects, an analysis of actual performance needs to be completed. This analysis does not exist for on-base renewable energy projects in the Air Force.

3.1 Goal and Objectives

The goal of this research is to compare the initial design estimated performance versus actual performance of large-scale on-site renewable energy projects in the Air Force and to compare the factors affecting performance to common factors identified in previous studies as affecting building performance. The initial estimated performance is completed during the design phase of the project. This design can be completed by an Architectural and Engineering design firm or by the energy company contracted to construct the project. The independent variables correlating with performance that will be considered for this research are the execution methods and the renewable energy sources. The execution method impacts the initial cost and life cycle cost of a renewable energy project. Traditionally, a lower initial cost has been more important than a lower life-cycle cost for funding of a project. This is supported by the NDAA of 2011, which limits federal agencies ability to pursue LEED gold or platinum certification if the cost is larger than two percent of the project cost (HR 2011). The availability of renewable energy sources will dictate what types of projects can be pursued for an installation. These two variables are connected to the economics and availability of future projects. Thus they will be critical in the future development of renewable energy for the Air Force and the Department of Defense. The development of renewable energy projects will be limited by the sources that are feasible for any given location and how the project will be financed. The execution methods considered for this study are 1) Air Force owned and operated versus 2) third party owned and operated. By comparing the performance of these two types of projects, this study aimed to determine which one of the execution methods would be most beneficial to the Air Forces and other branches of the Department of Defense. The Air Force is currently pursuing projects utilizing resources including biomass, landfill gas, and waste to energy opportunities in addition to solar, wind and geothermal. Although the Air Force is pursuing projects from these sources, the operational large-scale renewable energy projects are mainly limited to solar arrays and wind farms. For this reason, this study limited its focus to the operational solar and wind projects for the Air Force. The objectives of this research are to accomplish the following:

1. Identify renewable energy projects meeting study criteria at existing Air Force bases. This will include the energy source and execution method for each project
2. Identify the expected and actual energy production of the projects
3. Compare the expected and actual performance for the selected projects
4. Identify the factors that impact energy production and can be used to explain any differences between expected vs. actual

The steps to achieve these objectives are described in the methods section.

3.2 Hypotheses

The primary hypothesis to be tested in this research is that projects developed using the execution method of power purchase agreements will have more accurate predictions of project performance than the Air Force owned and operated method. This is because the profit for the contractor will be reliant on the actual production of the project for the next 20 to 40 years, placing a strong incentive on the contractor to accurately forecast performance. Conversely, projects that are built and owned by the Air Force typically have a warranty period of 12 months and then the original contractor is not responsible for the maintenance and repair of the project. One contractor may complete the design and construction for an Air Force owned and operated project, but the contractor responsible for construction may simply be executing a design completed by another contractor. Conversely, the contractor owned and operated projects are likely to be designed and constructed by the one contractor. Shifting responsibility to installation personnel for the operation and maintenance of the system may lead to greater deviations from predicted performance.

A second hypothesis to be tested is that the actual large scale renewable energy project performance will differ less overall from the expected performance than differences identified in previous studies of buildings as discussed in section 2.5. This is expected because the renewable projects have less dependence on user behavior than the building projects.

4 Methodology

4.1 Population

In order to evaluate the Air Force's large-scale renewable energy projects, a set of potential projects was identified. This research separated these projects into two categories. The first category was on-site government owned and operated facilities. The second category was third party owned and operated facilities. The third party owned and operated projects are typically power purchase agreements for projects on military installations, where the project was located on base, but was owned and operated by the energy company. Other categories of potential consideration were the purchase of renewable energy from sources that are located off-site and provide power directly to the installations and the purchase of renewable energy credits, but these were determined to be outside the scope of this study. A second variable that was considered for this research was the type of renewable energy utilized for the projects. Sources of renewable energy that are being pursued by military installations include solar, wind, geothermal, biomass, landfill gas to energy, and waste to energy. This study chose to focus on the solar and wind projects because they comprise almost all of the operational renewable energy projects that produce electricity.

The Air Force Civil Engineer Support Agency (AFCESA) tracks all of the planned and operational renewable energy projects for the Air Force. The analysis was limited to the first two execution categories (on-site government owned and power purchase agreements), since off-base projects were not expected to have sufficient information for study. This was because the Air Force had no oversight of the projects outside of the installation. This research also concentrated on large-scale utility size projects instead of facility-sized projects because the current effort of Air Force is to study and implement projects on the utility scale (USAF 2010). Utility scale projects are stand-alone projects that supply electricity to more than one facility. Figure 7 displays all of the operational renewable energy projects on Air Force installations across the United States from AFCESA’s database. The list included 18 potential projects using four types of renewable energy including solar, wind, geothermal and landfill gas. However, all of the geothermal projects were ground source heat pumps that are used to produce thermal energy but not electricity. Based on the desire to avoid single facility projects, the existing database of renewable energy projects was reviewed. The capacities of the projects were listed as MMBtu per day or kWs. This study limited the population to projects with a minimum of 500 kW of electricity generation capacity. This allowed the study to concentrate on projects that were stand alone projects as opposed to single facility projects. These considerations provided a sample size of eight sites for analysis. These eight sites included all of the operational large-scale renewable energy projects that produce electricity except for the one project at Hill Air Force Base.

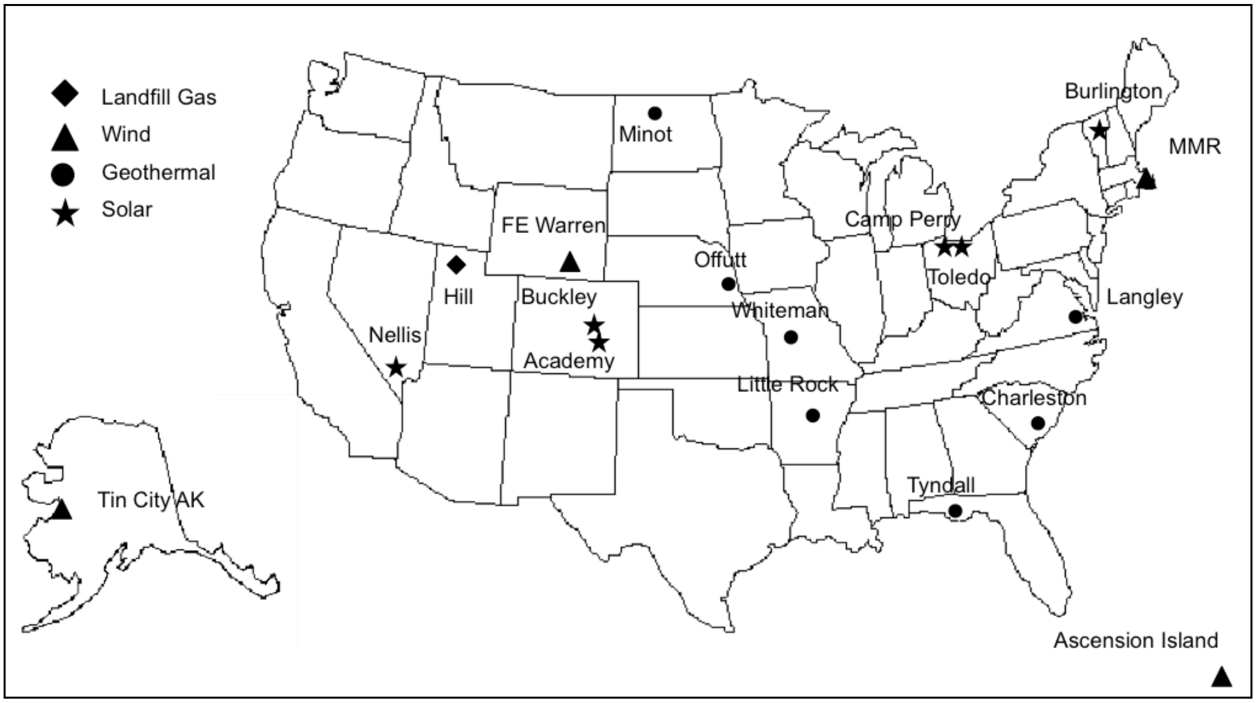

Figure 7: Potential Projects from AFCESA database (USAF 2009) (http://www.roa.org/site/DocServer/A7CAE_Brief_constellation_ver1.ppt?docID=18341) (public domain)

4.2 Performance

The next step was to collect information on the expected and actual performance for each selected project. There were several documents (DoD 2010, DoD 2011, USAF 2010) that provided the maximum capacity of the projects, the expected annual production and/or the actual production of the projects. However, there was no document that contained all of the performance information for projects being studied. The expected performance and actual performance of each project was collected from interviews with base personnel at each installation. The interview protocol development and personnel selection will be discussed in section 4.4.

4.2.1 Expected Performance

Most bases used available solar and/or wind data for the area considered for the potential renewable energy project calculated the expected performance for each project. On one occasion the expected performance was based on information provided by a solar panel manufacturer. For two of the projects the expected performance was based on the minimum performance guarantees from the contractor instead of the estimated performance data. In these cases the researcher inputted the known information about the solar arrays into the PVWATTS software to develop an expected performance of the arrays. Ideally the performance was normalized to give a yearly average performance, which minimized the effect that any given month had on the overall study. Some simulation models such as PVWATTS, which calculates the performance by month, do this. The PVWATTS report for each of the solar projects is included in Appendix A.

4.2.1.1 Capacity Factor

The capacity factor of a project can be determined by dividing the actual performance by the maximum capacity. If the expected capacity factor is known, the expected performance can be calculated by multiplying the capacity factor by the maximum capacity of the system and the timeframe of the performance. Below is an example of calculating the capacity factor or actual performance for a year.

$$Capacity\ Factor\ = \frac{Actual\ Performance}{Max\ Capacity * 24\ hrs\ per\ day * 365\ days} = 18\%$$

$$Actual\ Performance\ = Max\ Capacity * 24\ hrs\ per\ day * 365\ days * Capacity\ Factor$$

Example:

$$Actual\ Performance\ = 1{,}200\ kW * 24\ hrs\ per\ day * 365\ days * 0.18 = 1{,}891\ MWh$$

$$Actual\ Performance\ = 1{,}200\ kW * 24\ hrs\ per\ day * 365\ days * 0.14 = 1{,}462\ \text{MWh}$$

Using a higher capacity factor would be a case of optimistic modeling and set the project up for underperformance. In the case of the example the difference in performance was 22 percent.

4.2.1.2 Solar Modeling

PVWATTS was used to estimate the performance for several of the solar photovoltaic projects. PVWATTS uses weather information from the closest weather station to the site. The user inputs the following information for the potential project: DC rating (kW), DC to AC derate factor, array type, array tilt (degrees), array azimuth (degrees), and the cost of electricity (cents/kWh). This allows the software to calculate the AC energy production and energy savings per month. The DC rating is the size of a photovoltaic system and is the nameplate DC power rating. The DC-to AC derate factor accounts for losses from the DC power rating and is calculated by multiplying the component derate factors including the PV module, DC rating, inverter and transformer, mismatch, diodes and connections, DC wiring, AC wiring, soiling, system availability, shading, sun-tracking, and age. The array type may be fixed, one axis tracking or two axis tracking PV arrays. The tilt angle is the angle form the horizontal of the inclination of the PV array. The azimuth angle is the angle clockwise from the true north that the array faces. The current electricity cost is used to calculate the monthly savings for the solar array (PVWATTS 2012).

4.2.1.3 Wind Modeling

The 3Tier Firstlook wind assessment tool was used for at least one of the wind turbine projects. Firstlook analyzes the wind potential for a potential site. It uses 3TIER's advanced numerical weather prediction modeling technology. Once the project sites were selected a more in depth wind assessment was accomplished. This was typically accomplished by using anemometers to measure the wind speeds at various heights for any given site.

4.3 Comparison

The actual performance data was compared to the expected output for each project. The comparison included the execution method for each project as well as the renewable energy source. The hypothesis that the Air Force owned and operated projects would differ from the expected performance than the third party owned and operated projects was examined. Next the overall Air Force projects performance ratio was compared to the ratios from existing LEED studies to test the second hypothesis that LEED building post occupancy performance would differ more than the large-scale renewable energy projects.

4.4 Factors Affecting Performance

If there was a difference between the expected and actual performance of the projects, the next step was to determine what factors contributed to the performance differential. After comparing the expected and actual performance for each project, any difference was investigated to find potential factors that affected the outcome of the project. These factors were determined through interviews with stakeholders involved in each project.

4.4.1 The Process

4.4.1.1 Step One - Selection of Interview Subjects

The selection of the interview subjects was vital to the validity of this research. The interviewees were selected using a purposive sampling technique (Robson 2011) in which the interview subjects were selected based on their knowledge of the renewable project development and construction at each base. The potential individuals included AFCESA's renewable energy point of contact for each project's development and construction. According to current practice, AFCESA reviewed the feasibility studies, opportunity assessments and business case analyses that are conducted at each base prior to a large-scale renewable energy project being awarded. Individuals at the base level included in the interview process were personnel from the civil engineer squadron at each base that would have knowledge of these aspects of the process for each project. The points of contact for each base either oversaw the project planning, design and construction for construction projects or were responsible for tracking the monthly energy use for each base. As part of the monthly assessment, the performance of energy projects at each base was tracked. This typically includes the status of energy savings performance contracts and renewable energy projects. Thus, these individuals were typically able to answer questions regarding the design, construction and/or operation of the various renewable energy projects.

4.4.1.2 Step Two - Development of Interview Questions

The interview questions were developed to determine design and actual performance and the factors that affect the performance of the renewable energy projects on the various bases. Table 11 displays the interview questions utilized for the interviews.

Table 11: Interview Protocol

	QUESTION	SUPP. QUESTION
1	What is the source and size of the renewable energy project on your installation?	Was the project completed at once or in stages? What was the cost of the project?
2	How was the project completed?	Is the project contractor owned and operated or Air Force owned and operated?
3	What was the expected annual production for the project?	What percent of the base electricity consumption was the expected production?
4	How was the expected performance modeled or calculated?	Was the estimate normalized for expected conditions over a year?
5	What has been the actual performance of the renewable energy project?	What is the payback period of the project?
6	Does your project provide energy security for the base?	
7	What factors can you identify that may explain the difference between the expected and actual performance of the project?	Were there changes between the design model and the built project? How was the commissioning for this project? Did this project utilize any experimental technologies?
8	What other issues have you identified with utilizing large-scale renewable energy projects?	

The first two questions provided general information on each project. The first question provided general background for each project including the source and size of the renewable energy project. It also identified if the project was completed in one phase or multiple phases and the total cost of the project. The cost of the project was used to calculate the cost per MW for each project and to verify the expected payback period for the projects. The second question determined the age of the project and the execution method used for each project. Some of the projects were completed less than 12 months before this study, which limited the capability to compare the actual performance to the expected annual performance. The execution method allowed for the comparison between Air Force owned and operated projects to third party owned and operated projects. This information was used to test the first hypothesis that the actual performance of third party owned and operated projects would differ less from the expected performance of Air Force owned and operated projects.

Questions three through five addressed the expected and actual performance of each project. Question three requested the expected performance for each project. The expected performance was given in MW hours for a year. Question four asked how the expected performance was modeled or calculated. The main goal of this question was to determine if the expected performance took into account the variability throughout the year. As discussed in section 4.1, some simulation models such as PVWATTS calculate the performance by month and identify the expected variation throughout the year. The fifth question asked for the actual performance of each project. Ideally the performance was tracked by month, allowing for comparison of performance for each month in addition to annual performance. The actual performance also enabled the payback period for each project to be calculated.

Question six attempted to identify factors that explained the difference between the expected and actual performance of each project. As discussed in section 2.5, there have been several studies that compared expected versus actual performance for high performance building, but little research has been done to study the factors of large-scale renewable energy projects. This question was aimed at comparing the factors of previous studies to that of the renewable energy projects. It was expected that fewer factors would affect the renewable projects resulting in the actual performance of the renewable projects to differ less from the expected performance than the high performance buildings. This section of the interviews included some open-ended questions to allow interviewees to identify other possible explanations not included in previous studies.

4.4.1.3 Step Three – External Review of the Questions

Once the interview questions were developed, the Virginia Tech Institutional Review Board reviewed the interview questions to ensure that individuals are not harmed in the process. The interview questions were given to the personnel from AFCESA for additional review and validation.

4.4.1.4 Step Four - Execution of Interviews

Once the interview questions were reviewed and approved, the interviews were scheduled with the points of contact identified in the first step. The interviews took place between the middle of March and the middle of April in 2012. These interviews were accomplished by asking the base personnel to participate in a phone interview in order provide timely responses to the questions. The interviews were recorded to allow accuracy in compiling the results.

4.4.1.5 Step Five - Analysis of Responses

After accumulating the responses from the base personnel, the interview responses were transcribed. First, the performance data was compared for each project based on its execution method. Next, the factors affecting the performance of each project were identified and factors responsible for performance discrepancies were compared to the factors identified in the LEED studies discussed in section 2.5. Additionally, responses outside of the set of factors identified in previous studies were listed as opportunities for further research. A common approach for analyzing data from interviews in previous studies was to code responses looking for similarities and differences. Many studies have also utilized computer software packages, such as NVivo, that assist in the coding process (Wong 2008, Fonteyn 2005). This study did not utilize this software due to the small number of interviews and questions. Instead the responses to the factors affecting performance were separated into themes based on the stages of the project where the factor occurred. These themes included design, construction operations and maintenance of the project and other for factors that did not fit into the initial themes.

5 Case Studies

As discussed in section 4.1, there were eight renewable energy sites selected for this study. Figure 8 displays the sites that were considered for this study.

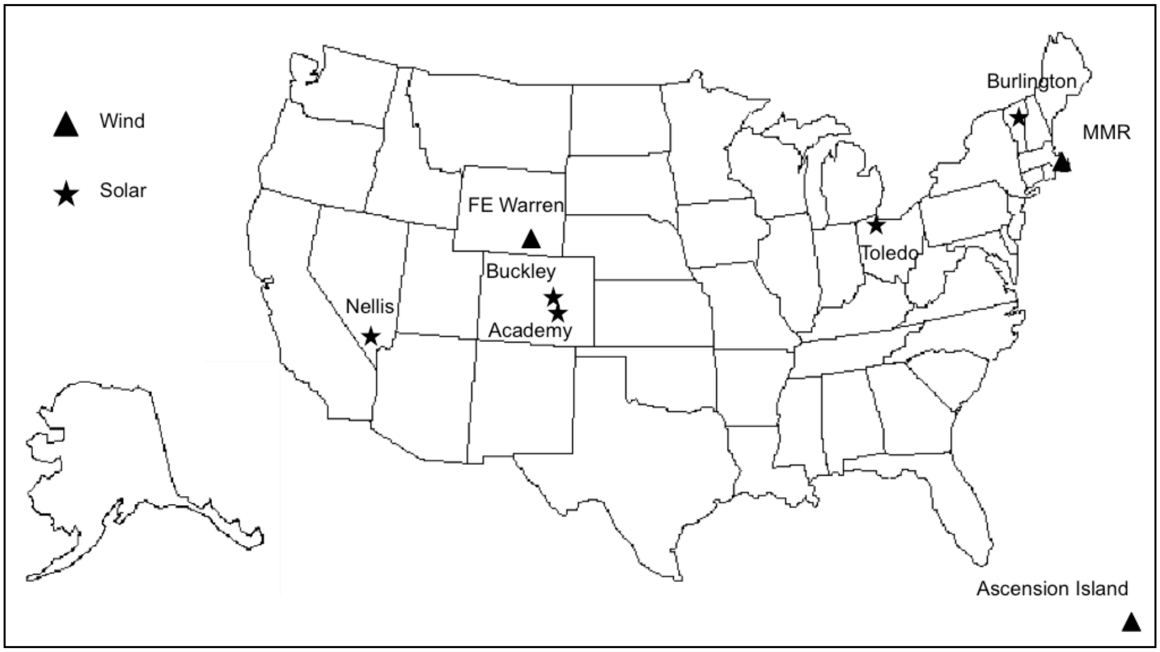

Figure 8: Large Scale Operational Renewable Energy Projects in the Air Force (USAF 2009) (http://www.roa.org/site/DocServer/A7CAE_Brief_constellation_ver1.ppt?docID=18341) (public domain)

The basic information for each site is summarized in Table 12. The wind turbines at the Massachusetts Military Reservation were treated separately because the data was separated by Wind I and Wind II and there were significant differences in the execution and performance of the two projects.

Table 12: List of Air Force Renewable Energy Projects

Installation Name	Location	Renewable Source	Size (kW)	Execution Method
Ascension Island	Ascension Island	Wind	2,700	Air Force Owned and Operated
Buckley AFB	CO	Solar	1,200	Air Force Owned and Operated
Burlington ANGB	VT	Solar	1,446	Air Force Owned and Operated
F.E. Warren AFB	WY	Wind	3,320	Air Force Owned and Operated
Mass Mil Reservation	MA	Wind	4,500	Air Force Owned and Operated
Nellis AFB	NV	Solar	14,200	Third Party Owned and Operated
Toledo ANGB	OH	Solar	1,600	Air Force Owned and Operated
USAF Academy	CO	Solar	6,000	Third Party Owned and Operated

5.1 Ascension Island Auxiliary Air Field (AAF)

Ascension Island is a British territory located over 5,000 miles southeast of Patrick Air Force Base between South America and Africa. The primary mission for the Air Force detachment at Ascension Island AAF is to provide radar-tracking data to support space launches. It also provides radar-tracking data for locating and cataloging space objects in support of U.S. Space Command. This small volcanic island with an area of 34 square miles is the site of the oldest renewable energy project studied for this research.

Figure 9: Four 225 kW Turbines at Ascension Island (INEEL 2004) (http://www.windpoweringamerica.gov/winddiesel/pdfs/2004_wind_diesel/operational/dod.pdf) (public domain)

5.1.1 Project

The first renewable energy project for Ascension Island AAF was the installation of four Micon 225 kW wind turbines in 1997, Figure 9. The turbines are Air Force owned and contractor operated. The project was funded through the Air Force Energy Conservation Investment Program. The second phase included the installation of two Micon 900 kW wind turbines in 2004.

5.1.2 Expected Performance

Base personnel did not provide the projected performance for the Ascension Island projects. However, presentations from the Idaho National Engineering and Environmental Laboratory (INEEL) provided that the total capacity of the Ascension Island wind farm for both phases is 2,700 kW (INEEL 2004).

5.1.3 Actual Performance

Based on the INEEL presentation, the average power output of the first phase was 342 kW. This equated to a capacity factor of 38 percent. After phase 2 was completed, the average power output was 1026 kW, once again resulting in a capacity factor of 38 percent (INEEL 2001). However, the actual production of the Ascension Island wind farm is in unknown for the past decade. The two large wind turbines have been taken off line and changes to the connection between the turbines and the generators are being investigated to improve performance.

5.1.4 Comparison

Since the expected performance was not available, the comparison for the Ascension Island wind farm was not possible. Nonetheless, the performance for the first six years of operation for the four was documented by the INEEL. Between October 1996 and September 2002, the wind farm produced 19,200 MWhs of electricity. The downtime ranged from 89 hours and 489 hours per year or 97 percent availability during this time frame.

5.1.5 Factors Affecting Performance

The factors identified during the interview that affected performance of the wind farm were attributed to the operation and maintenance of the wind turbines. The replacement parts for the four 225-kW turbines are no longer available. Thus, parts from one turbine were used to repair the remaining three turbines. Next, another turbine was used to provide parts for the last two turbines. This process continued until all four turbines were inoperable. The two 900-kW turbines had ramping issues and were causing damage to the generators. Ramping is a quick change in wind turbine performance based on the change in the wind speed. This requires the back up generator to "ramp" up or down quickly. This had caused damage to the generators connected to the 900 kW turbines. Solutions for this situation were subsequently considered in order to return the 900 kW turbines to production. Another challenge that was noted was corrosion control. Although this factor could be placed in the maintenance of the wind turbines, another theme, the environment, was created for this factor.

5.1.6 Discussion

The location of Ascension Island also provided a unique challenge for the wind farm. The island is located 5,000 miles from the Port Canaveral and had a restricted shipping schedules and pier restrictions (INEEL 2001). In spite of the challenges at Ascension Island, the Idaho National Labs stated that the simple payback for the four wind turbines was 4 years (INEEL 2001). Other documentation (USAF 2009) indicated that all six turbines had paid for themselves by 2009. The annual savings per year was listed as $350,000 with a total cost of $3 million; the payback period for the entire project based on these numbers would be about 9 years.

5.2 Buckley AFB

Figure 10: Buckley AFB Solar Array (USAF 2012c) (http://www.af.mil/news/story.asp?id=123262109) (public domain)

Buckley Air Force Base is in the Air Force's Space Command located in Aurora, Colorado. The primary mission for the 460th Space Wing is to deliver global infrared surveillance and tracking missiles warning for theater and homeland defense. The base supports 6,400 military, 3,800 civilians, and 2,400 contractors (USAF 2012b).

5.2.1 Project

Buckley Air Force Base constructed a 1.2-MW solar array covering six acres in 2009 (Figure 10). The array is Air Force owned and operated and cost $7.3 million. The project consisted of 5,040 panels and two 500 kW inverters. The panels are stationary and are tilted at 35 degrees.

5.2.2 Expected Performance

The base calculated the predicted performance for the array using the expected performance provided by the panel manufacturer. Based on the manufacturer's expected capacity factor of 18 percent, the base calculated an expected performance of 2,400-MW hours per year. The researcher inputted the basic information for the project into PVWATTS, using the default derate factor of 0.77, and calculated an expected performance of 1,821-MW hours annually, see Appendix A. The derate factor takes into account component derate factors including the PV module nameplate DC rating, inverter and transformer, diodes and connections, DC wiring, AC wiring, system availability, shading, sun-tracking and age. The default system availability for PVWATTS was 98 percent. This percentage might be reasonable for most projects, but this percentage was higher than the actual availability of the system for Buckley AFB.

5.2.3 Actual Performance

The actual production for the project has been about 1,800 MW hours. The actual performance for 2011 is displayed in Table 13. Each inverter collects energy from half of the array. Thus, it was expected that the two inverters would register approximately the same amount of energy each month if the systems were operating correctly. The months from April to November exhibit the expected trend.

Table 13: Buckley AFB Solar Array Performance 2011

Month	Inverter A (kWh)	Inverter B (kWh)	Total (kWh)
January	28390	46637	75027
February	71167	63120	134287
March	84833	98296	183129
April	84900	84801	169701
May	86432	86576	173008
June	90578	90589	181167
July	98590	98901	197491
August	99649	99648	199297
September	86189	86083	172272
October	75850	75851	151701
November	63418	63420	126838
December	66943	0	66943
Total	**936939**	**893922**	**1830861**

5.2.4 Comparison

The performance for the year was 76 percent of the estimated production used by the base.

$$\frac{Actual}{Predicted} = \frac{1830\ MWh}{2400\ MWh} * 100 = 76\%$$

If the array had an improved production for January, February, March and December to equal the better performing inverter, the performance would have improved to 81 percent of the expected performance. If the expected performance from PVWATTS was used, the ratio of actual to expected performance increased to 101 percent.

$$\frac{Actual}{Predicted} = \frac{1830\ MWh}{1821\ MWh} * 100 = 101\%$$

There was uncertainty for this comparison based on the use of the default derate factor and the published uncertainty of 10 percent for PVWATTS.

5.2.5 Factors Affecting Performance

The themes of factors identified by the base personnel for the Buckley AFB array were design, construction and operation and maintenance of the array. During the planning and design of the Buckley array, the expected performance included an optimistic value from the panel manufacturer for the capacity factor for the solar panels. The design included a capacity factor of 18 percent. The actual capacity factor was claimed to be closer to 14 percent. A second factor identified was the construction of the panels. During the initial installation, the panels were supposed to be stationary, but the panels were moving several inches vertically and horizontally. This issue was corrected by the contractor and should not have any long-term impact on the performance. The last theme discussed that could affect performance was the operation and maintenance of the array. As depicted in Table 12, the array is split into two sections. Each section consists of half of the array and they should have approximately the same production each month. From January through March of 2011 the performance differed between 13 and 39 percent. The following eight months performance was almost identical for both inverters. However, starting in December, one inverter started having mechanical problems. This reduced the actual production of the array to 50 percent of the expected performance for December 2012.

5.2.6 Discussion

Based on the actual production for the Buckley array, the base personnel estimated the simple payback period would be around 55 to 60 years. The expected life of solar arrays ranged between 25 and 40 years from literature (Dunlop 2005, Wohlgemuth 2008). Outside of the solar panels, the rest of the project had a one-year warranty. It was unclear from the interview if the issues experienced at the end of the 2011 were covered by warranty.

5.3 Burlington ANG

The Burlington Air National Guard Base is located in South Burlington, Vermont and is home for the 158th Fighter Wing. The base operates alongside the Burlington International Airport. The 158th Fighter wing is a F-16 unit, which provides combat units and personnel for active duty in the Air Force and supports the local and state communities during disasters (Burlington ANG 2011).

Figure 11: Burlington ANG Ground Mounted Array (Burlington ANG 2011) (http://www.engineersconstruction.com/projects/vtang-solar/) (public domain)

5.3.1 Project

The Vermont Air National Guard Base (ANGB) utilized an $8.8 million federal grant obtained by a U.S. Senator from Vermont for research, development, testing and evaluation to construct solar arrays on the base. The project consisted of multiple installations, which included fixed ground-mounted, roof-mounted, and ground-mounted dual-axis tracking arrays. The project involved the construction of three solar arrays totaling 1.446 MW in capacity for $8.5 million. Figure 11 displays the main portion of the project, a 1.389 MW ground-mounted PV array. This array consists of 5,668 Kyocera modules with a fixed angle of 30 degrees. Other portions of the project include six ground-mounted, tracking arrays rated at 25 kW; a 32 kW roof mounted system, and 28 kW roof mounted system. Since the last three systems are significantly smaller, this study limited the performance analysis to the 1.389 MW array. The project is Air Force owned and operated. The construction was completed in September 2011, which is a limitation for analyzing the data for this project because it does not have 12 months of performance data.

5.3.2 Expected Production

The predicted performance was for the projected was based on the PVWATTS modeling software. Burlington used a DC/AC derate factor of 0.83 and the electricity rate of $0.12 per kWh to determine the energy savings. The derate factor of 0.83 is slighter higher than the default rate of 0.77 for PVWATTS, but it is close to the suggested 0.817 derate factor recommended by the Enphase study (Enphase 2011). Based on the model the project has a projected production of 1,840 MWh per year. The researcher input the basic information into PVWATTS and the model is attached in Appendix A.

5.3.3 Actual Performance

The actual production for the project has been about 1,469 MWh through the first 10 months of performance. The actual performance for fiscal year 2012 is displayed in Table 14. Unfortunately, the Burlington array has not been in operation for a full year as of the time of this study. Nonetheless, 10 months of performance gave an initial impression on the overall performance of the arrays.

Table 14: Burlington ANG Solar Array Performance FY 2012

Month	Solar Array (kWh)
October	119
November	97
December	54
January	46
February	139
March	167
April	166

May	214
June	229
July	238
Total	**1469**

5.3.4 Comparison

The comparison of the actual to the projected performance was done for the 10 months of operation.

$$Predicted\ Performance = 1840\ MWh - 193\ MWh - 158\ Mwh = 1489\ MWh$$

This required subtracting the expected performance of August and September. The performance for the year was 98 percent of the estimated production.

$$\frac{Actual}{Predicted} = \frac{1469\ MWh}{1489\ MWh} * 100 = 98\%$$

5.3.5 Factors Affecting Performance

The Burlington ANGB has limited performance, but the personnel did not identify any factors that affected the performance in the design, construction, operations or maintenance areas of the project. The differences in the monthly actual and predicted performance for the array were attributed to the varying weather patterns from year to year or error consistent with using PVWATTS.

5.3.6 Discussion

The base personnel indicated that the main focus of this project was for research and that the economics of the project was not a driving factor in the development of the project. Nonetheless, the base's fact sheet estimated the project to have a 33-year simple payback. The base expected performance of the project to degrade over time, but to have a minimum production of 80 percent of capacity at 25 years. In terms of the energy security, the array does reduce the overall energy needed for the base, but it was connected directly into the grid and does not have capability to operate if the local grid loses power. This project will be used to evaluate the success of several types of solar installations for the Vermont region. The project also allows Burlington ANGB to meet the DoD mandate for renewable energy.

5.4 F.E. Warren AFB

Figure 12: F.E. Warren AFB Wind Farm (USAF 2012e) (http://www.bagram.afcent.af.mil/photos/mediagallery.asp?galleryID=255&?id=-1&page=53&count=24) (public domain)

F.E. Warren Air Force Base is in the Air Force's Global Strike Command and is located in Cheyenne, Wyoming. The primary mission centers on strategic missile defense. It is home of the 90th Space Wing and operates and maintains 150 Minuteman III and 50 Peacekeeper Intercontinental Ballistic missiles. The base supports about 3,400 military, 11,500 family members, 600 civilians, and 3,800 retirees. The base was established in the 1860's as Fort Russell. After several changes, the fort became Francis E. Warren Air Force Base in 1949 (USAF 2012d).

5.4.1 Project

F.E. Warren executed a $2.52 million project to build a 1.32 MW wind farm in August 2005, Figure 12. The project was the first Air Force wind project in the continental United Stated and included two 660 kW Vestas wind turbines. A second project, a 2 MW Gamesa wind turbine, was completed in 2009. Similarly to the wind projects for Ascension Island, the Idaho National Laboratory performed large portions of the development, design and construction management for the wind farm. This project was designed for testing energy security by utilizing "microgrid" possibilities. The turbines were "grid connected" directly to the base electrical distribution system.

5.4.2 Expected Performance

The predicted performance for the F.E. Warren wind farm was based on data collected from two meteorological data towers. The first tower consisted of one anemometer and one wind vane located at 20 meters above the ground. The second tower consisted of two anemometers at 50 meters, one anemometer at 40 meters, one anemometer at 30 meters, one wind vane at 50 meters and one wind vane at 37 meters. The data was collected for two years in order to develop the estimated production of the wind farm. The projected average wind speed for the Gamesa wind turbine was 7.7 meters per second. The projected annual production for the total project was 10,000,000 kWhs per year.

5.4.3 Actual Performance

The actual production for the project has been about 1,730 MWh. The actual performance for 2011 is displayed in Table 15. The performances of all three wind turbines were near zero for January and February. Vestas 2 started generating electricity again in March. However, the Vestas 1 and Gamesa turbines were not fixed until November. The performance of the F.E. Warren wind farm was listed as 8,725 MWhs in the 2011 Air Force Infrastructure Energy article (Gray 2011).

Table 15: F.E. Warren AFB Wind Farm Performance 2011

Month	Vestas 1 (kWh)	Vestas 2 (kWh)	Gamesa (kWh)	Total (kWh)
January	-	-	-	-
February	-	-	2141	2141
March	-	169797	-	169797
April	-	212481	780	213261
May	-	160394	-	160394
June	30	100552	-	100552
July	-	62809	-	62809
August	-	79821	-	79821
September	-	96917	-	96917
October	1	151422	-	151423
November	105003	209083	3777	317863
December	142926	98773	129726	371426
Total	**247960**	**1342050**	**136424**	**1726434**

5.4.4 Comparison

The expected performance for the F.E. Warren wind farm was 10,000 MWh annually, while the actual performance has been inconsistent since the Gamesa wind turbine was put into operation in 2009. The actual production from 2011 was 1,726 MWhs.

$$\frac{Actual}{Predicted} = \frac{1{,}726MWh}{10{,}000\ MWh} * 100 = 17\%$$

The actual performance for the F.E. Warren wind farm was only 17 percent of the expected performance for 2011. Some of the problems with production were addressed towards the end of 2011. This resulted in the production in 1,200 MWhs through March of 2012, which is about 50 percent of the expected performance.

5.4.5 Factors Affecting Performance

The themes of factors for the F.E. Warren AFB wind farm were operation and maintenance of the wind farm. The Gamesa wind turbine has had several issues with alarms and down time since it was commissioned. The base personnel stated that the maintenance contract should be changed from response time to a percentage of availability for the system. On a few occasions, it took several days to get a response to a minor problem for the turbines. A new maintenance contract started in March 2012 with hopes of increasing the operation of the wind farm.

5.4.6 Discussion

The F.E. Warren fact sheet for the turbine project provided details on the expected performance and payback for the wind farm. The payback period for the F.E. Warren wind farm was calculated using an overall cost of $6.3 million, electricity cost of 5.2 cents per kWh, and expected performance of 10 million kWhs. This provided the base with a simple payback period of 12 years. However, based on the actual production of the wind farm, payback will be longer than expected. As mentioned in the project description, F.E. Warren conducted an energy security test in April 2010. A successful microgrid implementation allowed the base to disconnect from commercial power and operate using only energy produced internally through the wind turbine production and generators. Phase II of the project was commissioned in April 2009 and operated for one year before testing the energy security capabilities in April 2010. The energy security test assumed one third of the base load and created a microgrid comprised of the load, base infrastructure, diesel generators and the wind farm. As discussed in the background section, a successful energy security test would allow the base to operate the wind farm at all times, even during a power outage.

5.5 Massachusetts Military Reservation

The Massachusetts Military Reserve (MMR) is a 22,000-acre military facility located in Cape Cod, Massachusetts. The MMR currently houses facilities for the U.S. Coast guard, Massachusetts Army National Guard, and Otis Air National Guard Base. The MMR also supports the Barnstable County Sheriff's Office, two public schools and U.S. Department of Agriculture facilities. The MMR also supports the Installation Remediation Program (IRP).

Figure 13: MMR Wind 2 (MMR 2012) (http://states.ng.mil/sites/MA/MMR/afcee-documents/fact-sheet-wind-2-oct-2011.pdf) (public domain)

5.5.1 Project

The Massachusetts Military Reserve has completed two wind turbine projects, Figure 13, over the past four years. The first project, Wind I, consisted of installing a 1.5 MW wind turbine in the southwestern area of the MMR and started production in December of 2009. The second project, Wind II, included the installation of two 1.5 MW wind turbines and started production in November 2011. Although Wind II has limited performance data, there is sufficient information from the installation to treat the projects separately for this study in terms of lessons learned and factors affecting performance.

5.5.1.1 Wind I

The MMR constructed a 1.5-MW wind turbine, Wind I, in 2009. The Wind I turbine is a Fuhrlander wind turbine. The turbine is approximately 390 feet tall with a rotor diameter of 250 feet. The turbine was designed to start at a wind speed of 6.7 mph and stop at a wind speed of 45 mph. The blades and tower were manufactured in the U.S., while the generator manufactured in Germany and shipped to the United States. The Air Force and the Army jointly funded the project and the costs are displayed in Table 16. The Title II costs include fees used to hire additional quality assurance personnel for construction management of large projects. The project planning, design and construction process took almost 5 years for the Wind I project.

Table 16: MMR Wind I Cost Breakdown

Wind I	**Cost ($000)**
Constructability Assessment	400
Construction and 2 Yrs O&M	4,870
Title II/Oversight	150
Interconnection with Grid	54
Total	**5,474**

5.5.1.2 Wind II

The MMR constructed two additional 1.5-MW turbines, Wind II, in 2011. The Wind II turbines are GE wind turbines. The turbines are the same size as Wind I, approximately 390 feet tall with a rotor diameter of 250 feet. The turbines were designed to start at a wind speed of 7.8 mph and stop at a wind speed of 56 mph. The blades, tower and generator were all manufactured in the U.S. The Air Force and the Army jointly funded the project and the costs are displayed in

Table 17. The timeline from planning to operation was reduced from 5 years to less than two years for Wind II.

Table 17: MMR Wind II Cost Breakdown

Wind II	Cost ($000)
Constructability Assessment	462
Construction and 2 Yrs O&M	9,400
Title II/Oversight	341
Interconnection with Grid	272
Total	**10,475**

5.5.2 Expected Performance

In order to develop an expected performance for wind turbines for the MMR, the contractor performed an analysis of historical wind data for the area. They used the First Look wind assessment software to analyze the reservation's wind potential. The expected production for Wind I was 3,810 MWhs annually using a 29 percent capacity factor and P50 for wind. The model form First Look calculated an average capacity factor of 33 percent. A 2009 study examined the actual capacity factors in the U.S. and Europe over the last five years compared with the assumed capacity factor for the last 20 years. The average capacity factor that has been used in the United States was 35 percent capacity factor; however, the average capacity factor for the last five years was 26 in the United States (Boccard 2009). Thus the 29 percent capacity factor could be reasonable based on the First Look computer model. This would account for 25 to 30 percent of AFCEE's total electrical requirement annually at the MMR.

The expected production for Wind II was 6,833 MWhs annually using a 26 percent capacity factor and P50 for wind. The estimate increased to 7,621 MWhs by using a 29 percent capacity factor and P50 for wind. Based on the higher projected and the monthly wind assessments, Wind II was expected to produce 3,679 MWhs of energy between November 2011 and March 14, 2012.

5.5.3 Actual Performance

Table 18 displays the monthly performance of Wind I for 2011.

Table 18: MMR Wind I Wind Performance since December 2009

Month	2011 (MWh)
January	126
February	360
March	32
April	355
May	252
June	144
July	151
August	157
September	179
October	271
November	310
December	331
Total	**2668**

Table 19 displays the actual performance of Wind II since its startup in November 2011. The actual production was 3,408 MWhs for this time period.

Table 19: MMR Wind II Wind Performance since November 2011

Month	2011 (MWh)	2012 (MWh)	Total (MWh)
November	844	-	844
December	491	-	491
January	-	838	838
February	-	708	708
March	-	527	527
Total	**1335**	**2073**	**3408**

One aspect that has benefited Wind II is that the turbines have managed to have a 98.5 percent availability time. Wind II has also operated at a 40 percent capacity factor.

5.5.4 Comparison

The actual performance for Wind I was 78 percent for 2011.

$$\frac{Actual}{Predicted} = \frac{2{,}668\ MWh}{3{,}810\ MWh} * 100 = 78\%$$

Wind II has operated at approximately 93 percent of the projected performance for its limited lifespan.

$$\frac{Actual}{Predicted} = \frac{3{,}408\ MWh}{3{,}679\ MWh} * 100 = 93\%$$

When the initial performance of Wind II was compared to the performance of Wind I, Wind II has performed 20 percent better compared to the predicted performance.

5.5.5 Factors Affecting Performance

The base personnel identified themes of maintenance and weather as potential factors affecting the performance of the MMR wind farm. The maintenance issues were identified for the Wind I project. The contractor that built the wind turbine was not local and the base had difficulty getting a quick response for maintenance or warranty issues. The weather factor identified was that the first year of performance for Wind I had an average wind speed much lower than expected. The wind speed for the first year had an exceedance probability of P90, or a 90 percent chance that the wind would exceed the wind speed for that year.

5.5.6 Discussion

Wind I had a projected payback of 6 to 8 years based on the expected performance of the wind turbine. The expected payback for Wind II was anticipated to be 8 to 10 years. Based on the actual performance of Wind I, the estimated payback will be shorter than the actual payback period. Conversely, if Wind II can maintain its performance, it will have a shorter actual payback than the projected payback period.

5.6 Nellis AFB

Nellis Air Force Base, a USAF Air Combat Command installation, is located near Las Vegas, Nevada. Nellis is known for being the home of the Air Force Warfare Center, Red Flag, and the Thunderbirds. Red Flag is a training exercise that includes aircraft from the Army, Navy, Marine Corps and allied forces from around the world. The Thunderbirds are the Air Force's Air Demonstration Team. The base also covers more than 14,000 acres and supports 9,500 military and civilians.

5.6.1 Project

The solar array, completed in 2007, at Nellis Air Force Base covers 140 acres of land and has a capacity of 14.2 MWs, see Figure 14. The contractor owns and operates the solar array. The project was executed through a land lease combined with a power purchase agreement. The Department of Defense has recently started the practice of leasing federal land to companies for private use.

Figure 14: Nellis AFB Solar Array (USAF 2012f) (http://www.nellis.af.mil/news/story.asp?storyID=123071269) (public domain)

This is typically accomplished by executing enhanced use leases, where the private organizations pay for the land with money or "in-kind" services. A solar power purchase agreement is a financial agreement between the third party, who owns, operates, and maintains the solar array, and the Air Force, who agrees to purchase the electricity produced by the system for a predetermined period. At Nellis Air Force Base, the contractor signed a 20-year land lease, and the electricity produced from the project was purchased by the Air Force through a power purchase agreement with no escalation of the rate for the length of the lease. Once the lease expires, another contract could be signed to extend the use of the array or the contractor could choose to remove the array and return the site to its previous condition. Some factors existed that made the solar array attractive for a contractor. First, Nevada has a Renewable Portfolio Standard requiring that 15 percent of all electricity, 5 percent from solar, is from renewable sources by 2013. Second, the Renewable Energy Certificate prices in Nevada are higher than in other areas and thus accounted for 35 to 45 percent of the value of the project.

5.6.2 Expected Performance

The contractor guaranteed an annual production of 30,100,000 kWh for the array. The researcher inputted the basic information for the project into PVWATTS, using the default derate factor of 0.77, and calculated an expected performance of 31,157,692 kWh annually, see Appendix A. Although this guaranteed production was certainly a percentage of the contractor's estimated production to reduce the risk of failure to perform, the base personnel did not know the actual production estimate. Therefore, this study assumed that the guaranteed production was equal to the estimated performance from PVWATTS. The PVWATTS estimate was 3 percent larger than the guaranteed performance for the contractor. This assumption accepts some risk of error, but it also bases the expected performance on the same data as the other solar arrays.

5.6.3 Actual Performance

The actual performance for the Nellis array for fiscal year 2011 was 31,477,262 kWh (Table 20). It is possible even that the actual performance for Nellis is lower than the expected performance.

Table 20: Nellis AFB Solar Array Performance Fiscal Year 2011

Month	2010 (kWh)	2011 (kWh)	Total (kWh)
January	-	2,043,948	2,043,948
February	-	2,399,064	2,399,064
March	-	2,720,202	2,720,202
April	-	3,166,851	3,166,851
May	-	3,332,467	3,332,467
June	-	3,429,681	3,429,681
July	-	2,915,770	2,915,770
August	-	3,183,498	3,183,498
September	-	2,582,771	2,582,771
October	2,355,329	-	2,355,329
November	2,166,992	-	2,166,992
December	1,180,689	-	1,180,689
Total	**5,703,010**	**25,774,252**	**31,477,262**

5.6.4 Comparison

The expected performance for the Nellis AFB solar array was 31,158 MWh annually, while the actual performance was 31,477 MWh for fiscal year 2011.

$$\frac{Actual}{Predicted} = \frac{31{,}477\ MWh}{31{,}158\ MWh} * 100 = 101\%$$

The actual performance for the Nellis array was 101 percent of the expected performance for fiscal year 2011. Nellis was able to provide the annual performance for the last three fiscal years, see Table 21. The average performance has been 102 percent of the expected performance from PVWATTS.

Table 21: Nellis Solar Array Actual Performance vs. Guarantee

Nellis Solar Array	Annual Performance (kWh)	Percent Estimate
FY 09	31,655,538	102%
FY 10	32,136,403	103%
FY 11	31,477,262	101%
Average	32,330,000	102%

5.6.5 Factors Affecting Performance

The base personnel mentioned that portions of the array had to be closed that had been flooded, but it was not a concern because the contractor was able to provide the guaranteed amount of electricity. Other than flooding, the base personnel did not identify any factors that had affected performance. The contractor might have additional factors that have affected their performance, but the contractor respectfully declined to supply any information for this study.

5.6.6 Discussion

This project did not fit the pattern for expected payback based on the other seven projects because there was almost no initial cost to the Air Force; the only initial cost was the survey of the land used for the array. Additionally, the cost that the Air Force agreed to pay for the electricity produced by this project was significantly lower than the rate Nellis paid for the rest of its electricity. The Air Force agreed to a purchase rate of 2 cents per kWh for the energy produced by the solar array. This allowed the Air Force to realize a savings of over one million dollars per year over the current rate of electricity, which is currently 7 cents per kWh for Nellis. The contractor for the project was able to earn tax incentives for the project, sell the electricity to the Air Force and sell the RECs to the local energy company. The Air Force must purchase replacement RECs for the amount sold from the Nellis project in order to take credit for the environmental benefits of the electrical production. The conclusion that can be drawn from the Nellis AFB array is that unique circumstances can dictate the feasibility of a renewable energy project.

5.7 Toledo Air National Guard (ANG)

The Toledo Air National Guard Base is located in Swanton, OH and is home for the 180th Fighter Wing. The base supports over 1,100 personnel for monthly exercises and over 400 full-time military and civilian personnel. The 180th Fighter wing is a F-16 unit, which provides combat units and personnel for active duty in the Air Force and supports the local and state communities during disasters.

5.7.1 Project

The solar array, Figure 15, at Toledo Air National Guard Base covers 10 acres and has a capacity of 1.558 MWs. The array contains over 16,000 panels and was constructed in four phases. The first phase came online in September 2008. The project is Air Force owned and operated with a total cost of $13.8 million. The final stage of the project was brought online in July 2011. The array is stationary with a tilt angle of 7 percent for the first three phases to maximize the production in the summer months. The fourth phase utilized a 22-degree angle designed for year round sunlight. The performances of the four phases were tracked as one project since each phase simply added panels to the current array. Once the second phase was complete, the performance of the first phase was not tracked separately from the second phase. For this reason, the four phases were not evaluated separately. The angle of the array, type of film, and type of inverter are among the variables that differed from phase to

Figure 15: Toledo ANG Solar Array (USAF 2012g) (http://www.180fw.ang.af.mil/photos/mediagallery.asp?page=12) (public domain)

phase and will allow the base to determine what type of system should be used for future projects in Ohio. This supports the reason that Department of Defense Research and Development Testing and Engineering funds were used to construct the arrays.

5.7.2 Expected Performance

The projected energy production has changed over the past four years as each phase was added to the array. For all of the four phases of the project the base utilized the PVWATTS software to develop the predicted production of the solar array. For the purpose of this study the expected production from March 2011 to February 2012 was used. The expected performance was calculated by combining the three estimates from PVWATTS because the array increased in size twice during the year. The PVWATTS reports were provided by Toledo ANGB and are attached in Appendix A. The array capacity increased from 1,128 kW to 1,518 kW in June 2011. The final array capacity increased to 1,558 kW in December 2011. The expected performance calculated by the base as 1,690 MWh annually.

5.7.3 Actual Performance

Table 22: Toledo Solar Array Performance

Month	Actual Output (kWh)
March	117,840
April	121,430
May	157,690
June	189,000
July	191,360
August	179,580
September	121,720
October	132,630
November	89,490
December	58,450
January	59,570
February	99,210
Total	**1,517,970**

The actual production for the project has been about 1,517 MWh. The actual performance for 2011 is displayed in Table 22. The performance of the array was lower than expected for the last three months.

5.7.4 Comparison

The expected performance for the Toledo ANGB solar array was 1,690 MWh annually, while the actual performance was 1,518 MWh from March 2011 through February 2012.

$$\frac{Actual}{Predicted} = \frac{1{,}518\ MWh}{1{,}690\ MWh} * 100 = 90\%$$

The actual performance for the Toledo array was 90 percent of the expected performance.

5.7.5 Factors Affecting Performance

The main themes identified by the Toledo personnel were maintenance, design, and weather factors. The lower production for the last three months was attributed to maintenance. The decline in production was due to a problem with the inverters for the array, which has subsequently been fixed. If these months are discarded, the performance is about 97 percent of the estimated production at design. Other maintenance issues that have affected the performance include ground fault issues. Toledo has a recloser that keeps the solar array from harming the utility grid. On multiple occasions the recloser has closed and shut off the base power. When this occurred, the base personnel have turned off the solar array and connected the base back to the utility grid. Investigation into the problem usually identified a ground fault. The ground faults have not occurred for the last year, but for a while it happened every time there was a big storm.

The design theme was due to the difference in available technology at the time of construction more than an error in design. The first phase of the Toledo array was limited to inverters in the range of 7 to 10 kilowatts. The panels were wired into towers of six inverters, so each tower had about 42 kilowatts of capacity. When the system reached about 780 kW, Toledo bought a system that had a centralized bus bar that connected to all solar power. The system has a logic controller and a series of six 150 kW inverters. The system monitors the amount of power being produced globally and turns on the inverters one at a time as needed. By allowing all of the energy to go into one inverter, the efficiency of the individual inverters was increased. This resulted in some production gains fro the second half of the system. Toledo was able compare the two halves of the system and see that the half with the centralized bus bar and six inverters performed better than the half that has about 100 inverters.

The weather factors identified by Toledo related to snow or ice accumulation on the arrays during the winter. The base can see production drop of after a snow or ice storm; however, the base allows the snow to melt instead of paying for personnel to go out to array and brush off the panels. It was determined that the amount of money spent cleaning off the panels was more that the amount of electricity the base was losing, so it was not cost effective to continue to clean off the array.

5.7.6 Discussion

Since this project is being used for research development and testing, Toledo stated that the payback period of the project was not a primary concern for the array. Nonetheless, the amount of energy produced and estimated energy saving is tracked for the project. The project saved approximately $141,000 from July 2011 to February 2012. Overall, the project has produced 3,527-MW hours since inception and saved approximately $545,000.

5.8 United States Air Force Academy

The Air Force Academy is a four-year institution located in Colorado Springs, Colorado. The Academy provides instruction designed to provide cadets with the knowledge and leadership needed as an Air Force officer. Every cadet graduates with a Bachelor of Science degree and is commissioned as a second lieutenant in the Air Force. The Academy is home of the 10th Air Base Wing which provides the education and development of more than 4,000 Air Force cadets. The wing is also responsible for supporting more than 25,000 military and civilian personnel (USAF 2012d). The USAF Academy was selected to be a Net Zero Energy Installation, meaning that it aims to produce 100% of its electricity through on-site generation.

Figure 16: USAFA Solar Array (SunPower 2012) (http://us.sunpowercorp.com/commercial/success-stories/federal-government/) (public domain)

5.8.1 Project

The USAF Academy received $18.3 million as part of the Recovery and Reinvestment Act to pursue an on-site solar project. The state laws in Colorado require installations to go to their existing provider for right of first refusal. Thus, the Academy approached Colorado Springs Utilities about the prospect of building an on-site solar array in 2009. The project was executed by paying Colorado Springs Utilities an $18.3 million connection charge for the array and it subcontracted the project to SunPower. The expected size for the project was 3 MW based on the cost of similar utility sized projects in Colorado. However, the final project was 6 MW, double the expected size. It was unclear how the contractor was able to build the larger array for $3 million per MW as opposed to the $6 million per MW of capacity that was done at two military bases in Colorado. The 6MW solar array, Figure 14, was completed in April 2011. The array covers 43 acres near the south gate of the Academy and consists of 18,888 T0 Tracker solar panels. Several aspects of the solar array set the Academy project apart from other projects. First, although it is a third party owned and operated project, the Academy paid $18.3 million for the project as opposed to the contractor paying for the construction of the project. Second, the electricity is sold from SunPower to Colorado Springs Utilities (CSU) under a 25-year power purchase agreement. Then CSU provided the electricity to the Academy at 0 cents per kWh for the life of the array, which is expected to be 30 years rather than 25 years. Another difference in this project was a maintenance charge of 1 cent per kWh for the life of the project. Lastly, the contract for the solar array reimbursed the Academy 50% of the sale for the Renewable Energy Certificates. This was not done in any of the other projects studied.

5.8.2 Expected Performance

The third party contractor, SunPower, calculated the predicted performance for the USAF Academy solar array based on the construction of a 6MW array. The expected annual production for the total project was 11,600,000 kWhs per year using an expected degradation of the array of 0.5% annually. The minimum guarantee is 10,000,000 kWhs. The researcher inputted the system specifications into PVWATTS and the report is attached in Appendix A.

5.8.3 Actual Performance

The actual production for the array is displayed in Table 23. The actual performance represents the first full year of production for the Academy array.

Table 23: USAF Academy Solar Array Performance

Month	2011	2012	Total
July	1,298,603		1,298,603
August	1,151,149		2,449,753
September	1,022,764		3,472,517
October	990,451		4,462,968
November	746,941		5,209,910
December	594,380		5,804,290
January		685,637	6,489,927
February		805,232	7,295,159
March		1,197,328	8,492,487
April		1,251,529	9,744,015
May		1,378,154	11,122,169
June		1,351,402	12,473,571
Total			**12,473,571**

5.8.4 Comparison

The expected performance for the Air Force Academy solar array was 11,600 MWh annually, while the actual performance was 12,473 MWh from July 2011 through June 2012.

$$\frac{Actual}{Predicted} = \frac{12{,}473\ MWh}{11{,}600\ MWh} * 100 = 108\%$$

The actual performance for the Academy array was 108 percent of the expected performance.

5.8.5 Factors Affecting Performance

The base personnel did not identify any factors that had affected performance. The contractor might have additional factors that have affected their performance. This could be due to the performance exceeding the expected and guaranteed performance tor the first year of operation.

5.8.6 Discussion

This project was unusual in the execution and payment. First the base paid a lump sum for a connection charge for the project. An Inspector General report in 2011 stated that USAFA incorrectly determined that the entire solar array project could fall under the term “connection”. The Academy provided the local utility with a request to design to determine the size of a solar array that could be built for $18.3 million. The government estimate and the contractors estimate both included a cost for connecting the system to the grid but also labeled the total cost as total connection charge (IG 2011). The electricity produced by the solar array was provided to the Air Force at no additional cost. However there was a one-cent per kWh charge for maintenance of the array. Another difference in the execution of the Academy array was the agreement for the energy company to pay the Air Force half of the proceeds from the REC sales. The base calculated the payback period for the USAFA solar array based on the initial cost, the expected annual savings and the expected profit from the REC sales annually. The base personnel estimated the payback period to be between 13 and 20 years.

6 Findings

6.1 Performance Comparison

Table 24 displays the projected and actual performance for each of the projects, calculated as described in chapter 5.1 through 5.8. As discussed earlier, the data available from Massachusetts Military Reservation allowed the two phases to be examined as two separate projects. The contractor owned and operated projects are highlighted in the last two rows in the Table 23. The data is from the most recent year and may not be representative of the project's life cycle. The performance data discussed in the case study for Ascension Island from the Idaho National Labs was general performance from 10 years ago. Since data was not available for the projected and actual performance of Ascension Island it was not included for comparison for either hypothesis.

Table 24: Projected Versus Actual Performance

Project Site	Project Description	Projected Performance (MWh)	Actual Performance (MWh)	Percent of Expected
Ascension Island	4 - 225kW Turbines - 1997 2 - 900 kW Turbines - 2004	-	-	-
F E Warren AFB	2 MW Turbine 2007 2 - 660 kW Turbines 2005	10,000	1,726	17%
Mass Mil Res	1 - 1.5 MW Turbines – 2009 2 - 1.5 MW Turbines - 2011	3,810	2611	78%
		3679	3418	93%
Toledo ANGB	168 kW Solar Array - 2008 300 kW Solar Array - 2009 700 kW Solar Array - 2010 1.6 MW Solar Array - 2011	1,690	1,517	90%
Burlington ANG	1.446 MW Solar Array - 2011	1,489	1,469	99%
Buckley AFB	1.2 MW Solar Array - 2009	1,821	1,830	100%
Nellis AFB	14.2 MW Solar Array - 2007	31,158	31,477	101%
USAF Academy	6 MW Solar Array - 2011	11,600	12,473	108%

6.1.1 Evaluation of First Hypothesis

The first hypothesis to be tested in this research was that projects developed using the execution method of power purchase agreements would be more accurate in predictions of project performance than the Air Force owned and operated method. Figure 17 displays the performance of the eight projects by their execution method, based on the data in Table 23.

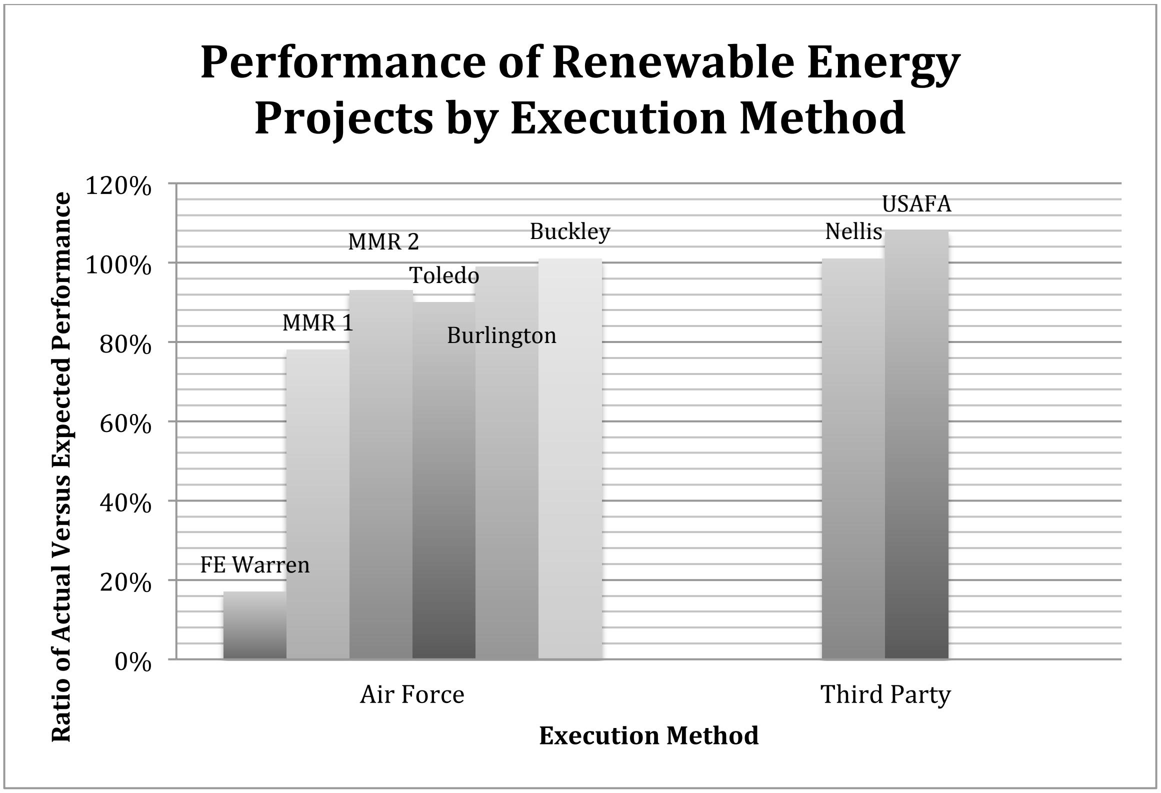

Figure 17: Performance of Projects by Execution Method

Although there was two Air Force owned and operated projects that performed as almost exactly as expected, the average performance of the six projects with actual production was 80% of the expected performance. The average is based on percentage of each project and does not take into account the relative size of the project. The wind farm at F.E. Warren brought the average down due to operation and maintenance issues with two of the turbines. If the F.E. Warren project was removed, the Air Force owned and operated projects average performance would have increased to 92%. The average performance of the third party operated projects was 105% of the projected performance. However, as discussed in the case studies, the performance of the Nellis project was compared to the estimated performance from PVWATTS report completed by the researcher since the only data available was the guaranteed performance. The Academy array was compared to the estimate provided by the base. Nonetheless these results support the hypothesis that the third party owned and operated project performance would differ less from the predicted performance than the Air Force owned and operated projects.

6.1.2 Evaluation of Second Hypothesis

The second hypothesis stated that the actual performance for the large-scale renewable energy projects would be more accurate than the performance of high performance buildings from previous studies.

6.1.2.1 Performance of Renewable Energy Projects

The performance of the renewable energy projects for this study ranged from 17% to 108% of the predicted performance.

Average of all Projects

$$Avg = \frac{17 + 78 + 93 + 90 + 99 + 100 + 101 + 108}{8} = 86\%$$

The average performance of the solar arrays was closer than the performance of the wind farm. None of the solar projects were more than 10 percent away form the predicted performance. The average performance for the solar arrays was 100%.

Average of Solar Projects

$$Avg = \frac{90 + 99 + 100 + 101 + 108}{5} = 100\%$$

The average performance for these projects was 86% of the predicted performance if the size of the project was not taken into account. Similarly, if the results from F.E. Warren were disregarded the average of the other seven projects was 96% of the predicted performance.

Average of Projects without F.E. Warren

$$Avg = \frac{78 + 93 + 90 + 99 + 100 + 101 + 108}{7} = 96\%$$

This shows the impact that one project can have in a small sample size like this study.

6.1.2.2 Performance of High Performance Building Projects

The Torcellini and Turner studies comparisons between predicted and actual performance for high performance buildings. The Torcellini study found that the actual performance saving was 63 percent of the predicted performance. Only two of the projects were within 20 percent of the expected performance. The 2006 Tuner study found the actual energy use was 110 percent of the projected design. However, none of the building performances were within 20 percent of the predicted performance. The 2008 Turner study found that the actual savings for the buildings was 28 percent compared to the expected 25 percent, or approximately a 12 percent better performance. However, the 2008 study had less than 50 percent of the projects within 25 percent of the predicted performance.

6.1.2.3 Comparison of Renewable Energy and High Performance Building Projects

The results from this study supported the second hypothesis. The expected outcome was that the actual performance of the renewable energy projects would differ less from the predicted performance than the high performance building projects from previous studies. The predicted performances for six of the eight Air Force projects were more accurate than any of the projects in the 2004 and 2006 study. They were also more accurate than more than 50% of the LEED buildings in the 2008 study. The average for the buildings in the 2008 study was comparable to the average in this study. However, the 2008 study had less than 50 percent of the projects within 25 percent of the predicted performance. Whereas this study had 75 percent of the renewable energy projects had actual performance within 10 percent of the expected performance.

6.2 Factors Affecting Performance

The performance of many of the projects in this study differed from the expected performance. The base personnel interviewed for this study were asked to provide reasons or factors that attributed to the difference in performance. The responses regarding the factors were clustered into groups of similar responses from the other bases. The clusters of responses included factors regarding design, construction, maintenance and weather.

6.2.1 Design/Modeling

Four of eight base personnel noted potential issues with the modeling for estimated performance. Three of the solar projects used PVWATTS for to model the estimated performance for their solar projects. This software does take into account the change in performance by month throughout the year to take into account the length of daylight and the angle of the sun; however, the National Renewable Energy Laboratory, which provides the software online, states that the long-term performance of the PVWATTS calculations has an overall accuracy within 10 to 12 percent. Another issue for a wind project was that the estimates were based on exceedance probabilities of P50, which means that 50% of the time one could expect performance to equal or beat the estimate. By using the P75 or P90 probabilities, the base would have lowered the estimated performance while increasing the chance of meeting or exceeding the estimate.

The last instance where the expected performance differed from the actual performance based on modeling was when the performance was based on a vendor stated performance of the solar panels. In this case, the capacity factor given by the vendor was 18 percent, while the actual performance was between 12 and 14 percent capacity factor. This would be a case of optimistic modeling and set the project up for underperformance. In the case of using a capacity factor instead of 14 would result in an underperformance of 22 percent. If the actual capacity factor was 12 instead of 18, the underperformance would be 33 percent.

6.2.2 Construction/Commissioning

Several personnel identified the construction or commissioning of the systems as a factor that affected the performance of their projects. One issue identified by the interviewees resulted from breaking the projects into phases due to funding for projects. Several of the bases phased their projects over several years for design and construction. The first phase of one project used sets of inverter towers to connect the solar arrays to the grid. Each tower had 6 inverters with 7 kWs of capacity each. Thus, each tower had 42 kWs of capacity, whereas the last phase of the project incorporated a series of four 150 kW inverters. The base started off with systems that were designed for smaller size installations, which led to some maintenance issues.

Many of the projects had initial problems with the mechanical or controls portion of the project. One wind turbine would not restart after shutting down for high wind, low wind or a power outage. It would also shut down as a result of gusts that were less than the cutout speed. Reprogramming the system fixed these problems. However, slow response to issues resulted in extended reductions in production for multiple sites.

6.2.3 Maintenance

Maintenance contracts are a concern for all projects. However, the Air Force only has input and control over the Air Force owned and operated projects. The third-party owned and operated projects have a performance guarantees and conduct their own maintenance for their projects. Four of the base personnel for third-party maintained systems discussed issues with the operation and maintenance of their wind and solar projects. Many times the wording of the contract added to the problems for maintenance of the systems. One contract had a response time of 25 days for the maintenance contractors to address the problem. Lengthy response time in maintenance contracts caused long periods of downtime for even minor problems. Instead of response time contracts, two of the interviews recommended performance based contracts. A performance-based contract would require the contractor to keep the wind turbines or solar array operating for a minimum percentage of the time. For example, the contract could state that a wind turbine have a 95% uptime. Penalties for non-compliance of a performance-based contract would be financial reimbursement to the Air Force for the time that the project was inoperable above the agreed uptime. This would be similar to delay damages that a construction contractor does not meet the contracted completion date.

6.2.4 Weather

Since all of the wind and solar projects operate outside and are reliant on the sun and wind for their performance, weather could potentially have a significant impact on the performance of the projects. The weather patterns could be analogous to the impacts of occupancy for building projects. The probability of exceedance for wind projects by P factors. A P90 year represents a year that would be outperformed 90 years out of 100. For instance an unusually poor year, P90 to P99, would be the bottom ten or one percent of yearly performance. These years could be compared to a building where the occupants fail to follow policies regarding turning off lights and equipment. While an unusually good year with regards to sun or wind, P10 to P1, could be compared to a building that has environmentally conscientious occupants that exceed the behavior expected for a given building. For two of the projects, an unusually poor year was noted for the performance of the system. Since many of the projects only had one or two years of performance, one poor year will take awhile to overcome in terms of performance. Another issue identified by some projects was the corrosion of the project due to close proximity to the ocean. This is more of an environmental issue than weather issue, but it is a concern that needs to be considered for projects that are planned for the more corrosive sea air.

6.2.5 Comparison of Factors from POE and High Performance Building Studies

The renewable energy had several themes similar to the high performance building studies including optimistic modeling, mechanical problems, controls issues, and operation and maintenance issues. Two of the main factors identified in the high performance building studies that did not appear in the interviews for this study were occupancy behavior and changes in design from the modeling to final construction. Both of these omissions make sense since there are no occupants for the renewable projects and the design of the renewable projects are less complex than full building design. The lack of occupants might also account for the reduced changes between the modeling and final construction. The modeling software also has limited inputs for the solar projects. The main factor that affected the renewable energy projects that was missing from the high performance studies was the impact of weather on the performance of the project. The uncertainty of weather also affects the modeling of the projects.

6.3 Lessons Learned

This study identified lessons learned by the personnel overseeing large-scale renewable energy projects across the Air Force. Lessons learned were also noted during the collection of data for the study. Many of the lessons learned could be captured by utilizing the renewable energy playbook developed by the Air Force (AFCESA 2011b).

6.3.1 Execution Method

This study separated all of the projects into two execution methods, Air Force owned and operated or third party owned and operated. However there were significant differences between the projects within each execution method. The third party owned and operated projects were the 14.2 MW solar array at Nellis Air Force Base and the 6 MW solar arrays at the USAF Academy. Each of these projects executed their projects using unconventional aspects that make it difficult to repeat their contracts.

6.3.1.1 Nellis Execution Method

The renewable portfolio standard (RPS) in Nevada required that 15% of all electricity come from renewable energy by 2013. Of that 15%, five percent was required to be solar energy. This led to unsolicited interest from a third party to build a solar array on Nellis Air Force Base. The final project used solar panels from SunPower and financing from MMA Renewable Ventures to accomplish the project. The project was designed and constructed by SunPower. The $100 million system is owned and operated by MMA Renewable Ventures, and it sells the power generated from the array to Nellis Air Force Base at a guaranteed rate for 20 years. It also sells the Renewable Energy Certificates to Nevada Power. The requirement from the renewable portfolio standard and the profit from the RECs provided a financial beneficial situation for both the base and the contractor. However, even ideal scenarios like in Nevada have a limited window of opportunity. Since the energy companies have subsequently reached the requirements of Nevada's RPS, a second solar array, 17 MW in capacity, is on hold for Nellis Air Force Base.

6.3.1.2 USAFA Execution Method

The Academy paid upfront for a third party owned and operated project. The base paid Colorado Springs Utility $18.3 million for a connection charge for a 6 MW solar array. There are several aspects that are beneficial for the Academy. First, they were able to build an array twice the size expected. The design estimate was based arrays that cost between 6 and 7 million dollars per MW of capacity. Nonetheless, the Academy was able to build a solar array for $3 million per MW of capacity. Second, the Academy pays zero cents per kWh of production for the life of the array. They do pay an operations and maintenance fee of one cent per kW hour, but that is still less than half of what Nellis is paying per kW for their array. Third, USAFA negotiated to receive half of the profits from the sale of the RECs for the project. This should allow the project to have a relatively short payback period followed by very low cost electricity for the remainder of the usable life of the array. Despite all of the financial benefits of the contract, the project has received negative attention for aspects such as the connection charge. This will make it hard for another base to duplicate the success of the USAFA project.

6.3.2 Improvements for Phased Projects

The trend for Wind II to operate better than the initial project in terms of performance might be attributed to applying lessons learned during the first project. The later phases of the Toledo solar array also implemented new technology and lessons learned to improve the performance of the project. This is opposite of what occurred during the second phase projects at F.E. Warren AFB and Ascension Island wind farms. The second phase of the F.E. Warren wind farm has had more problems maintaining availability than the first two smaller turbines. The second phase of the Ascension Island wind farm added issues that were not present in the first phase, specifically the ramping issue between the turbines and the generators connected to them.

6.4 Summary

This study examined the actual and expected performance of operation large-scale renewable energy projects in the Air Force. The performance of each project was also evaluated against factors identified in previous sustainable construction studies. The study found that actual performance of third party owned and operated projects differed from the expected performance by less than the Air Force owned and operated projects. The study also found that the performance of renewable energy projects differed from the expected performance by less than high performance buildings from previous studies. Lastly the study identified factors that contributed to the gap between the expected and actual performance including optimistic modeling, unusual weather, operational issues and higher than expected maintenance of the projects.

7 Discussion

7.1 Contributions

Currently, most of the post-occupancy research centers on building performance, such as LEED certified buildings or high performance building performance. Although renewable energy projects have not had the same emphasis, the impact on the environment could be just as important. Consequently, no study had provided reliable energy production assessments for large-scale renewable energy projects.

This research attempted to validate the performance of large-scale renewable energy projects, specifically solar arrays and wind farms. The actual performance of renewable energy project were important for forecasting the Air Force's and Department of Defense's energy goals. The same can be said for energy companies long-range plans to meet state's renewable portfolio standards. The renewable energy analysis consisted of the comparing performance with expectations and identifying factors that affected a base from achieving its projected goals.

This research provided the following two main contributions while satisfying the four research objectives.

7.1.1 Contribution 1 - Initial validation of renewable energy project performance

While meeting research objective 3, initial energy performance was validated for large-scale renewable energy projects. By conducting analysis on the actual production of energy from these projects, the critical role of feedback can improve the long-term modeling performance of renewable energy. The energy performance varied based on execution method. Nonetheless, the overall performance of the renewable energy modeling was closer to the actual performance the modeling for the high performance buildings. These results were the first step in developing a comprehensive renewable energy plan. The results also supported the idea of the Air Force, or any other entity trying to increase renewable energy production, would get better performance by pursuing third-party owned and operated projects.

7.1.2 Contribution 2 – Identification of factors affecting performance

As part of meeting research objective 4, several factors that affect the performance of renewable energy projects were identified. The list of factors including optimistic modeling, operation concerns such as ramping and ground faults, maintenance issues such as inverter problems and response time, and weather impacts constitute the beginning of what hopefully will be a comprehensive list of factors used to improve modeling and designs for future projects

7.2 Lessons Learned

Several lessons learned during this study could improve the process for future research. First, finding the right point of contact is critical and time consuming. If the project involves military personnel, the process of locating and contacting contacts would be much easier to accomplish from a military installation. I would recommend traveling to the closest base and working with the unit personnel to gain access through the e-mail and network systems.

Second, most of the projects in the Air Force have limited performance timelines which makes it difficult to know if the performance year is an abnormality for the project itself or if the project will continually under or over perform. Additionally, if projects have more than one year of performance, the researcher should try and obtain all of the performance data to provide a more accurate depiction of the project performance.

Third, the sample size for this study was relatively small. Future studies should either include projects from other military services or wait five to ten years and reassess the projects in the Air Force. In the future, the project sample would increase as a whole and include additional renewable resource projects such as biomass and waste to energy.

Fourth, since economics are a primary factor in deciding which projects are completed, more emphasis should be given to the initial cost and life-cycle cost of renewable projects. Combining post-occupancy evaluations with life-cycle cost will provide a more in depth tool for forecasting performance and planning projects in the future.

Lastly, conducting interview is a long process and any future research should concentrate on allowing sufficient time to make at least three rounds of contact since there was several follow-up questions or requests for data that extended the initial timeline.

7.3 Study Limitations

This study attempted to examine large-scale renewable energy projects in the Air Force. There were nine sites identified as potential projects. Of these nine projects, only the landfill gas project at Hill AFB was not included in the study. Personnel for eight of the projects were contacted and data from seven bases was sufficient to include in the study. Thus, the response rate for the projects was 89% and data was available for 78% of the potential projects. Nonetheless there were several limitations of this study that could be addressed in future studies. First, the number of electricity producing projects operating on Air Force installations in 2011 was relatively small in number and type of resource utilized. Second, the length of performance of the complete project was less than three years for most of the projects. Lastly, the actual performance data was inconsistent in the level of detail provided.

The number of renewable energy projects in the Air Force currently producing electricity was limited to wind and solar projects for this study. There is one project at Hill AFB that uses landfill gas to energy that should be considered in future studies. There are also biomass and waste-to-energy projects in the planning or construction phase that would allow for broader comparisons of renewable energy sources. Future studies could also include projects from the other branches in the Department of Defense to increase the pool of potential projects for analysis.

Many of the projects examined for this study were operating for one or two years, which allows for initial analysis on the performance of the projects but not extended performance. Projects depend on the weather for performance and one year of performance can differ significantly from the projected performance, so longer periods of performance are needed to get an accurate sense of system performance. For example the performance for one wind project was calculated using the P50 for the area and the first year was a P90, leading the project to underperform compared to the predicted performance.

The data gathered from the projects ranged from reported hourly since start-up to only an annual performance of the project. Ideally data would be available monthly from the beginning of the project through the time of study. This would minimize the affect that a given month or year has on the actual performance used for the study. For example, the data reported for the F.E. Warren wind farm was from 2011, when there were several issues with keeping the turbines operational.

Lastly, the process for execution of each project was unique when compared to the other projects. This was partially due to the variety of state incentives and renewable portfolio standards, the feasibility of renewable energy at the given base and the funding available at the time of planning, design and construction. Phasing projects may allow a base to apply lessons learned in the earlier phases, but it also requires the complete project to be segmented and may limit efficiencies in the system by increasing the connections and inverters for a project. A formal approach to capturing lessons such as the renewable energy playbook that was developed by AFCESA would allow many of the lessons learned from the existing projects to be captured to improve and streamline the process.

7.4 Future Research

The intent of this study was to determine the accuracy of performance projections for large-scale renewable energy projects on United States Air Force bases for Air Force owned and operated and third party owned and operated projects. The research attempted to identify factors that affect the actual performance and account for differences between the design and the actual performance. Many of the factors affecting the actual performance of renewable energy projects and the methods used to execute the same projects require a more intensive study to develop a better understanding of the complexity of the business case for renewable energy projects. The following are suggestions for additional research topics that would provide benefits to the Air Force as well other organizations pursuing large-scale renewable energy projects.

First, applying this research across the Department of Defense would provide a larger database of projects in number, execution method and type of renewable energy resource. This study was limited to the performance accuracy of solar and wind projects.

Second, conducting this research again in in four to six years would provide a better analysis of the long-range accuracy of performance of the Air Force projects. This would also allow for a larger sample size because a large number of projects currently under design and construction would be operational.

Third, expanding this study to include the performance of projects that produce energy but not electricity will also be beneficial to how the Air Force and Department of Defense addresses energy consumption in the future. Most notably for the Air Force is the large number of geothermal ground source heat pumps and solar hot water projects. Although these projects do not produce electricity, they can significantly reduce the amount of electricity that a base needs from on-site generation or from the electrical grid.

7.4.1 Recommendations for Practice

The development and application of the renewable energy playbook could provide insight into the best options for future renewable energy development at the Air Force level instead of each individual base level. The playbook is a nine-step process to identify requirements, feasibility and construction of renewable projects. The third step is for centers on the study and evaluation to determine the potential outcome of renewable energy projects. The project development process involves a feasibility study, opportunity assessment and business case analysis. In order to maximize the benefit to the Air Force, AFCESA conducted a nationwide feasibility assessment in 2010 and opportunity assessments of potential projects in 2011. By consolidating all of the base studies into one endeavor, AFCESA will hopefully be able to pursue the most advantageous projects in terms of funding and performance in the near future.

In addition to the use of playbooks, educational opportunities exist in the Air Force and other branches of the Department of Defense to promote changes for renewable energy initiatives and policies. For example the Civil Engineer School and Air Force Institute of Technology have courses that cover energy management, asset management and sustainability that provide an avenue for disseminating information to civil engineer leadership throughout the Air Force.

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10 U.S.C § 2911 (2010). “Energy Performance Goals master Plan for the Department of Defense.” < http://www.law.cornell.edu/uscode/text/10/2911> (Jan 29, 2012)

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Executive Order (EO) 13514 (2009). "Federal Leadership in Environmental, Energy, and Economic Performance." <http://wbdg.org/ccb/FED/FMEO/eo13514.pdf> (May 26, 2011).

This Executive Order sets sustainability goals for Federal agencies and focuses on making improvements in their environmental, energy and economic performance. The Executive Order requires Federal agencies to produce or procure 25 percent of total energy consumed by its facilities from renewable energy sources by 2025. Additionally, in response to E.O. 13514, every agency of the Federal Government was required to develop and implement a strategic sustainability performance plan.

Gray, K. (2011). "Installation Renewable Energy Development: A Ten-step Guide." *Air Force Facility Energy*, 18-19.

This article reviewed the renewable energy goals for the Air Force. It provided a ten-step process to follow in order to implement a renewable energy project at the base level. The article also detailed the recommended execution method for renewable energy projects.

Newsham, G., Mancini S., and Birt B. (2008). "Do LEED-certified Buildings Save Energy? Yes, but…" *Energy and Buildings*, 41(8), 897-905.

This article conducted an analysis on energy use from 100 LEED-credited buildings. The data was compared to energy use of the general US commercial building. Buildings were evaluated based on certification level and energy-related credits achieved. This article also provided a summary of research comparing the projected and actual energy use of LEED buildings. The key factors that impacted actual performance included: different occupancy hours between design and operation; changes between as-built design and initial design; experimental technologies not performing as predicted; differing plug loads; and improper commissioning.

U.S. Department of Defense (DoD). (2005). "DoD Renewable Energy Assessment Final Report." <http://www.acq.osd.mil/ie/energy/library/final_renew_asesmtreport.pdf> (Jan 27, 2012).

The Department of Defense outlined a short and long-term strategy to increase use of renewable energy to Congress in 2005. The report is the result of a cross-service assessment of renewable energy alternatives at or near military installations. The study found that the DoD should pursue on-installation production of renewable energy where it is economical because it provides energy savings, reduces dependence on foreign energy, and saves money while increasing energy security. Purchasing energy produced from renewable resources could provide the greatest source of renewable energy, but it was difficult to accomplish due to complexities in procurement. The study noted that biomass showed promise as a potential renewable resource, but that it needed further study. It also noted that few installations were capable of supporting large utility-sized renewable systems.

U.S. Department of Defense (DoD). (2011). "Strategic Sustainability Performance Plan FY 2010." <http://denix.osd.mil/sustainability/upload/DoD-SSPP-FY11-FINAL_Oct11.pdf> (Jan 15, 2012).

The 2011 Strategic Sustainability Performance Plan laid out the DOD's goals and performance expectations for the next ten years. This will allow the DoD to achieve its mission, lower life cycle costs, and advance technologies that enhance the sustainability goals of the US. The plan hopes to meet all energy regulations and policies. The plan reviewed progress that the DoD made in each of the goal areas over the last year. The main focus for 2011 and 2012 aimed to reduce the DoD's reliance on fossil fuels through energy efficiency and increased use of renewable energy.

U.S. Government Accounting Office (GAO). (2009) "DoD Needs to Take Actions to Address Challenges in Meeting Federal Renewable Energy Goals." <http://www.gao.gov/assets/300/299750.pdf> (Jan 4, 2012).

The Government Accounting Office assessed the Department of Defenses progress toward meeting federal renewable energy goals. It found that the DoD was the largest single energy consumer in the United States, spending over $4 billion on facility energy in fiscal year 2008. This report assessed the progress DOD had made toward the three key goals for consuming renewable energy in fiscal years 2007 and 2008, identified the challenges that may affect DOD’s ability to meet the renewable energy goals, and assessed DOD’s plans to meet the renewable energy goals.

Appendix A: PVWATTS Projections

PVWATTS Projections

1. Buckley AFB – 1,200 kW Solar Array

PVWatts

AC ENERGY & COST SAVINGS

Cautions for Interpreting the Results

(Type comments here to appear on printout; maximum 1 row of 80 characters.)

Station Identification	
City:	Colorado_Springs
State:	Colorado
Latitude:	38.82° N
Longitude:	104.72° W
Elevation:	1881 m
PV System Specifications	
DC Rating:	1200.0 kW
DC to AC Derate Factor:	0.770
AC Rating:	924.0 kW
Array Type:	Fixed Tilt
Array Tilt:	35.0°
Array Azimuth:	180.0°
Energy Specifications	
Cost of Electricity:	8.4 ¢/kWh

Results			
Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	4.67	137470	11547.48
2	5.19	135853	11411.65
3	5.80	163737	13753.91
4	6.15	164036	13779.02
5	6.07	162499	13649.92
6	6.36	158134	13283.26
7	6.12	155025	13022.10
8	6.32	162052	13612.37
9	6.31	159688	13413.79
10	5.94	160892	13514.93
11	5.01	137696	11566.46
12	4.29	124274	10439.02
Year	5.69	1821357	152993.98

2. Burlington ANGB – 1,446 kW Solar Array

PVWatts

AC ENERGY & COST SAVINGS

Cautions for Interpreting the Results

(Type comments here to appear on printout; maximum 1 row of 80 characters.)

Station Identification	
City:	Burlington
State:	Vermont
Latitude:	44.47° N
Longitude:	73.15° W
Elevation:	104 m
PV System Specifications	
DC Rating:	1446.0 kW
DC to AC Derate Factor:	0.830
AC Rating:	1200.2 kW
Array Type:	Fixed Tilt
Array Tilt:	30.0°
Array Azimuth:	180.0°
Energy Specifications	
Cost of Electricity:	12.0 ¢/kWh

Results			
Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	2.78	109694	13163.28
2	3.71	132840	15940.80
3	4.71	179657	21558.84
4	5.18	180951	21714.12
5	5.86	202575	24309.00
6	5.88	194460	23335.20
7	5.88	198247	23789.64
8	5.67	192965	23155.80
9	4.68	157804	18936.48
10	3.59	128951	15474.12
11	2.21	78590	9430.80
12	1.94	73355	8802.60
Year	4.34	1830089	219610.68

2. Nellis AFB – 14,200,000 kW Solar Array

PVWatts *** AC ENERGY & COST SAVINGS

Cautions for Interpreting the Results

(Type comments here to appear on printout; maximum 1 row of 80 characters.)

Station Identification	
City:	Burlington
State:	Vermont
Latitude:	44.47° N
Longitude:	73.15° W
Elevation:	104 m
PV System Specifications	
DC Rating:	1446.0 kW
DC to AC Derate Factor:	0.830
AC Rating:	1200.2 kW
Array Type:	Fixed Tilt
Array Tilt:	30.0°
Array Azimuth:	180.0°
Energy Specifications	
Cost of Electricity:	12.0 ¢/kWh

Results			
Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	2.78	109694	13163.28
2	3.71	132840	15940.80
3	4.71	179657	21558.84
4	5.18	180951	21714.12
5	5.86	202575	24309.00
6	5.88	194460	23335.20
7	5.88	198247	23789.64
8	5.67	192965	23155.80
9	4.68	157804	18936.48
10	3.59	128951	15474.12
11	2.21	78590	9430.80
12	1.94	73355	8802.60
Year	4.34	1830089	219610.68

4. Toledo ANGB – 1,128 kW Solar Array

AC Energy & Cost Savings

(Type comments here to appear on printout; maximum 1 row of 90 characters.)

Station Identification	
Cell ID:	0249368
State:	Ohio
Latitude:	41.8 ° N
Longitude:	83.8 ° W
PV System Specifications	
DC Rating:	1182.0 kW
DC to AC Derate Factor:	0.770
AC Rating:	910.1 kW
Array Type:	Fixed Tilt
Array Tilt:	41.8 °
Array Azimuth:	180.0 °
Energy Specifications	
Cost of Electricity:	8.4 ¢/kWh

Results

Month	Solar Radiation (kWh/m²/day)	AC Energy (kWh)	Energy Value ($)
1	3.06	89719	7529.22
2	3.85	102366	8590.55
3	4.63	131139	11005.19
4	5.49	145638	12221.94
5	5.66	148127	12430.82
6	5.88	143881	12074.49
7	5.74	143036	12003.58
8	5.64	142000	11916.64
9	5.43	135632	11382.24
10	4.17	111319	9341.89
11	2.73	72810	6110.22
12	2.40	68129	5717.39
Year	4.56	1433797	120324.25

Toledo ANGB – 1,518 kW Solar Array

Station Identification	
City:	Toledo
State:	Ohio
Latitude:	41.60° N
Longitude:	83.80° W
Elevation:	211 m
PV System Specifications	
DC Rating:	1518.0 kW
DC to AC Derate Factor:	0.770
AC Rating:	1168.9 kW
Array Type:	Fixed Tilt
Array Tilt:	41.6°
Array Azimuth:	180.0°
Energy Specifications	
Cost of Electricity:	8.5 ¢/kWh

Results			
Month	Solar Radiation (kWh/m ^{2}/day)	AC Energy (kWh)	Energy Value ($)
1	2.90	109600	9316.00
2	3.82	131154	11148.09
3	4.24	154484	13131.14
4	5.30	181620	15437.70
5	5.71	192018	16321.53
Jun 6	5.60	177532	15090.22
Jul 7	5.80	186153	15823.01
Aug 8	5.70	185692	15783.82
Sep 9	5.13	164599	13990.92
Oct 10	3.87	133616	11357.36
Nov 11	2.57	88590	7530.15
12	2.17	79772	6780.62
Year	4.40	1784830	151710.55

Toledo ANGB – 1,558 kW Solar Array

Station Identification	
City:	Toledo
State:	Ohio
Latitude:	41.60° N
Longitude:	83.80° W
Elevation:	211 m
PV System Specifications	
DC Rating:	1558.0 kW
DC to AC Derate Factor:	0.770
AC Rating:	1199.7 kW
Array Type:	Fixed Tilt
Array Tilt:	41.6°
Array Azimuth:	180.0°
Energy Specifications	
Cost of Electricity:	8.5 ¢/kWh

Results			
Month	Solar Radiation (kWh/m ^{2}/day)	AC Energy (kWh)	Energy Value ($)
Jan 1	2.90	112489	9561.57
Feb 2	3.82	134610	11441.85
Mar 3	4.24	158555	13477.18
Apr 4	5.30	186406	15844.51
May 5	5.71	197077	16751.55
Jun 6	5.60	182210	15487.85
Jul 7	5.80	191058	16239.93
Aug 8	5.70	190585	16199.73
Sep 9	5.13	168936	14359.56
Oct 10	3.87	137136	11656.56
Nov 11	2.57	90925	7728.62
Dec 12	2.17	81874	6959.29
Year	4.40	1831862	155708.27

5. USAFA – 6,000 kW Solar Array

PV Watts ***** AC ENERGY & COST SAVINGS ***** Cautions for Interpreting the Results

(Type comments here to appear on printout; maximum 1 row of 90 characters.)

Station Identification	
Cell ID:	0206365
State:	Colorado
Latitude:	38.8 ° N
Longitude:	105.0 ° W
PV System Specifications	
DC Rating:	6000.0 kW
DC to AC Derate Factor:	0.770
AC Rating:	4620.0 kW
Array Type:	1-Axis Tracking
Array Tilt:	20.0 °
Array Azimuth:	180.0 °
Energy Specifications	
Cost of Electricity:	12.2 ¢/kWh

Results

Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	5.03	753310	91572.36
2	5.80	775612	94283.40
3	6.79	982704	119457.50
4	7.62	1048355	127438.04
5	8.43	1169140	142120.66
6	8.96	1161604	141204.58
7	8.67	1143352	138985.87
8	8.16	1087421	132186.90
9	7.64	999274	121471.75
10	6.67	935038	113663.22
11	4.97	702626	85411.22
12	4.59	685981	83387.85
Year	6.95	11444418	1391183.47