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BUILDING INTEGRATED PHOTOVOLTAIC (PV) ROOFS FOR SUSTAINABILITY AND ENERGY EFFICIENCY

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Energy and Water

ESTCP Number: EW-200813

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14. ABSTRACT
The objective was to study how well a building integrated photovoltaic (BIPV) roof, mainly consisting of photovoltaic (PV) laminates bonded to a polyvinyl-chloride (PVC) membrane, performed as PV and roofing systems. The project focused on studying three BIPV systems, but additional sites were surveyed for ancillary information and comparison. In-person roof surveys using the ROOFER Engineered Management Systems approach and laboratory testing based on ASTM D 4434 tests were used to evaluate roof longevity. Energy output and weather data were used to evaluate PV performance. Temperature and air conditioning system data was collected at one location. ROOFER identified a number issues with the PVC part of the roof, but was insufficient for unanticipated issues with the PV system, such as PV adhesive failures. The PV system performed as expected, but is highly susceptible to soiling in low-slope roof applications. The BIPV system was shown to produce an overall reduction in roof temperature, but the air conditioning saving analysis was inconclusive due to problems with the facility that was studied. A computer model was used to estimate what savings could have been achieved and additional models were used to estimate the savings in other U.S. climates. This BIPV system is no longer commercially available, but similar implementations still exist and will benefit from the lessons learned during the study.

15. SUBJECT TERMS
building integrated photovoltaic roof; PV; renewable energy; rooftop PV

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ABBREVIATIONS & ACRONYMS

A/C	Air Conditioning
a-Si	Amorphous Silicon
AC	Alternating Current
AFB	Air Force Base
AHU	Air Handing Unit
APS	Arizona Public Service
ASTM	American Society for Testing and Materials
AZ	Arizona
BIPV	Building Integrated Photovoltaic
BTU	British Thermal Units
C	Celsius
CA	California
CdTe	Cadmium Telluride
CIGS	Copper Indium Gallium Di-Selenide
DC	Direct Current
DoD	Department of Defense
DOE	Department of Energy
EMS	Engineered Management System
EO	Executive Order
EXWC	Engineering & Expeditionary Warfare Center
ESPC	Energy Savings Performance Contract
ESTCP	Environmental Security Technology Certification Program
EUL	Enhanced Use Lease
FEAD	Facilities and Engineering Acquisition Division
FCI	Flashing Condition Index
FL	Florida
FY	Fiscal Year
HVAC	Heating, Ventilation, and Air Conditioning
ITC	Investment Tax Credit
kW	Kilowatt

kWh	Kilowatt-Hour
LBNL	Lawrence Berkeley National Lab
LEED-NC	Leadership in Energy & Environmental Design for New Construction
M&V	Measurement and Verification
MCAS	Marine Corps Air Station
MCI	Membrane Condition Index
MD	Machine Direction
MILCON	Military Construction
NAVFAC	Naval Facilities Engineering Command
NAS	Naval Air Station
NREL	National Renewable Energy Laboratory
O&M	Operations and Maintenance
PPA	Power Purchase Agreement
PV	Photovoltaic
PVC	Polyvinyl Chloride
PVL	Photovoltaic Laminate
REM	Renewable Energy Management
RCI	Roof Condition Index
ROICC	Resident Officer in Charge of Construction
SIR	Savings to Investment Ratio
SRM	Sustainment, Restoration and Modernization
STC	Standard Test Conditions
TPO	Thermoplastic Olefin
UFGS	Unified Facilities Guide Specification
VA	Virginia
W	Watts
WA	Washington

EXECUTIVE SUMMARY

Rooftop solar photovoltaic (PV) systems have gained popularity partly due to the lack of ground real estate and the large availability of unused roof space. However, the increased load can compromise roof integrity and void the roof warranty since the roof and PV systems are often provided by different companies. One solution is to use a building integrated photovoltaic (BIPV) roof consisting of flexible, thin-film, amorphous silicon (a-Si) PV modules factory adhered to a highly reflective polyvinyl-chloride (PVC) carrier sheet, which is then field bonded to an Energy Star-rated PVC roof membrane. This integrated system provides energy efficiency benefits and provides renewable energy. The cost of a BIPV roof can be less than a conventional roof and PV system and have a shorter payback period.

The objectives of this project were to demonstrate and validate how well BIPV roofs perform as both PV and roofing systems. Roof integrity was evaluated using the ROOFER Engineered Management System in-person surveys approach. ROOFER calculates roof membrane, flashing and overall condition indices to quantify roof maintenance and repair requirements. Site I (Luke AFB) and Site III (MCAS Yuma) BIPV roofs both showed very little-to-no change to their roof condition indices over time, whereas the Site II (NAS Patuxent River) BIPV roof showed a significant reduction in its membrane condition index due to extensive mold growth on the PVC membrane. However, it should be noted that ROOFER does not address issues with the adhered PV modules, which occurred at Site I (Luke AFB) and at least two other non-ESTCP-funded BIPV roofs. Therefore, while ROOFER indicates that the roof may endure for many more years, the failing PV component will reduce the intended functionality.

Roof integrity was also evaluated by taking field samples of weathered PVC roof membrane from under the PV modules and out in the open and applying select tests from ASTM D 4434 for PVC roofs. Use of these tests was driven by concern over the higher temperature exposure to the PVC under the PV modules. Both samples still met all the original ASTM requirements except for the tearing strength. Based on the similarities between the results for each PVC sample, there is no conclusive evidence that the different conditions impacted the PVC membrane’s longevity.

Renewable energy generation was evaluated to assess the PV performance. The source of the data for Site I (Luke AFB) was originally to be from a performance contract that was in place at the site. That contract was terminated before data was attained and while the roof manufacturer provided some data, much of it was found to be flawed due to problems with the data collection system. The two months of data that appeared credible indicated that the BIPV roof at Site I (Luke AFB) was only meeting 80% of the expected output. Based on the observations of the roof during ROOFER surveys, the reduced output was likely due to the natural soiling of the PV modules, which impacts conventional and a-Si PV modules alike. Results from Site II (NAS Patuxent River) were more promising. That BIPV roof primarily experienced partly cloudy to mostly cloudy weather conditions, but performed roughly 30% better than expected based on the measured solar resource. Observations from Site III (MCAS Yuma) show that the BIPV roof there also suffered from soiling issues, but not to the same extent as the Site I (Luke AFB) BIPV roof due to the facility’s much smaller size and resulting simple roof design. Data shows that the Site III (MCAS Yuma) BIPV roof has a relatively steady power conversion efficiency and met renewable energy generation expectations.

Increased energy efficiency was evaluated by measuring the BIPV roof reflectivity several times during the course of the study. At certain points, both Site I (Luke AFB) and Site III (MCAS

Yuma) BIPV roofs experienced up to a 29 percent reduction in BIPV roof reflectivity due to desert soiling. Site II (NAS Patuxent River) fared slightly better with a 24 percent reduction, but its reduction is primarily attributed to mold growth. Since these measurements are made at most annually, they do not represent the average roof reflectivity. The measurements do show an overall trend in the decrease of the BIPV roof reflectivity at all three locations. While desert sand soiling may be mitigated by rain events, the mold growth at Site II (NAS Patuxent River) will only get progressively worse. However, while the reflectivity values have degraded under different circumstances, they were still better than that of the pre-existing, conventional, dark roofs. Similar reflectivity degradation would still have occurred had Site I (Luke AFB) and Site III (MCAS Yuma) been equipped with any other cool roof material since the primary cause was natural soiling. Reflectivity degradation would also be expected to occur at Site II (NAS Patuxent River) since mold growth had been seen on other cool roof materials, but the magnitude of reduction would depend on the material's resistance to the local mold type.

Increased energy efficiency at Site III (MCAS Yuma) was evaluated by studying the BIPV roof's temperature at various layers and the impact to the cooling load. The temperature measurements show a significant reduction in heat transfer through the roof. However, due to the attic space being naturally ventilated and malfunctions with the air conditioning equipment, it was not possible to directly correlate the energy consumption to the roof temperature. As an alternative, computer models were used to simulate the BIPV impact to a prototypical office building and results were generated for this facility as if it was in Phoenix, AZ; San Diego, CA; Seattle, WA; Norfolk, VA; and Jacksonville, FL. The locations were chosen to represent different climates, the most common locations of DoD installations within the United States, and the available weather data. The simulations showed that BIPV roofs can result in a net positive energy savings at each location. It should be noted that the overall reflectivity of a BIPV roof is significantly dependent on the proportion of PV coverage, which generally means that a BIPV roof experiences an increase to solar heat gain as the amount of PV coverage increases.

Operations and maintenance requirements were qualitatively evaluated. Site I (Luke AFB) experienced some failures with the adhesive used to bond the PV to the PVC membrane. The BIPV system manufacturer attempted to apply a tape to hold the PV to PVC, but that tape failed as well. Two other non-ESTCP-funded BIPV roofs also experienced this adhesive failure. The Site II (NAS Patuxent River) BIPV roof experienced a problem with a pin-size hole. The manufacturer had a recommended procedure using a small flame to patch the hole, but there was difficulty in finding qualified local personnel to perform the maintenance. The PV cell will eventually fail, but the PV module should remain functional due to the bypass diode. This problem was occasionally found in other BIPV roof surveys as well. Mold growth was also a problem at Site II (NAS Patuxent River), but attempting to remove the mold would likely cause more damage to the roof. The mold problem was commonly found at other BIPV roofs in coastal/humid locations. Evidence of water ponding was found in several locations and indicates a poorly designed and/or poorly installed BIPV system or problems with the previous roof that were not resolved prior to BIPV roof installation.

The cost effectiveness of BIPV roofs primarily depend on the comparable cost of conventional roofing and rooftop PV systems. Roofing labor and material costs are relatively steady, but costs vary based on the roofing type and quality, so a range of $5 to $20 per square foot was used in cost comparison scenarios. The $20 per square foot cost is representative of a good quality modified-bitumen roof, a common, low-slope, roof type found within the Navy. However, the installed cost of conventional PV systems in 2008, the year that the BIPV roof contract was awarded for Site II (NAS Patuxent River) and Site III (MCAS Yuma), were roughly two-to-three times the cost of recently installed systems. California Solar Statistics websites shows that the cost range was roughly $7.5-$10 per Watt in 2008 and was $4-$7.5 per Watt in 2012. The price reduction is due to a number of market conditions, but a significant factor is the selling price of crystalline PV modules. BIPV roofs that utilize a-Si PV modules, like the ones in this study, experienced a significantly lower price reduction, which makes them less cost competitive today than in 2008 and appear to be mainly considered when roof penetrations and/or additional weight loading must be avoided. The four capital investment cost scenarios using the ends of the cost ranges show that BIPV roofs, when compared to the combination of conventional systems, were generally cost competitive in 2008 unless compared to a conventional roofing cost scenario of $5 per square foot. When using the 2012 PV cost range, BIPV roofs were only cost competitive in the $20 per square foot roof scenarios.

BIPV roof technology and products are still relatively new and evolving. The type of BIPV system studied in this project is no longer commercially available due to performance problems that have emerged in recent years. However, rooftop PV systems using an adhered approach are still being used. In some newer systems, thermoplastic-olefin membranes have replaced PVC because they are more compatible with common adhesives; flexible PV modules based on different materials have been used because of higher conversion efficiencies; conduit became surface mounted to be more firefighter friendly.

In spite of the changes, the same problems identified by this ESTCP study may still occur with the new adhered systems. The National Electric Code addresses some PV safety concerns, but fire and firefighter safety standards for PV systems still need further development, so consult with base fire safety personnel before and during the design phase. Improper water drainage can reduce roof longevity and may be remedied with a thorough review of the BIPV roof design by a roofing specialist, using a rigorous quality assurance/control plan, and performing a BIPV roof assessment before the expiration of the workmanship warranty. In the case of a retrofit, problems with the existing roof need to be identified and remedied prior to BIPV roof installation. Mold growth can reduce roof reflectivity even if it does not reduce roof longevity so ensure that the manufacturer and installer warranties address this aspect. PV adhesives may still fail and improperly tested solutions may make the situation worse by making future remedies more difficult to implement. A long-term warranty that addresses the adhesives mitigates the risk, but it is possible that the warrantor may go out of business prior to the end of the BIPV roof life as it was with the BIPV roofs in this study. Third-party solutions may be available, but may also compromise any remaining warranties. Various acquisition vehicles can mitigate the technical risks, but contracting complexity, costs, and risk management must be balanced.

The concerns with BIPV roofs can be mitigated, so DoD personnel in charge of rooftop solar projects need to determine whether or not the cost and benefits outweigh those of conventional rooftop PV systems. It is recommended that DoD personnel interested in BIPV roofs be aware of the issues, consult with a roofing specialist and, ideally, obtain training and/or consultation from experienced personnel prior to the design and construction phases. It is recommended that DoD revisit the BIPV roofs in this study several years from now, maintain a list of adhered PV systems, identify their basic PV and roof components, and survey a sample set every few years to identify performance and durability trends of the different components.

1.0 INTRODUCTION

1.1 BACKGROUND

Renewable energy systems are typically long term investments and require large areas of land. The lack of open real estate has contributed to the adoption of rooftop solar photovoltaic (PV) systems. However, this has led to concerns about increasing roof loading, compromising roof integrity and violating the warranty since the roof and PV systems are often provided by different companies.

One solution is to use building integrated photovoltaic (BIPV) roofs. In one form of BIPV, thin-film PV modules are factory adhered to a highly reflective polyvinyl-chloride (PVC) carrier sheet, which is then field bonded to an Energy Star-rated PVC roof membrane. Replacing an old, inefficient roof system with new insulation, an Energy Star rated roof membrane, and an integrated photovoltaic system is an approach that may yield a positive return on investment. Also, if BIPV roof installation coincides with a re-roofing effort, the avoided re-roofing cost may be used to fund the installation of a BIPV roof, which will significantly shorten the payback period and provide immediate environmental benefits.

Department of Defense (DoD)-wide implementation of this technology has the potential to increase energy security, generate renewable energy credits to meet energy goals, decrease energy consumption by reducing building interior cooling loads, reduce greenhouse gas emissions, improve air quality, and lower building-life-cycle-costs.

1.2 OBJECTIVE OF THE DEMONSTRATION

The objective was to demonstrate and validate whether BIPV roofs can endure weather conditions as well as conventional roofs, and to verify whether an integrated rooftop solar photovoltaic system can result in an energy efficient roof. This Environmental Security Technology Certification Program (ESTCP) project also investigated whether a BIPV roof system is structurally sound, how the system is expected to perform over 20 years under normal operation, and its effectiveness in providing on-site renewable energy generation. Implementation guidance was provided to help with future use of this technology.

1.3 REGULATORY DRIVERS

Sustainment, restoration and modernization (SRM) funds are generally allocated towards the highest priority projects first. As facilities go unmaintained, energy efficiency will be reduced and maintenance and energy costs of facilities will increase. To mitigate future maintenance and environmental problems, DoD has policies in place for attaining Leadership in Energy & Environmental Design for New Construction (LEED-NC) certification. In addition, the Energy Independence and Security Act of 2007 directed DoD to implement green building technologies and reduce fossil fuel requirements of our buildings. New technologies applied to these buildings will require revisions/addendum to design guidelines, such as the UFGS, in order for the systems to be properly implemented. Furthermore, both the Energy Policy Act of 2005 and Executive Order (EO) 13423 mandate a reduction in building-energy intensity by 30% by Fiscal Year (FY) 2015. The Defense Authorization Act for Fiscal Year 2007 dictates that DoD services are to achieve 25% renewable energy usage by 2025. EO 13423 further requires that at least half of the required renewable energy consumed comes from projects placed in service after January 1, 1999.

Renewable energy projects are typically characterized by long payback periods and large land area requirements. These types of systems often benefit from large economies of scale, but as Base Realignment and Closure (BRAC) and DoD release of land reduce the area of military installations, placement of renewable energy projects will be more difficult and DoD may have to resort to purchasing renewable energy at premium rates.

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY OVERVIEW

Most PV systems are mounted on aluminum racks. These racking systems have been used on rooftop systems as well as on ground-mounted systems for many years. As the solar energy industry developed, new racking systems were invented for different roof types and for certain aesthetic features. These systems can be integrated with the roof by penetrating the roof to attach the racking system. Another method is to attach the PV modules to the roof using an adhesive. The use of adhesives reduces, if not eliminates, roof penetrations and works with a variety of roof types, but the PV module's mounting angle is restricted to the slope and orientation of the roof. A third type of BIPV system uses heat welding and adhesives to bond the PV modules to a membrane roof. The backing of the module is made of the same material as the roof, which allows for this method of PV integration. This also eliminates roof penetrations and is potentially more reliable than the adhesive-only approach, but is restricted to certain roofing materials.

Crystalline silicon based PV technology is currently the most commonly used. Several years ago, the increased demand of silicon from both the PV and the electronics industries resulted in a silicon shortage and an increase to the cost of PV modules. The shortage has since disappeared but may still return depending on market and supply changes.

Other PV materials, such as thin film PV, are also available. Different thin film materials have different properties, but in general, they are more flexible in building integrated applications than crystalline-based PV and use relatively little-to-no silicon. This factor helps drive the industry's interest in the technology. Copper indium gallium di-selenide (CIGS), cadmium telluride (CdTe), and amorphous silicon (a-Si) are the three most common thin film technologies available today.

The form of BIPV roof demonstrated in this ESTCP project utilizes a-Si PV laminates (PVLs) factory adhered to an ENERGY STAR qualified PVC carrier sheet. ENERGY STAR qualified roof products are basically more reflective than non-qualified products. The PVLs and PVC carrier sheet forms the BIPV panel (Figure-1). The edge seal from the adhesive used to bond the PVL to the PVC carrier sheet can be seen. The dark border of a PVL does not produce power and only surrounds a set of PV cells like a frame. Figure-2 is an example of a cross-section of the BIPV roof assembly. The conduit runs in between the insulation boards.

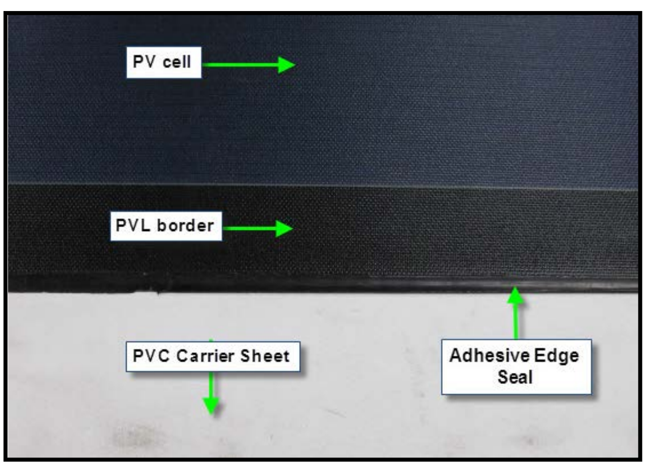

Figure-1: Close-up of the PVL and the PVC carrier sheet.

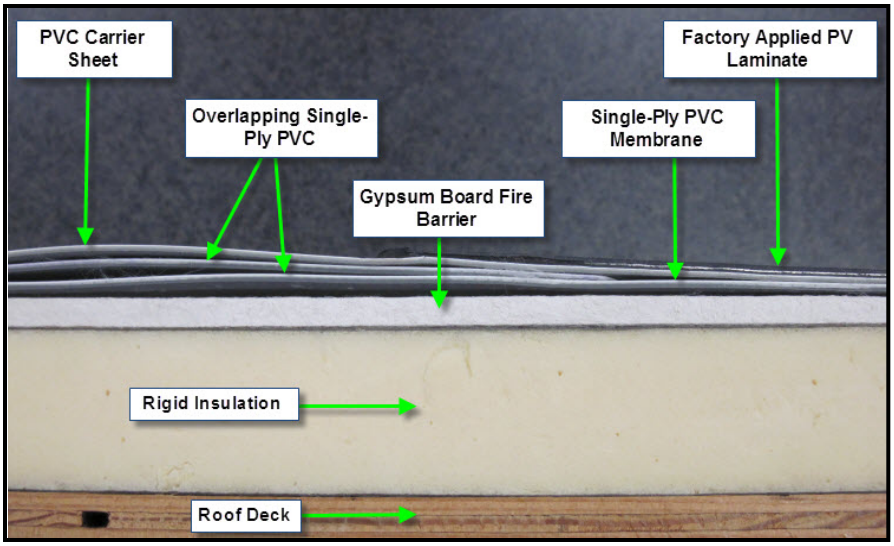

Figure-2: Cross-section of BIPV roof assembly without the conduit.

The conduit for the PV system and the roof insulation layer are first concurrently installed, followed by the installation of the PVC membrane layer. Then, the BIPV panels are connected to the conduit and finally heat welded to the PVC membrane to form an integrated roofing system. This design minimizes the concerns of exposed wiring and roof penetrations associated with the installation of some rooftop PV systems. If an existing roof is in good condition (e.g., no leaks or wet insulation, etc.), it is also possible to overlay the BIPV roof, from the insulation on up, on top of the existing roof. However, this may void the existing roof warranty, so the corresponding installer and manufacturer should be consulted prior to BIPV installation.

Figure-3 shows the mechanical fasteners that are used to attach the gypsum board and insulation to the roof deck. These fasteners are similar, if not the same, as the ones used in a regular PVC roof. The next layer up is the single-ply PVC membrane and is also visible in that photograph.

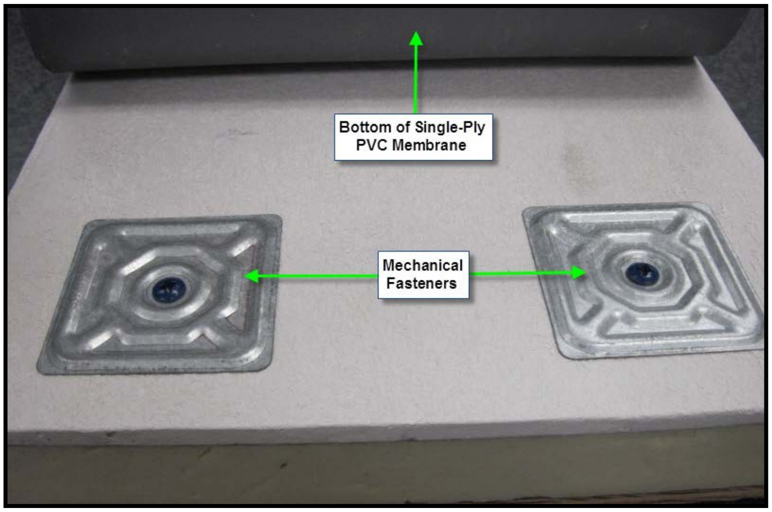

Figure-3: The mechanical fasteners under the single-ply PVC membrane

Figure-4 shows the top of the single-ply PVC membrane seen in Figure-3. The mechanical fasteners shown there are used to attach the PVC membrane to the roof components below it. These fasteners are only used along the edges of the PVC membrane sheet. To form a watertight roof, the sheets of PVC membranes are made to overlap so that the top PVC membrane seals off the fasteners below it. The bottom of the overlapping PVC membrane sheet can also be seen in Figure 4.

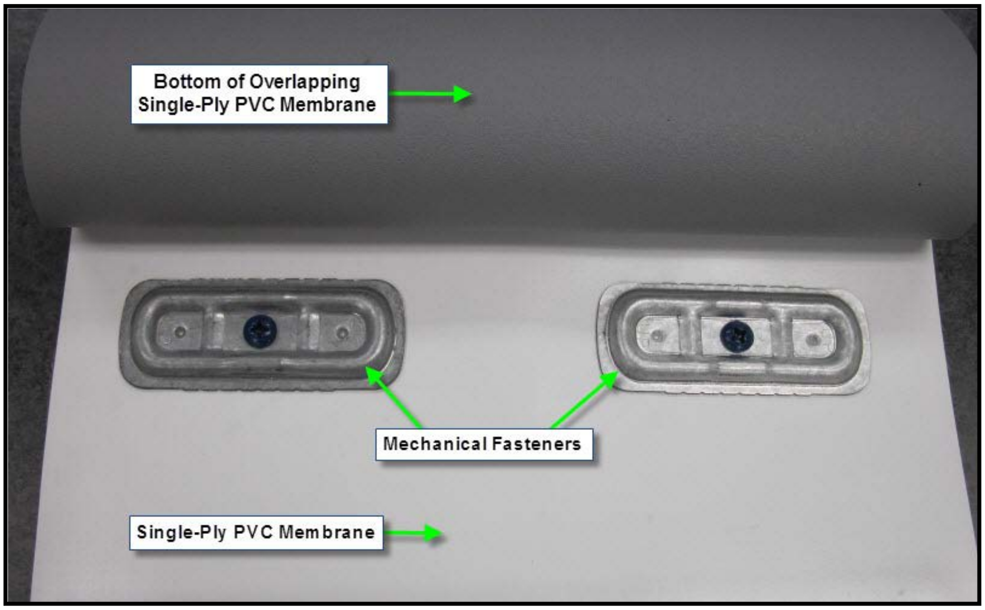

Figure-4: The mechanical fasteners holding down the single-ply PVC membrane.

Figure-5 shows the two PVC membrane sheets overlapping and the resulting seam from the heat welding used to form the bond between them. The PVC carrier sheet from the BIPV panel is attached to the PVC membrane using the same held weld process. This completes how the BIPV roof was assembled.

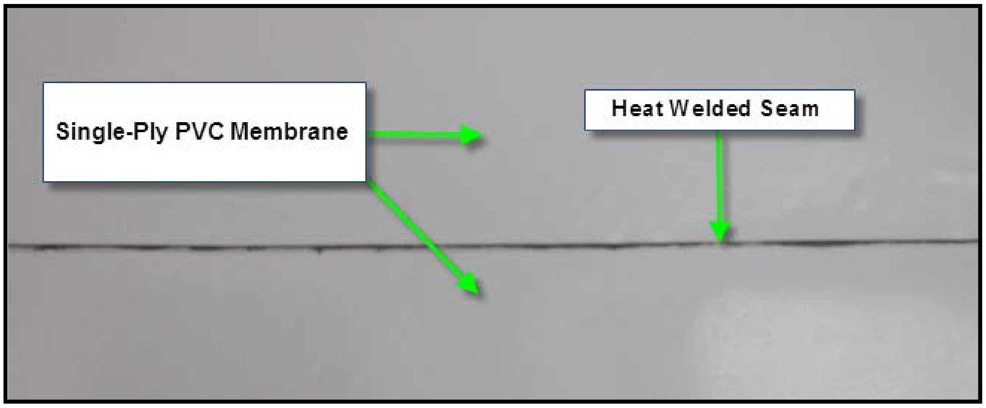

Figure-5: The overlapping area of single-ply PVC membrane under the BIPV panel.

2.2 TECHNOLOGY DEVELOPMENT

The technology studied in this ESTCP project utilized a commercially available product, thus, technology development was unnecessary. The pre-field demonstration portion of this ESTCP project pertains to site and facility selection. Since DoD installations are located in a variety of weather conditions, the BIPV roofs need be exposed to conditions that can be found in a large number of DoD installations. A map of DoD installations within the continental United States was used to identify which regions may be most representative of DoD (Figure-6). The Northeast and Southwest regions were determined to be the most representative due to the high number of DoD installations and climates.

However, the facilities used to host the BIPV roof needed to meet technical and budget requirements, so in-person site surveys were critical to facility selection. The chosen facilities are discussed further in section 4 of this report and the designs are in Appendix B.

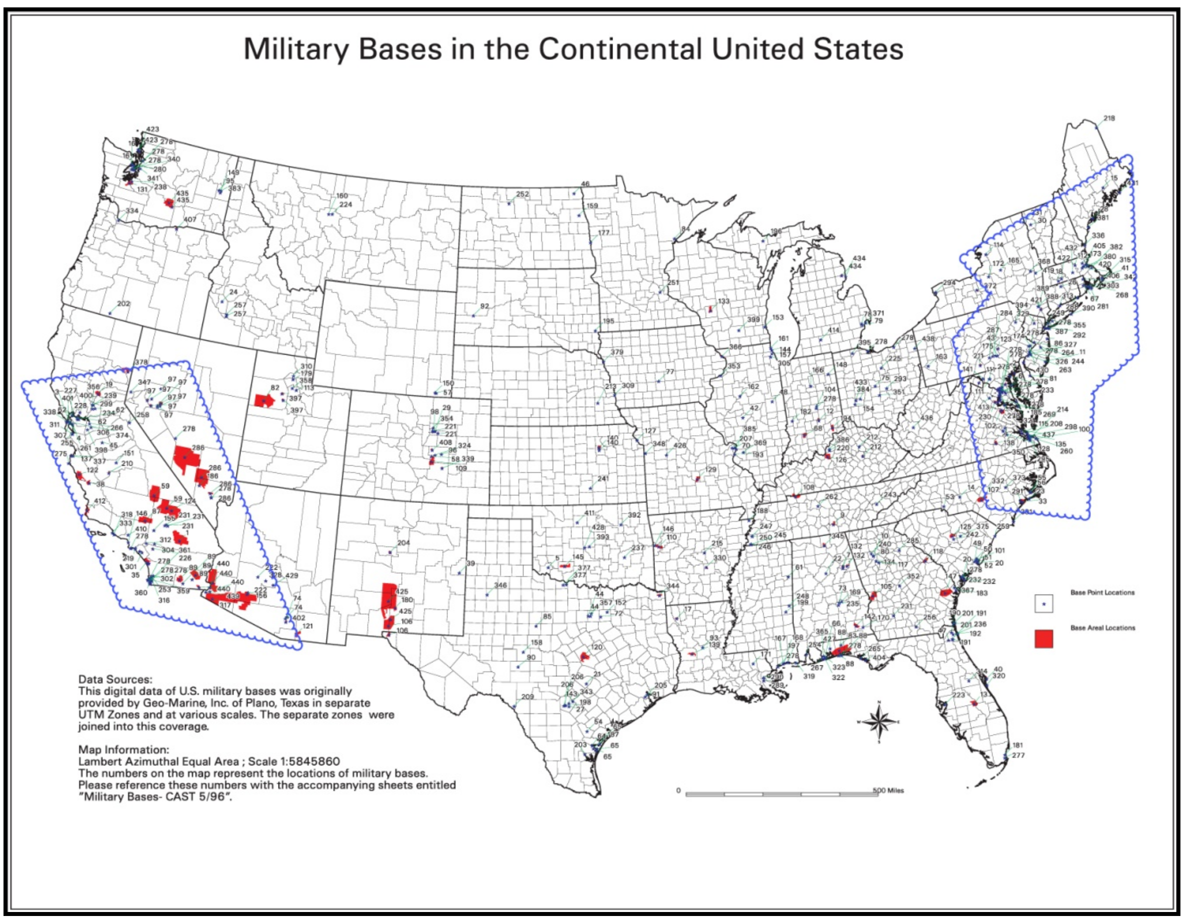

Figure-6: Map of U.S. military bases from the National Park Service website. The two areas with the greatest number of bases are as marked.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Currently, a-Si thin-film PV material has lower energy conversion efficiencies than crystalline silicon PV. However, a-Si cells can be manufactured at lower temperatures and deposited on low-cost substrates. The less energy intensive manufacturing process means that it takes less time for an installed a-Si PV module to generate the energy it took to manufacture the module when compared to crystalline silicon-based PV technology. Furthermore, a-Si PV is less dependent upon the angle of solar irradiance and its electrical conversion efficiency is less affected by temperature changes than crystalline PV. This potentially makes the use of a-Si PV more viable in BIPV applications since the installation angle is typically dependent upon the existing facility and the systems are mounted close to, if not flush against, the facility's surface. However, the surface that a BIPV panel is mounted to needs to be rigid enough to maintain the slope needed for proper water drainage. Failure in this area will cause water ponding, which can damage the PV panel, the PV attachment mechanism, the roof membrane, and encourage microbial growth.

Some studies projected that thin film PV will cost less to manufacture than crystalline PV and can achieve competitive electrical conversion efficiencies. The a-Si PV used in this demonstration has about a 6.3% solar-to-electricity conversion efficiency at the module level (i.e., the entire PVL including the dark border). For comparison, commercially available thin film CIGS PV panel manufacturers are boasting over a 12% module solar-to-electricity conversion efficiency and crystalline PV panels are considered to have a good conversion efficiency when over 15%, but 20% efficient crystalline PV panels have recently been made commercially available. Note that in this report, the use of PV module and PV panel have the same meaning, but BIPV panel specifically refers to the combination of the thin film PV modules and the PVC carrier sheet.

Highly reflective PVC roof membranes have the same major disadvantage that any white roof has, which is that its reflectivity can quickly diminish due to environmental conditions, which can result in an increase to the facility's cooling requirement if the roof is not periodically cleaned. Maintaining proper roof slope to avoid water ponding is also a concern, but is more significant in a single-ply PVC roofing system due to the fewer number of roofing layers when compared to a built-up roofing system. Also, since the solar-to-electricity conversion efficiency of the PV material is not 100%, there is potentially additional heat gain to the facility due to the dark colored PV panels. However, in the case of a BIPV roof retrofit, if the pre-existing roof was not highly reflective, these factors may not have a net negative impact on the cooling load. Another aspect to consider is that manufacturers of single-ply PVC roof systems typically provide 20 year warranties, whereas built-up or modified-bitumen roof systems may have warranties exceeding 20 years. In addition, due to the PV aspect of a BIPV roof, the capital cost of a BIPV roof is substantially greater than that of a conventional roof system. However, the cost for a BIPV roof may cost less than a new roof with a conventional rooftop PV system. Finally, although PVC membranes and PV panels are typically free of maintenance, BIPV roof systems are relatively new, so the long term costs and maintenance requirements of the system is still uncertain.

3.0 PERFORMANCE OBJECTIVES

Roof integrity, renewable energy generation, changes to the building envelope, and operations and maintenance (O&M) requirements were the four primary categories of interest for this demonstration. These areas were investigated at a total of three demonstration sites. Site I was an existing BIPV roof. Roof integrity and the renewable energy generation capability were investigated at that site. Site II and III had new BIPV roofs installed. Roof integrity and the renewable energy generation capability were investigated at Site II and III, but Site III also included the investigation of the BIPV roof's effects on the air conditioning system. The performance objectives and results are summarized in Table-1.

Table-1: Performance objectives of the demonstration.

DEMONSTRATION PERFORMANCE OBJECTIVES				
Performance Objective	**Metric**	**Data Requirements**	**Success Criteria**	**Results**
Quantitative Performance Objectives				
Roof Integrity at all sites (*Facilities*)	Roof condition assessments resulting in an overall condition index	In-person survey and evaluation of roofs using Appendix C methodology/ checklist	Deterioration characteristics of BIPV roof meets or exceeds predictive life curve in ROOFER EMS	Unsuccessful due to poor design/installation decisions and mold growth. However, design issues can be remedied to successfully meet the performance objective.
Roof Integrity (*Facilities*)	ASTM D 4434 for PVC Roofs	Certified laboratory testing	ASTM test results are equal or better than industry reported results for average roof types	Inconclusive. The test results for the weathered PVC samples were mixed.
Renewable Energy Generation at all sites (*Energy*)	Energy produced by solar PV system compared to available solar insolation	Measurement of KWH produced and weather conditions, including horizontal solar insolation	Measured energy produced corresponds to estimated energy production based on system efficiency	Successful based on measured solar-to-electricity conversion efficiency.
Increased energy efficiency (*Energy and Facilities*)	Reflectivity of roof system	Measured reflectivity of roof membrane and PV panels	Composite reflectivity of the two materials does not fall below that of pre-existing roof	Successful based on the criteria during the study period, but roof reflectivity has degraded significantly.
Increased energy efficiency at Site III (*Energy*)	Reduction of air conditioning heating/cooling loads	Measurements and model of air conditioning energy consumption, heat flux through roof, temperatures of environment and roof system, and weather conditions	A net reduction in the air conditioning system's energy consumption	Inconclusive due to the poorly insulated attic space, which resulted in immeasurable changes to the air conditioning energy consumption. However, temperature sensors in the roof did indicate significant temperature decreases after the BIPV roof installation.
Qualitative Performance Objectives				
Operations and Maintenance at all sites (*Facilities*)	Roof condition assessments and local public works O&M duties	Feedback from the roof surveyors and facilities maintenance staff and O&M records	O&M level of effort for the BIPV roof does not exceed that for conventional roofs	Unsuccessful due to the maintenance needed on the PV portion of the roof.

Roof Integrity – ROOFER EMS

In-person surveys of the roof's condition were used to evaluate the integrity of roof at all three sites. The ROOFER Engineered Management System (EMS) (Appendix C) provided the standard protocol that was followed. Each roof integrity survey resulted in a set of condition indices to be used as a quantitative metric. Indices are out of 100 and points are deducted based on the number and severity of problems that can be due to installation errors and/or damage. ROOFER EMS software uses built-in predictive life curves to project the life of a roof and lets the user determine if the roof will meet its rated life of 20 years. Using ROOFER EMS will help ensure that the results can be easily repeated by another organization and that the results are not questioned based on any usage of proprietary techniques, such as the manufacturer's performance evaluation package. Furthermore, since the evaluation of the roof integrity is limited to the period of the demonstration, it is ideal to use a standard roof evaluation procedure, which the facility manager can duplicate if any problems arise in the time following the demonstration period.

Based on the established criteria and evaluation methodology, the performance objective that evaluated roof integrity based on condition assessments was not met. The ROOFER EMS methodology was found to be severely harsh on improper installation due to poor design and/or defects, which resulted in roof life predictions that are less than 10 years. The most common installation/design error was roof flashing that did not meet minimum height requirements. In humid environments, mold growth on the PVC membrane was a common problem.

Roof Integrity – ASTM D 4434

Lab testing following American Society for Testing and Materials (ASTM) D 4434, *Standard Specification for Poly(Vinyl Chloride) Sheet Roofing*, was also used to evaluate roof integrity. The test results provide the quantitative metric that was used to compare different sections of the field-weathered PVC roof material to each other and the PVC specification standards.

The primary concern was premature degradation of the PVC roof membrane directly underneath the BIPV panel due to the greater temperature conditions the PV panels create. The results of the ASTM testing were inconclusive since the PVC membrane directly under the BIPV panel did not consistently yield significantly worse test results when compared to the PVC membrane that was away from the BIPV panel.

Renewable Energy Generation

The renewable energy generation performance objective utilized solar resource data collected by local weather stations and the power output data from the PV inverter or other energy- metering devices at Sites II and III. Site I already had existing monitoring equipment that collected similar data needed for this quantitative metric. The annual output and solar resource data helped determine the overall system efficiency. If the annual output corresponds to the estimated output, then the system met its renewable energy generation performance objective.

The PV systems generally met the expected energy output when looking at the mean conversion efficiency. Soiling due to environmental conditions was the primary factor impacting output. Soiling is most prominent on larger roofs that utilize interior drains due to the increased complexity in maintaining the slope for proper drainage.

Increased Energy Efficiency – Roof Reflectivity

The BIPV roofing system can potentially improve the energy efficiency of the building by reducing the load on the air conditioning system. The outer layer of the roof consists of a reflective PVC layer and a non-reflective PV layer. When compared to a conventional, dark roof, the cooling load on the building should be reduced. If the measured composite reflectivity of the PVC and PV materials does not fall below the measured reflectivity of the pre-existing roof, which is the baseline condition, then the system met this performance objective. This quantitative metric was originally planned to be studied at Site III only, but additional data was collected at the other sites during ROOFER EMS surveys. Reflectivity/albedo was determined using a modified version of ASTM E 1918 that Department of Energy Lawrence Berkeley National Lab (DOE LBNL) developed for smaller roof samples that LBNL calls E 1918A. This modified method was decided to be more accurate for measuring the PVC and PV components separately. The data collected can also be used to calculate albedo values according to ASTM E 1918, but is only provided in the appendices and was not used for assessing the BIPV roof.

The performance objective was met since the composite roof reflectivity values of the BIPV roofs during the demonstration period were generally greater than conventional dark roofs, but the degradation in the first few years was significant. This was primarily due to soiling and not actual roof membrane degradation. Since roof cleaning is not a typical DoD operations or maintenance activity, roof reflectivity was measured with the soiling during the site visits.

Increased Energy Efficiency – Reduced Air Conditioning Load at Site III

In addition, for Site III only, the energy usage of the air conditioning system was measured to characterize the performance of that system prior to installing the BIPV roof. Once the BIPV roof was installed, the air conditioning system and the weather will continue to be monitored during the demonstration period. Since the weather was not exactly the same in both the baseline and post-installation periods, the air conditioning energy consumption was normalized for weather and a resulting model using the measured data was used to compare the energy usage during two periods. The performance objective was met if the BIPV roof results in a net reduction to the air conditioning system's energy consumption and the result was used as a quantitative metric.

The data yielded inconclusive results due to the poorly insulated attic space. The poor insulation nearly eliminated the heat transfer from the roof to the occupied space, which resulted in immeasurable changes to the air conditioning energy consumption. However, temperature sensors in the roof did indicate significant temperature decreases after the BIPV roof installation.

Operations and Maintenance

Utilization of a BIPV roof system was expected to result in minimal O&M costs. Roof assessments and any available O&M records for the BIPV roof were collected and compiled to assess the O&M requirements of the BIPV roof at all three sites. If the level of effort required in operating and maintaining the BIPV roof does not exceed that of local conventional roofs, then the BIPV system met this qualitative performance objective.

The BIPV roof did not meet this performance objective at two out of three sites due to the maintenance required to maintain the PV system. The roofing membrane was generally maintenance free during the study period, but issues with damage to the PV panels and adhesion problems resulted in an increased maintenance requirement.

4.0 FACILITY/SITE DESCRIPTION

4.1 FACILITY/SITE LOCATION AND OPERATIONS

A total of 59 buildings were submitted by the Air Force, Army, Marine Corps, and Navy for consideration. Site I was chosen to be an existing BIPV roof and the decision to use this was based on the recommendation from the ESTCP review board. Sites II and III were chosen based on the size of the roof, type of roof, age of roof, local resources to support the project, solar insolation, access to the facility, roof condition, and geographic location. For Site II, the primary areas of study require a site with a wide variety of weather conditions. Since the existing condition of the facility did not matter, a roof in need of replacement was a better use of the funds. As for Site III, since one of the objectives was to study the effects on the heating, ventilation, and air conditioning (HVAC) system, it was desirable to choose a site where the solar insolation is very high, since this is where most systems will be likely to be installed due to project economics and where the solar insolation will more likely affect the HVAC system in an adverse manner. Also, in order to establish an energy consumption baseline, the roof needed to be in good condition. For both sites, the geographic location was an important consideration as to be representative of DoD installations. Figure-7 shows the locations of the three sites where the demonstration occurred.

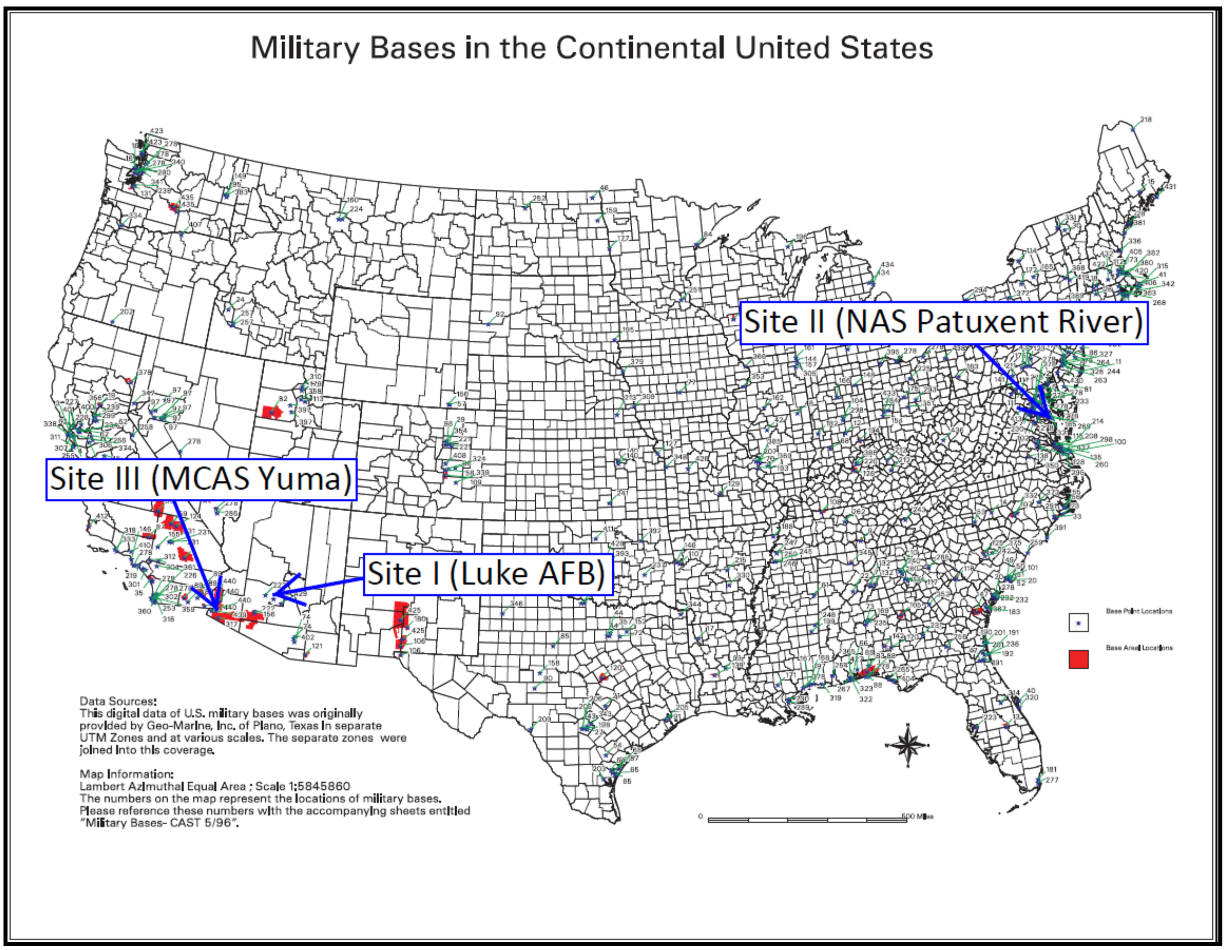

Figure-7: The three locations of the demonstration. Map is from the National Park Service website.

4.2 FACILITY/SITE CONDITIONS

Site I is a Base Exchange located at Luke Air Force Base (AFB) in Arizona (AZ). This site was chosen based on the ESTCP review board's recommendation, the large size of the BIPV roof, and the age of the roof. Site I (Luke AFB) has the same type of BIPV roof that will be installed at Sites II and III. Site II is a document storage facility located at Naval Air Station (NAS) Patuxent River in Maryland. Site III is an office space located at Marine Corps Air Station (MCAS) Yuma in AZ. Due the variety of weather conditions at these two locations, the BIPV roofs will be exposed to conditions that can be found in a large number of DoD installations, especially in the Northeast and Southwest geographic areas (Figure-6).

Site I (Luke AFB) and Site III (MCAS Yuma) are in close proximity to each other and will provide a good comparison of an older BIPV roof with a new BIPV roof. Also, the BIPV roof at Site I (Luke AFB) was originally under an Energy Savings Performance Contract (ESPC), which had different operations and maintenance criteria from non-ESPC roofs and has its performance validated by a measurement and verification plan. This was to allow a comparison to the ESTCP-installed BIPV roof at Site III (MCAS Yuma) and to evaluate whether or not more operations and maintenance should be included, but the Luke AFB ESPC was terminated shortly after this ESTCP project started.

Maryland and Arizona offer a high variation of climatic factors to demonstrate the system. Site II (NAS Patuxent River) site subjected the BIPV roof system to varied seasonal weather stresses while Site I (Luke AFB) and Site III (MCAS Yuma) in Arizona tested the system under high heat and sunlight conditions.

The roof at the Base Exchange at Site I (Luke AFB) is approximately 144,000 ft^2 and is equipped with a 122 kilowatt (kW) BIPV roof system installed in December 2005 (Figure-8). The BIPV roof was expanded to 375 kW in June 2006 to maximize the rebate received through the local utility. The PV laminates are estimated to cover about 42% of the roof.

Figure-8: Luke AFB BIPV roof being cleaned during adhesive-failure fix.

Building 515 at Site II (NAS Patuxent River) is a flat, built-up roof built in 1942. The facility is a single story warehouse building that has been converted to store contract documents. Only a few windows are still operable. The remaining windows are abandoned in place and covered with plywood siding to provide additional insulation to the building. The roof is approximately 16,000 ft^2 and covered with 4-ply built-up asphalt (Figure-9). The roof is 80 feet wide and 200 feet long. On each of the long sides, there is a 10 feet wide elevated covered loading dock. The roof structure is exposed. In as many as ten locations, it was noticed that the roof deck and support beams are rotten. The heights of the eaves range from 14 to 16 feet. The slope of the roof is 1/8 of an inch to one foot. The roof has two small plumbing stack vents. The roof was in poor condition, so the existing roof material, except for the existing roof deck, was removed and replaced with the BIPV roof. The installed PV laminates cover about 27% of the roof, resulting in an installed capacity of 27 kW (Figure-10).

Figure-9: Photo of Building 515 at NAS Patuxent River prior to BIPV installation.

Figure-10: Photo of Building 515 at NAS Patuxent River after BIPV installation.

Building 228 at Site III (MCAS Yuma) is a single story wood-frame building built in 1943 with a 9,270 ft^2 roof (Figure-11). The building height is 14 feet. The interior ceiling height is 8-10 feet. The attic height is 4-6 feet. The total wall area is 4730 ft^2 and the total window area is 478 ft^2. The Traffic Management Office and the Environmental department currently utilize the building. The building is operated 5 days a week from 6 am to 5 pm.

Figure-11: Building 228 at Site III (MCAS Yuma).

Site III (MCAS Yuma) is cooled with two 30-ton Carrier water cooled direct expansion chillers and heated with a small 580,000 British Thermal Units (BTU) Parker water tube boiler. Two air handlers provide conditioned air to the space. The interior temperature is kept at 76-78^{o}F. For part of the building, the supply and return air duct systems are in the attic and one leak was visible. The floor of the attic is insulated with fiberglass pad insulation (Figure-12). However, some insulation appeared to be removed and some was deteriorated. In addition, the roof was naturally ventilated with outside air. The ductwork and insulation remained unchanged for the baseline and post-installation demonstration periods.

Figure-12: Attic space of Building 228 at Site III (MCAS Yuma) showing poor insulation.

The roof appears to be in good physical condition and has one large exhaust vent with a small number of small vents around the center of the roof (Figure-13).

Figure-13: Rooftop photo of Building 228 at Site III (MCAS Yuma) prior to BIPV installation.

There is no indication that the thermal properties of this roof will be different from that of a new roof, so the BIPV roof system was installed on top of the existing roof. The existing antennae cable was laid across the roof once the BIPV roof was installed and held down by PVC strips so that the cable will not interfere with any of the solar panels or wear out the PVC membrane. The PV laminates cover about 36% of the roof (Figure-14).

Figure-14: Rooftop photo of Building 228 at Site III (MCAS Yuma) after BIPV installation.

5.0 TEST DESIGN

5.1 CONCEPTUAL TEST DESIGN

The objective was to demonstrate and validate whether BIPV roofs can endure similarly to conventional roofs and to verify whether an integrated, rooftop, solar PV system can result in an energy efficient roof. For the energy-monitoring portion of the demonstration project at Site III (MCAS Yuma), the following tasks were performed:

- Characterize and document heat flow through the roof for the baseline condition.
- Characterize and document heat flow through the roof for the cool roof section and the PV section after the BIPV roof is installed.
- Measure and document electricity generated by the PV system.

Using a series experiment approach, the performance at Site III (MCAS Yuma) was monitored for the baseline and post-installation conditions. The baseline condition was the measurement of the heat flow through the existing roof. The post-installation condition includes heat flow and energy characterization of both the single-ply PVC membrane and the BIPV panels installed on the roof.

Evaluation of the roof integrity at all three sites required periodic roof surveys using ROOFER EMS. This system includes procedures for collecting and maintaining roof condition data, surveying, rating, and evaluating roof conditions (Appendix C). The overall roof condition rating procedure uses standard inspection procedures and numerical indices for assessing the roof condition, which include separate condition indices for the membrane, flashing, and insulation. This data was entered into MicroROOFER software, which calculates an overall roof condition index (RCI). For the laboratory-testing portion, ASTM D 4434 for PVC roofs was used.

5.2 BASELINE CHARACTERIZATION

The roof integrity baselines for the three sites were established by performing evaluations using ROOFER EMS. Site I (Luke AFB) has an existing BIPV system, so the first ROOFER survey was used as the baseline. The evaluations for Sites II (NAS Patuxent River) and Site III (MCAS Yuma) occurred after the BIPV roofs were installed.

For the effects on the HVAC loads at Site III (MCAS Yuma), data was collected to characterize the cooling energy use of the building. Data analysis allowed for the characterization of the cooling energy use at the site. Both hourly and daily data was used in the analysis and will be normalized with the outdoor weather data. The weekend data was used to more accurately characterize the effect of the building shell on air conditioning (A/C) energy use since, during the weekend, the internal loads were limited to some lighting only. The weekday data was used to integrate the effect of the building shell and the dynamics of the building's operation and internal loads.

Baselines were not needed to evaluate the renewable energy generation capability of the systems since both the solar resource and the energy production will be measured concurrently.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

The evaluations of the roofs at all three sites used standard procedures to establish numerical indices from data collected from visual inspections. Additional information was acquired from nondestructive moisture surveys and gravimetric analyses of core cuts. The data generated overall RCI's.

For monitoring the energy production at Site I (Luke AFB), the monitoring system installed according to the terms of the ESPC was used. The site utilized the manufacturer's Renewable Energy Management (REM) system, which measured direct current (DC) power produced, alternating current (AC) power produced, AC energy produced, system voltage produced, PV panel temperature, below-surface temperature, ambient temperature, solar insolation, and wind speed. The original plan was to use the data from the annual verification reports from that ESPC to evaluate the BIPV roof's performance, but the ESPC was terminated shortly after this ESTCP project was initiated. However, some site specific data was acquired from the manufacturer.

Similar equipment was used to evaluate the energy production of the PV system at Site II (NAS Patuxent River) and Site III (MCAS Yuma). Equipment regarding the study of the load on the HVAC system, including measuring the reflectivity of the roof, was only installed at Site III (MCAS Yuma). A schematic of Site II (NAS Patuxent River) is shown in Figure-15. A thermocouple that measured the PV module temperature was located near the weather station. As indicated by Figure-15, the system is actually wired to accept an additional 7 kW in the event that the site decides to expand the system. Due to the condition of the PVC membrane, as will be discussed later, there are currently no plans for the expansion.

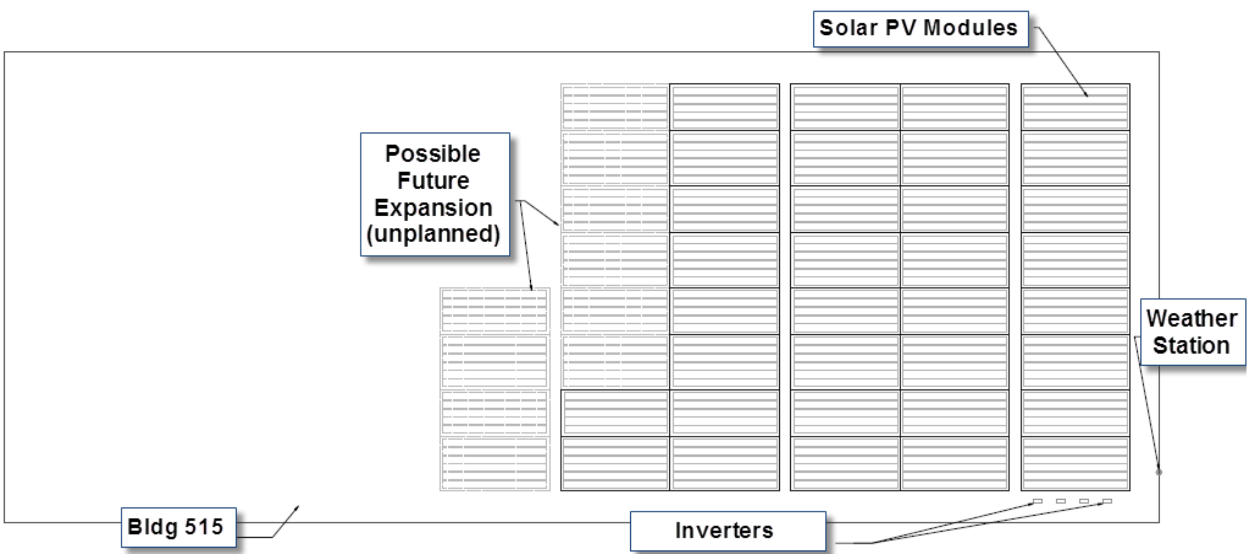

Figure-15: Diagram of major components on Building 515 at Site II (NAS Patuxent River).

For Site III (MCAS Yuma), a general diagram of the sensor locations are shown in Figure-16. In general, the parameters measured include the roof surface temperatures, roof underside temperatures, roof heat flux, indoor and plenum air temperatures, weather conditions, and whole-building energy use. A detailed list of monitoring points is shown in Appendix D.

In addition to the continuously monitored data, the following one-time measurements were made:

- Roof albedo/reflectivity before and after BIPV installation
- Wall and roof insulation levels
- A/C nameplate and power
- Internal equipment and power

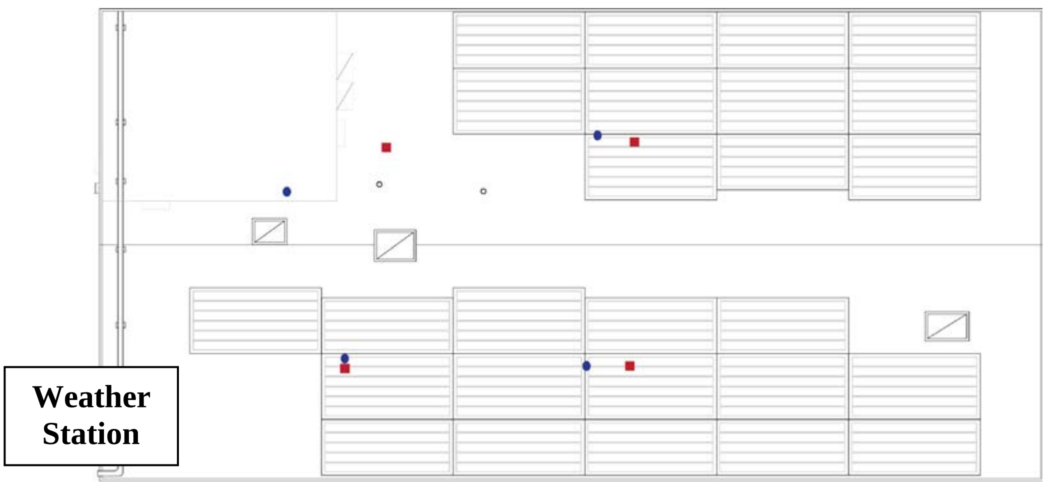

Figure-16: Locations of the temperature sensors at Building 228 at Site III (MCAS Yuma) during the baseline and performance period monitoring. Blue ovals indicate locations of roof deck underside sensors and red squares indicate locations of roof top surface sensors.

5.4 OPERATIONAL TESTING

The primary tasks performed during the planned testing period are shown in Figure-17. The time-lines for the three demonstrations sites were very similar once the BIPV roofs were installed. With the exception of the weather station, no other equipment will be installed for the purpose of the evaluation of the roof integrity. The personnel who performed the surveys were trained in ROOFER EMS protocols and experienced with roof evaluation procedures. DoD safety requirements were followed. ROOFER assessments were originally planned to occur annually in equal increments of time, but some assessment schedules were shifted to align with significant project events or due to scheduling conflicts.

		Task Name	Duration	Start	Finish
1		**- Site I (Luke AFB) - 3 ROOFER Surveys**	**826 days**	**Wed 8/13/08**	**Wed 10/12/11**
2		3 ROOFER Surveys	826 days	Wed 8/13/08	Wed 10/12/11
3		**- Site II (NAS Patuxent River)**	**720 days?**	**Tue 12/2/08**	**Mon 9/5/11**
4		BIPV Roof Construction	9 days	Tue 12/2/08	Fri 12/12/08
5		Data Collection & 3 ROOFER Surveys	660 days?	Fri 2/6/09	Thu 8/18/11
6		Site Report & Analysis	70 days	Tue 5/31/11	Mon 9/5/11
7		**- Site III (MCAS Yuma)**	**741 days?**	**Fri 5/1/09**	**Fri 3/2/12**
8		Energy Baseline	26 days?	Fri 5/1/09	Sat 6/6/09
9		BIPV Roof Construction	5 days	Mon 6/8/09	Fri 6/12/09
10		Post-Retrofit Data & 3 ROOFER Surveys	595 days?	Mon 6/15/09	Sun 9/25/11
11		Site Report & Analysis	115 days	Mon 9/26/11	Fri 3/2/12

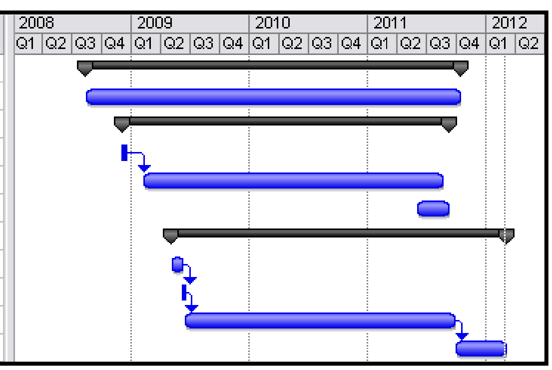

Figure-17: Approximate schedule of operational tasks for currently planned schedule.

For the energy monitoring at Site III (MCAS Yuma), there were two major periods of performance. For the baseline energy use characterization, sufficient data was collected to characterize the cooling energy use of the building. Analysis of this data allowed for the characterization of the HVAC system and how it correlates with the outdoor weather data. Once the BIPV roof was installed, the cooling energy use and heat transfer through the roof for both the PV and cool roof portions were analyzed. Monitoring of the baseline cooling period of Site III (MCAS Yuma) commenced on May 2009 and completed in June 2009, though the actual data collection was initiated several weeks prior to ensure that the data collection equipment was functioning. Both weekday and weekend data was analyzed.

After sufficient data was collected to characterize the roof system, the BIPV roof was installed. Installation of additional monitoring sensors and reinstallation of the weather tower and roof temperature sensors was coordinated with the BIPV roof construction contractor. The BIPV roof performance period was about two years.

The electricity generated by the BIPV and the local weather conditions was continuously monitored throughout the performance period at all three sites. Site I (Luke AFB) used locally available data, whereas Site II (NAS Patuxent River) and Site III (MCAS Yuma) utilized energy meters and data loggers installed within the building and small weather stations installed on the roof. The energy production measurements and the weather data were collected immediately after the system was commissioned.

At the end of the ESTCP project, the temperature and heat flux sensors were abandoned in place since they do not interfere with the roof or operations of the building and they do not contain any residual value. The weather towers and data loggers are left to the local installation to use for monitoring beyond the ESTCP demonstration period.

5.5 SAMPLING PROTOCOL

To ensure that the roof integrity was properly assessed, consistent roof condition evaluations must be performed each time the roof is surveyed to gain an understanding of the deterioration characteristics of the roof system. The ROOFER EMS software roof evaluation tool can repeatedly provide objective roof condition scores. This tool brings the strength to this test in that it can give the same objective condition assessment results regardless of who performs the survey as long as the proper procedures were followed. ROOFER EMS provides a numeric scores ranging from 0-100. Each BIPV roof was surveyed a minimum of two times. An informal assessment was made at Site II (NAS Patuxent River) after hurricane Sandy, but nothing notable was found since the site was not severely affected by the storm.

For the energy-monitoring portion, both hourly and daily data was used in the analysis. The energy consumption-monitoring portion at Site III (MCAS Yuma) took into account weekend and weekday energy usage behavior. The data was downloaded and reviewed periodically to ensure that the monitoring equipment was performing within established parameters. The following is taken from the draft journal version of the LBNL report and it describes the equipment used and data points that the equipment addresses for Site III (MCAS Yuma) [1]:

> Various research-grade sensors were used to measure indoor and outdoor air temperatures, outdoor air relative humidity, roof surface temperatures, heat fluxes

through the roof deck, solar radiation, wind speed, HVAC power demand and building power demand.

Outside air temperature and relative humidity (RH) were measured using a Vaisala HMP45C-L probe, which was housed in a Campbell Scientific 10-plate naturally ventilated Gill radiation shield (model 41003-5). The shield was located about 70 cm above the roof on a weather tower mounted on the building near its southwest corner. Global horizontal solar radiation was measured using a Kipp & Zonen CMP3 second-class pyranometer. The device was attached to a Campbell Scientific leveling mount, which was in turn affixed to the south end of the weather tower cross-arm. The instrument was located higher than all nearby obstacles (including a nearby chimney) to avoid shadows. Wind speed was measured with a Gill Instruments WindSonic two-axis time-of-flight ultrasonic anemometer. The device was attached to the top of the weather tower, about 2 m above the roof. Measurements of precipitation at Yuma Marine Corps Air Station, AZ were obtained from Weather Underground.

Three roof temperatures were measured in each roof quadrant (for a total of 12 roof temperature measurements) using Minco S667PD thin-film platinum resistance temperature sensors connected to Minco Temptran TT176PD temperature transmitters. Before installation of the BIPV system four roof top surface temperature sensors were installed. Each of these temperature sensors was attached to the roof using construction adhesive and then covered with an approximately 150 mm-square piece of asphalt cap sheet patch. The patch was adhesively bonded to the existing roof cap sheet. Four temperatures were also measured on the wooden underside of the roof deck beneath the roof top surface temperature sensors. Each temperature sensor was bonded to the wood with epoxy. During the subsequent installation of the BIPV system, four additional temperature sensors were added. These sensors were located on the top surface of the BIPV system gypsum board in the middle of each quadrant. The temperature sensor in the northwest quadrant was underneath the exposed white membrane (without laminated PV) while the other three sensors were underneath the membrane with laminated PV.

Heat fluxes were measured at the underside of the roof deck near the middle of each roof quadrant using Hukseflux HFP01-L heat flux sensors. Each heat flux sensor was attached to the underside of the roof deck near roof underside temperature sensors using epoxy and oriented for positive heat flux downward through the sensor. During installation of the BIPV system, two additional Hukseflux HFP01-L heat flux sensors were installed in the roof. These heat flux sensors were located on the top surface of the BIPV system gypsum board in the northwest and southwest quadrants immediately adjacent to the surface temperature sensors. The heat flux sensor in the northwest quadrant was located underneath the exposed white membrane (without laminated PV) and that in the southwest quadrant was under membrane with laminated PV.

Four air temperatures in the attic, one air temperature in the ceiling return plenum (northwest quadrant), and three air temperatures in conditioned spaces were measured using Campbell Scientific 108-L probes. In the attic and return plenum, the probe tips were suspended near the mid-height of the associated space. In each conditioned space, the probe tip was suspended about 8 to 10 cm below the ceiling.

Power drawn by each of the five HVAC system components (i.e., both sets of compressors and air handling units, and the evaporative condenser) and the entire building (including HVAC system power) was measured using Continental Control Systems WattNode WNB-3D-240-P three-phase four-wire power meters. Each power meter was connected to three Continental Control Systems split-core current transformers. During installation of the BIPV system an additional power meter of the same type was installed at the connection of the PV inverters to the building main power to measure PV power production, P_{PV}.

Building plug load, P_{other}, was calculated as

$$P_{\mathrm{other}} = P_{\mathrm{building}} - P_{\mathrm{HVAC}}, \tag{1}$$

where P_{building} is the total building load. (P_{building} was corrected for PV power production after installation of the BIPV system.) P_{HVAC} is the total HVAC power load, calculated as

$$P_{\mathrm{HVAC}} = P_{\mathrm{c1}} + P_{\mathrm{c2}} + P_{\mathrm{ahu1}} + P_{\mathrm{ahu2}} + P_{\mathrm{ec}}. \tag{2}$$

Subscripts c, ahu, and ec correspond to the compressor, air handler, and evaporative condenser, and subscripts 1 and 2 correspond to components for the south side (AHU1) and the north side of the building (AHU2).

Measurements were recorded by a pair of Campbell Scientific XP-CR1000 24-bit programmable data loggers. The instrumentation and data loggers were installed and commissioned in early December 2008. Each sensor was scanned once a second and average values were recorded every 30 seconds.

The instrumentation at Site II (NAS Patuxent River) was similar in purpose and is summarized below:

Measured Parameter	Manufacturer and Model
Ambient Temperature / Relative Humidity	Kele GEH5-O-TT2
Wind Speed	Kele A70-SL
Rain	Kele A70-RL
PV Surface Temperature	Omega RTD-830
Roof Surface Temperature	Omega RTD-830
Pyranometer	Apogee SP-215
Energy Meter	Veris H-8163-0200-1-3

5.5.1 Calibration of Equipment

ROOFER EMS does not require instrument calibration. As for the energy monitoring equipment, the data acquisition system were set up and tested to ensure the system performed as expected prior to deployment and installation. New sensors were purchased pre-calibrated from the manufacturer.

5.5.2 Quality Assurance Sampling

The ROOFER EMS process does not require roofing experts to conduct the inspections. The system is designed to provide consistent results regardless of the inspector and has been proven effective throughout DoD. The data collected for the energy monitoring were downloaded and reviewed periodically to ensure that the monitoring equipment is performing within established parameters.

5.6 SAMPLING RESULTS

The ESPC at Site I (Luke AFB) was terminated soon after this ESTCP project was approved, so the ESPC annual verification reports were not available for use. Raw data from the previously-installed data acquisition system had to be requested from the manufacturer. Due to problems with the data collection system and errors in the majority of the reported data, only energy (Figure-18) and power data (Figure-19) for April and May 2011 appear valid. Note that Figure-18 shows the solar resource as sun hours in kWh/m^2/day. Also known as solar insolation or irradiance, this value is the equivalent number of hours the sun is producing 1000 Watts per square meter in a day. This convention is very convenient because the PV industry rates a PV module's power capacity under Standard Test Conditions (STC), which basically consists of 1000 W/m^2 of solar irradiance on a PV module at a temperature of 25 ^{o}C and a reference solar spectral irradiance called Air Mass 1.5, and allows the PV system planner/designer/evaluator to quickly estimate the expected energy production. For the simplified calculation, the annual energy output can be estimated by multiplying the rated capacity in kW by 365 days and by an assumed de-rating value to account for losses due to the inverter, soiling, etc. Comparing the measured energy production to expected energy production based on the available solar resource will determine the effectiveness of the PV system in providing renewable energy.

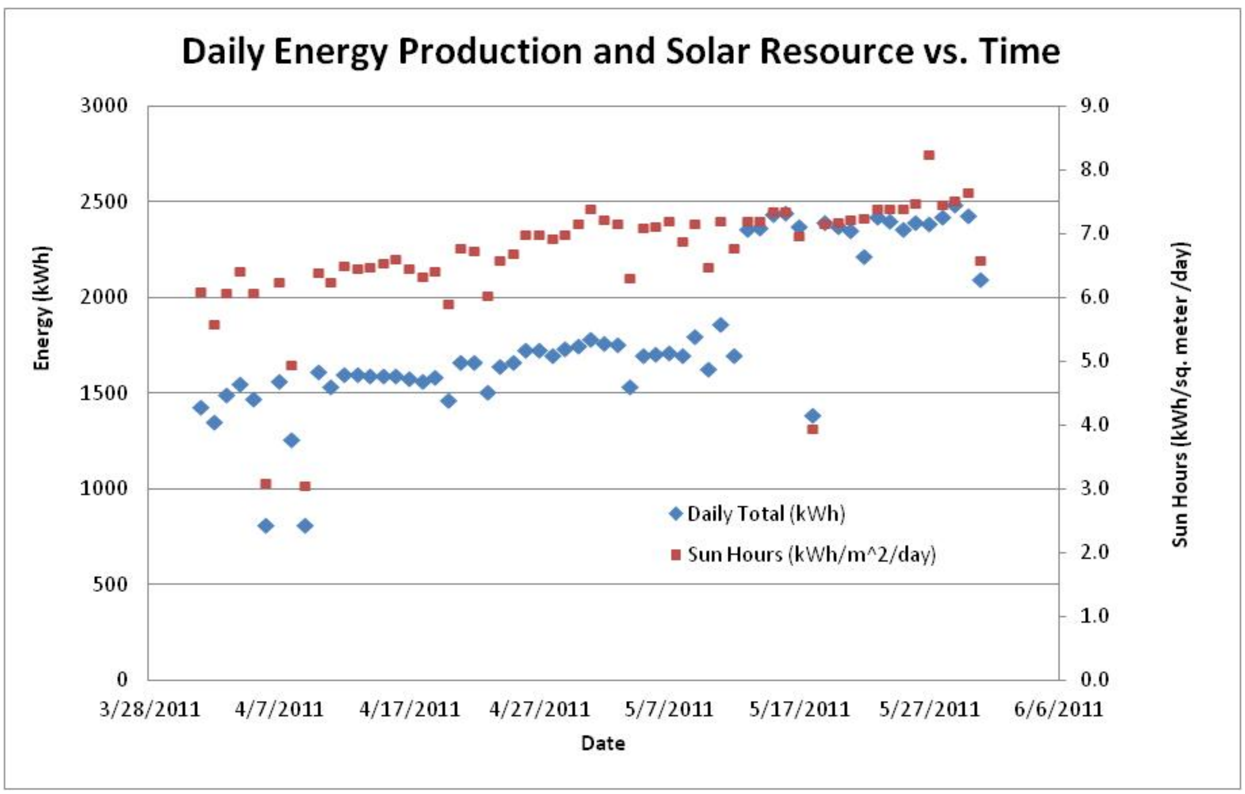

Figure-18: Total daily energy production and solar resource from April to May 2011 at Site I (Luke AFB).

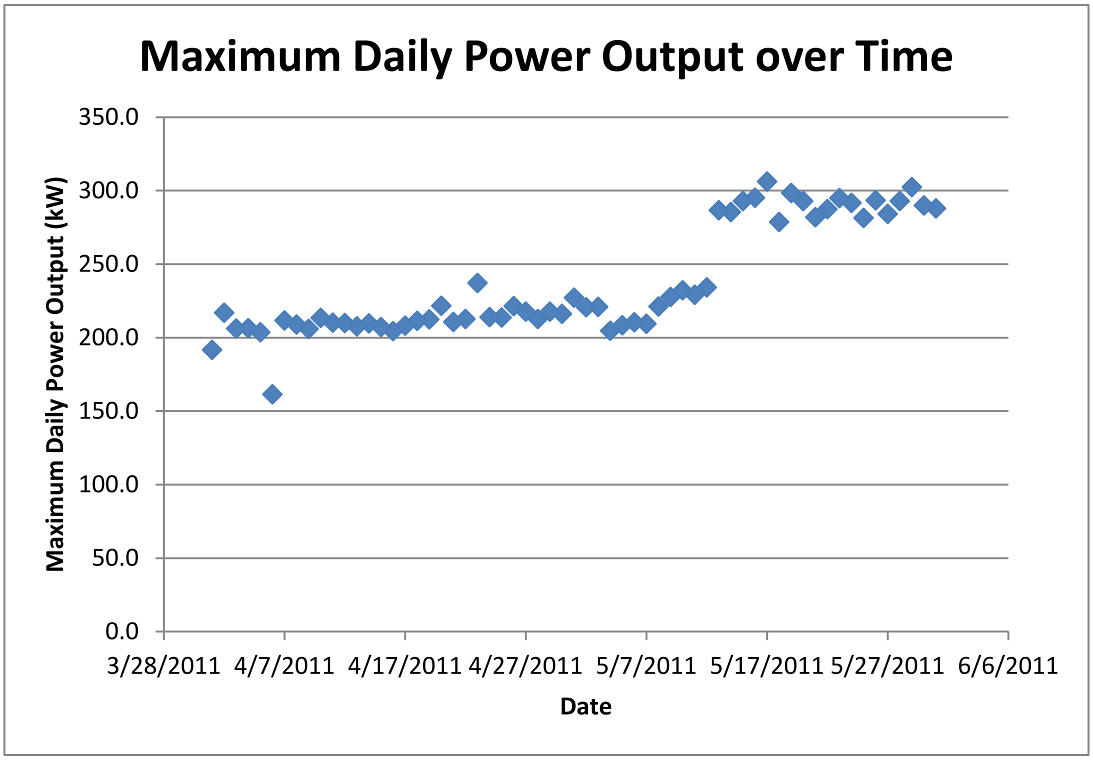

Figure-19: Maximum daily power output for April-May 2011 at Site I (Luke AFB)

ROOFER EMS survey records for Site I (Luke AFB) are shown Appendix E and the resulting condition indices are shown in Table-2. The RCI, Membrane Condition Index (MCI) and Flashing Condition Index (FCI) provide an overall assessment of the roof over time. However, note that ROOFER is currently designed to only assess conventional roofs and not BIPV roofs, so issues with the PV panels that do not impact the roof integrity are not accounted by ROOFER EMS and, thus, do not impact the condition indices.

Table-2: Condition indices results from ROOFER EMS surveys at Site I (Luke AFB).

	RCI	MCI	FCI
AUG 2008	94	96	94
MAR 2010	94	95	94
OCT 2011	94	94	94

For example, Figure-20 shows the bond failure between the PV and PVC carrier sheet. Since the carrier sheet may still provide for a water tight roof assembly, problems experienced by the PV modules may not impact ROOFER scoring. However, the indices still provide an indication of how well the PVC portion of the roof is enduring over time.

Figure-20: Bonding failure between PVL and PVC at Site I (Luke AFB).

In response to the bond failure, the PV manufacturer taped the frame around the PV laminate to the adjacent PVC membrane in an attempt repair the problem in May 2010 (Figure-21, left). Unfortunately, some of the tape deteriorated less than six months after the tape was applied. The photo on the right in Figure-21 was taken about one year after the tape solution was applied and shows the significant difference between the surviving tape and the deteriorated tape. The white portion of the area between the two PV laminates indicates where the tape survived and the brown portion indicates where the top layer of the tape deteriorated and collected dirt. In addition to impacting the roof integrity, the deteriorated tape reduces the overall roof reflectivity which can increase the facility's cooling load.

Figure-21: Tape solution soon after it was applied (left) and deterioration later that year (right) Site I (Luke AFB).

Figure-22 shows some of the tape deterioration along with soiling of the PV modules. The significant soiling is expected to be a result of the low-slope BIPV roof surface, which does not allow for all the water to completely leave the surface and causes any dirt trapped by the water to settle on the BIPV roof after the water dries. The soiling on the PV modules will reduce the overall roof reflectivity and the energy output of the PV system.

Figure-22: Tape detoriation and soiling of the PV system at Site I (Luke AFB).

Measuring BIPV reflectivity at Site I (Luke AFB) was not originally part of the scope, but since soiling was significant and it was a negligible cost increase when using the ROOFER survey team, the data was collected. Table-3 and -4 show the calculated roof and PV reflectance values (i.e., albedo), based on the average of the measured results listed in Appendix F. The original albedo value of the PVC was taken from the product specification data sheet and was determined by the manufacturer using industry standard ASTM D-4434 and is assumed to be accurate. The PV industry does not report an equivalent reflectance value for PV modules, so cleaned modules were used as the baseline. Note that the only time the PV was cleaned was when the roof was being prepared for the tape solution. The other measurements are for naturally soiled roof and PV surfaces.

Table-3: Average PVC membrane reflectance values at Site I (Luke AFB).

	Albedo	Vs. Original
Original PVC Specification	0.83	
MAY 2010 PVC – soiled	0.76	- 8 %
OCT 2011 PVC – soiled	0.59	- 29 %

Table-4: Average PVL reflectance values at Site I (Luke AFB).

	Albedo	Vs. Cleaned
MAY 2010 PV – cleaned	0.24	
MAY 2010 PV – soiled	0.23	- 4 %
OCT 2011 PV – soiled	0.18	- 25 %

The instrumentation at Site II (NAS Patuxent River) experienced some issues with remote communication and malfunctioning sensors soon after the BIPV roof was installed. Therefore, the contracted monitoring period for the energy data at that site was extended accordingly. SEI Group was contracted to perform the monitoring and the following is the section on data gaps from the contractor report which is included in Appendix G.

> Data was harvested from the data logger through a telephone line provided by the site. There were gaps in the data due to telephone line connection and sensor failures. At times, the phone line would not connect to the data logger and some data was lost. After several attempts to correct the problems with the phone line, local site personnel collected data directly from the data logger and forwarded the data to the analysts. In particular, data from June and July 2009, February 2010, and August 2010 were lost. Missing data appears as gaps in the data seen in the forthcoming charts.
>
> The original outside air temperature and humidity sensor was a GE model. After it failed, it was replaced with a Veris model. It is believed that these failed because high humidity associated with the site being located so close to Patuxent River. The roof and PV surface temperature sensors and transmitters were replaced after they began to produce temperature reading well above and below the expected ranges. These surface temperature sensors may have failed due to the hot roof environment. Data from the Patuxent River weather station (KNHK) located 1.2 mile east of building 515 were used for reference in determining if sensors were operating within expected range. The PV power meter stopped working. To correct this, the voltage leads were reconnected.

Sufficient data was collected to assess the PV power output performance. Figure-23 shows the power output of the PV system over the course of the monitoring period, which was from February 2009 to February 2011. Figure-24 shows the energy output of the PV system as it relates to the measured global, horizontal insolation at the Site II (Patuxent River).

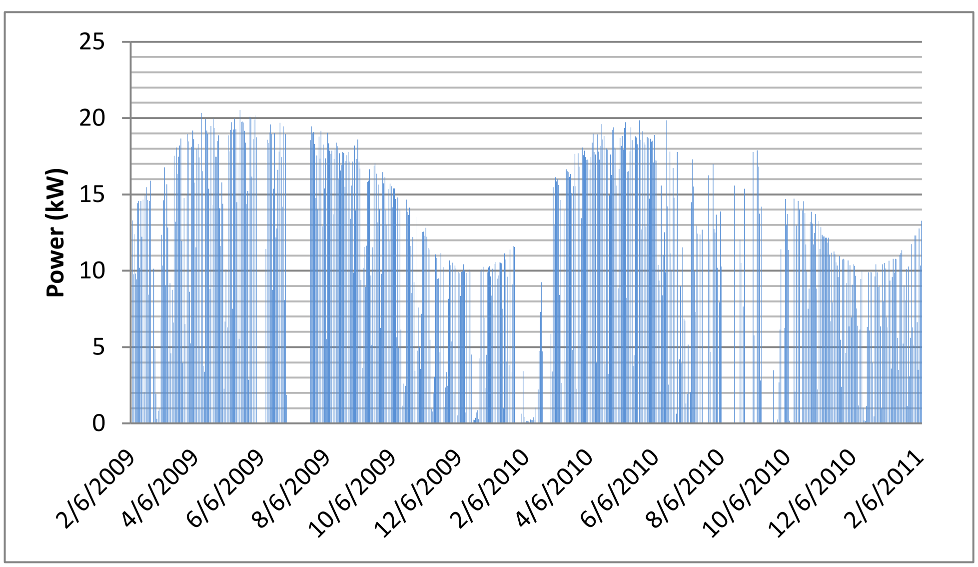

Figure-23: Power output over time at Site II (NAS Patuxent River).

While the higher insolation will increase power output, the conversion efficiency is reduced as the PV temperature increases, which occurs when the sun heats up the PV modules. Wind speed was measured to determine its impact on the PV surface temperature. Figure-25 shows the recorded temperature for certain wind speed ranges plotted against the solar insolation. Figure-26 shows the total power output plotted against the surface temperature of a PV module. Rainfall can also impact power output by reducing the BIPV temperature, reducing or increasing soiling, and the reduction in solar insolation due to cloud cover. Figure-27 shows the power output of the system versus the amount of rainfall during the monitoring period. As the graphs indicate, the most significant correlation to PV power output is the solar resource. The other weather-related factors do not identify any significant trends.

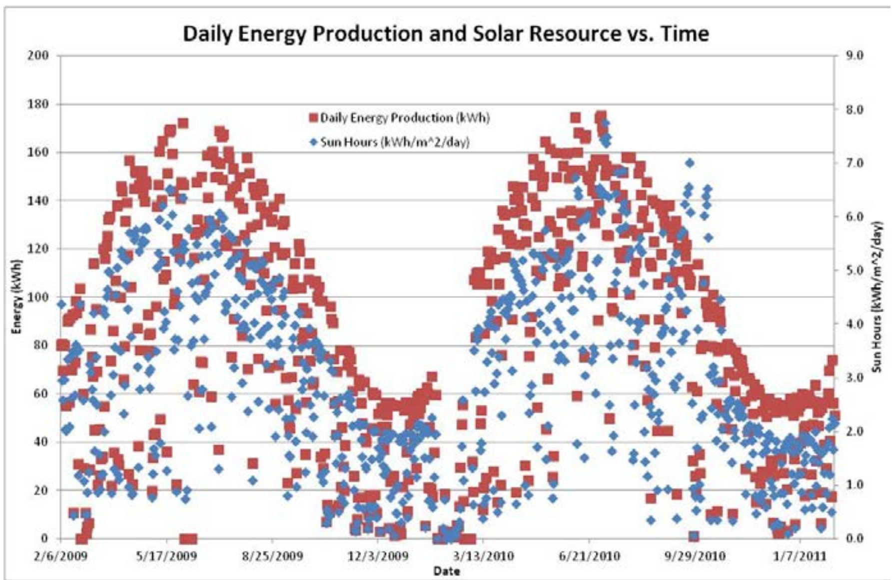

Figure-24: Total daily energy production and solar resource over time for at Site II (NAS Patuxent River).

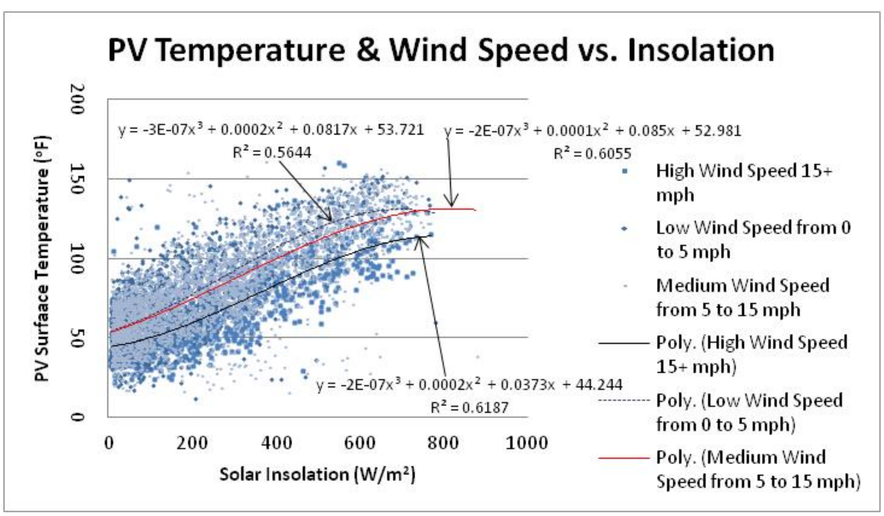

Figure-25: PV surface temperature as it relates to wind speed and solar insolation at Site II (NAS Patuxent River).

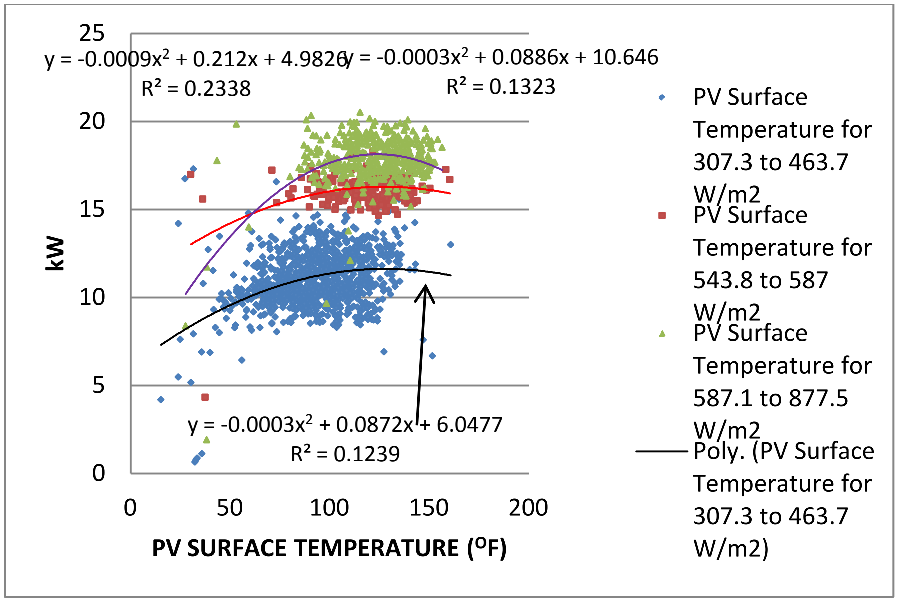

Figure-26: Total PV power output vs. PV surface temperature at Site II (NAS Patuxent River).

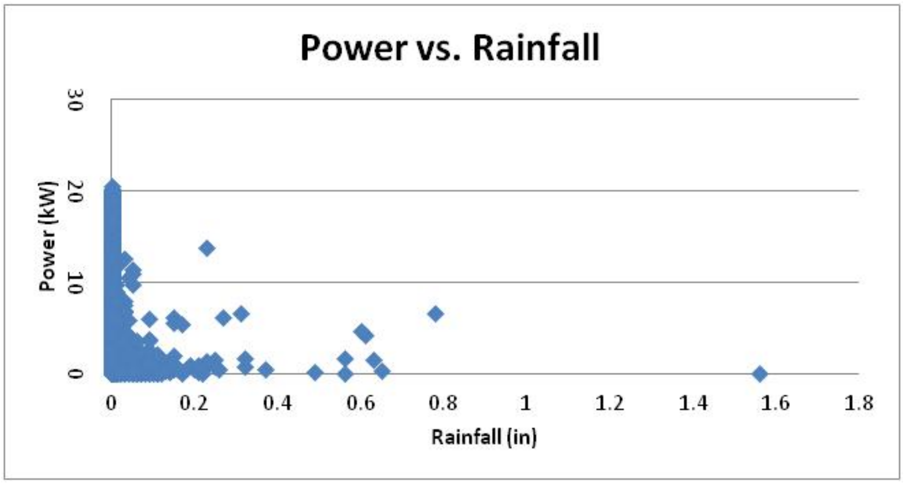

Figure-27: Total PV power vs. rainfall at Site II (NAS Patuxent River).

ROOFER EMS survey records for Site II (NAS Patuxent River) are shown Appendix H and the resulting condition indices are shown Table-5. The condition indices were significantly impacted by mold growth on the PVC and a warping dens-deck shown in Figure-28 and water ponding shown in Figure-29. Since mold growth was not present at either Site I (Luke AFB) or Site III (MCAS Yuma), it was once again determined to be worthwhile for the ROOFER survey team to measure the roof reflectance while they were on site (Table-6; Appendix I). Due to a lack of clear skies, a condition necessary for proper roof albedo measurement, only one measurement was acquired for Site II (NAS Patuxent River). In addition, it was impossible to properly measure the albedo of the PV modules due to water ponding. Water ponds also reduce the amount of sunlight the PV modules receive, thus, reduces the PV energy output.

Table-5: Condition indices results from ROOFER EMS surveys at Site II (NAS Patuxent River).

	RCI	MCI	FCI
JUL 2009	91	90	90
OCT 2010	85	81	88
JUL 2011	80	74	88

Figure-28: Mold growth (upper left corner) and warping dens-deck (center) at Site II (NAS Patuxent River).

Figure-29: Significant ponding at Site II (NAS Patuxent River).

Table-6: Average PVL reflectance values at Site I (Luke AFB).

	Albedo	Vs. Spec
Original PVC Specification	0.83	
JUL 2011 PVC – soiled	0.63	- 24 %

For Site III (MCAS Yuma), data collection equipment was installed soon after the demonstration plan was finalized, prior to the installation of the BIPV roof, in order to establish the energy use baseline. Some issues with the existing air conditioning equipment were identified soon after the baseline monitoring commenced. The fan starter in the evaporative condenser blower had failed and one of the compressors was low on refrigerant. The fan starter was quickly repaired and the compressor was recharged. These unexpected problems complicated the assessment of the BIPV roof's energy efficiency impact since the pre and post-installation conditions were not entirely consistent.

Figure-30 shows the weekday daily global, horizontal, solar insolation/irradiance, and daily mean wind speed during the course of the study at Site III (MCAS Yuma). Weekend data was excluded to be consistent with the air conditioning component of the analysis as that portion is impacted by building occupancy and indoor air temperature.

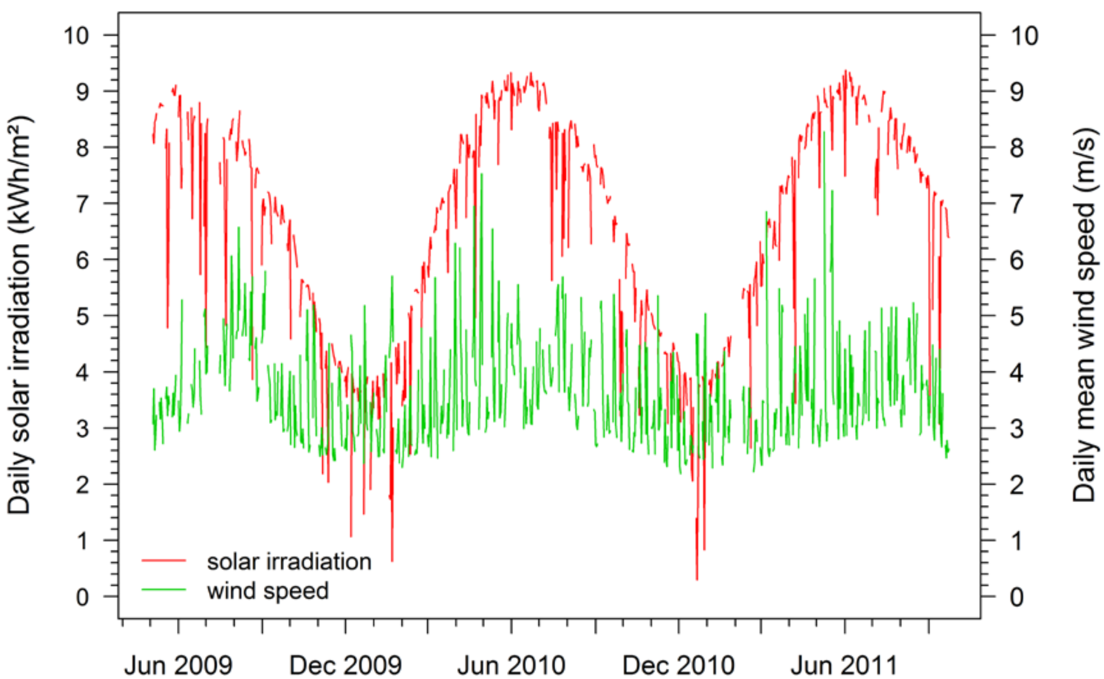

Figure-30: Weekday solar insolation and wind speed during the course of the study at Site III (MCAS Yuma).

Roof surface and attic temperatures can be impacted by the BIPV system. Short-term temperature measurements of the original roof were measured for comparison to the BIPV roof. In general, the PV surface temperature was greater than the original roof, but the PVC membrane was much lower. Figure-31 focuses on the roof temperature measurements and Figure-32 shows roof temperature measurements along with temperatures of the attic space and indoor air. Figure-33 is similar to Figure-32 except that outdoor air is shown. Once again, weekend data was excluded to be consistent for the air conditioning portion of the study.

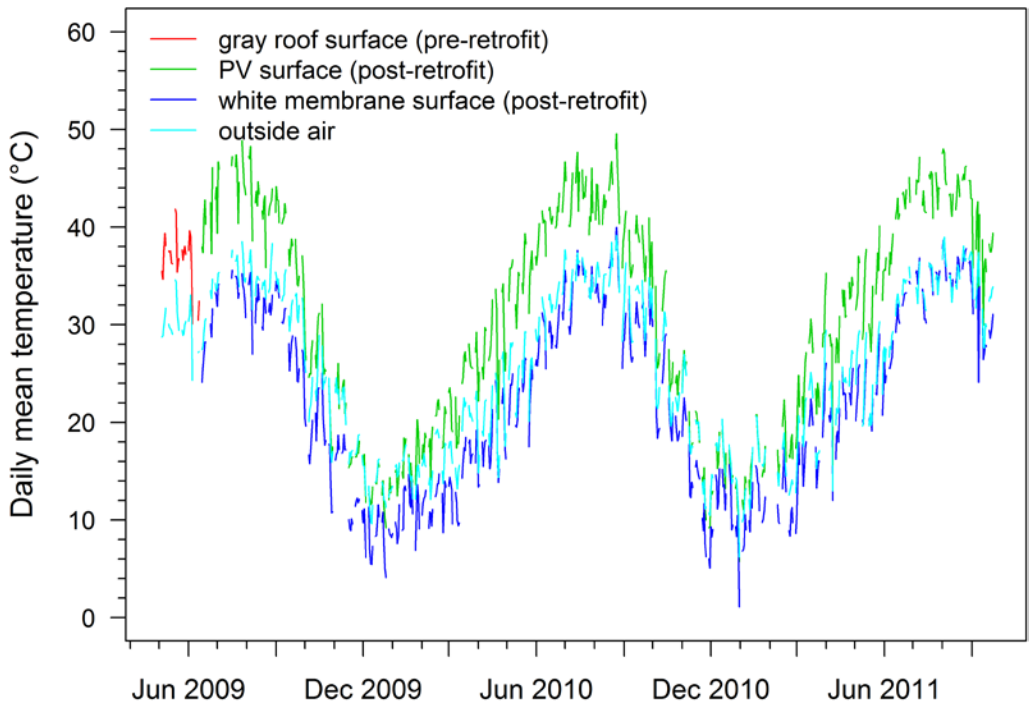

Figure-31: Site III (MCAS Yuma) daily, weekday, spatial-average surface temperature of pre and post-BIPV roof.

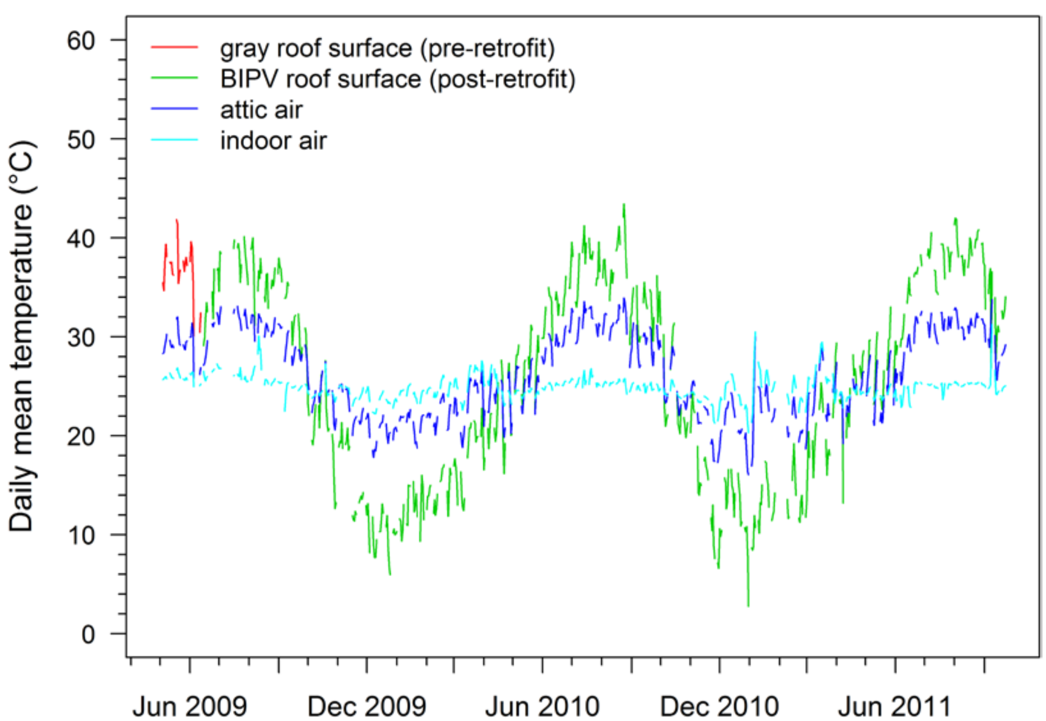

Figure-32: Site III (MCAS Yuma) daily, weekday, spatial-average roof surface and interior temperature of pre and post-BIPV roof retrofit.

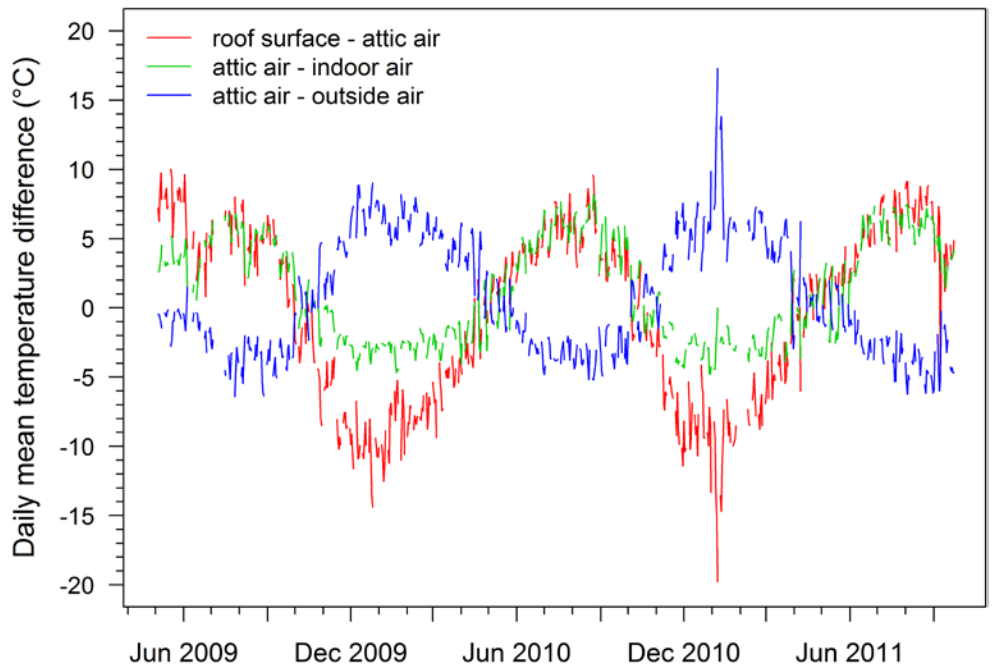

Figure-33: Daily, weekday, spatial-average roof surface, attic, and outdoor temperature of pre and post-BIPV roof retrofit at Site III (MCAS Yuma).

Heat flux was measured to determine the amount of thermal energy transmitted through certain roof layers. Figure-34 shows the measured heat flux through the roof surface and Figure-35 shows the measured heat flux through the deck in the pre and post-BIPV roof retrofit along with air conditioning energy use data. Weekend data was excluded.

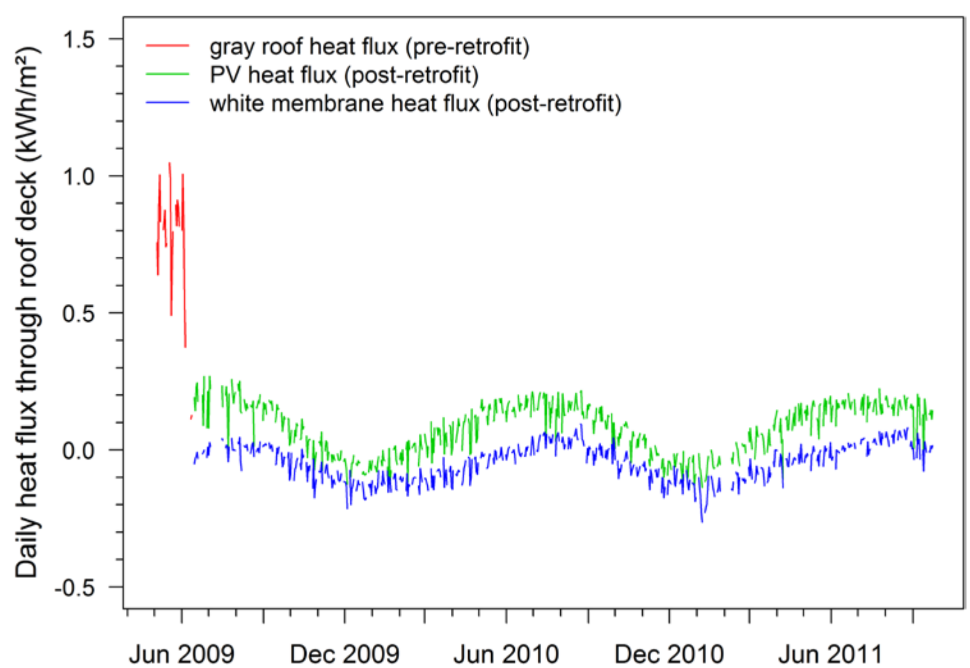

Figure-34: Site III (MCAS Yuma) daily, weekday heat flux through roof surface in pre and post-BIPV roof phases.

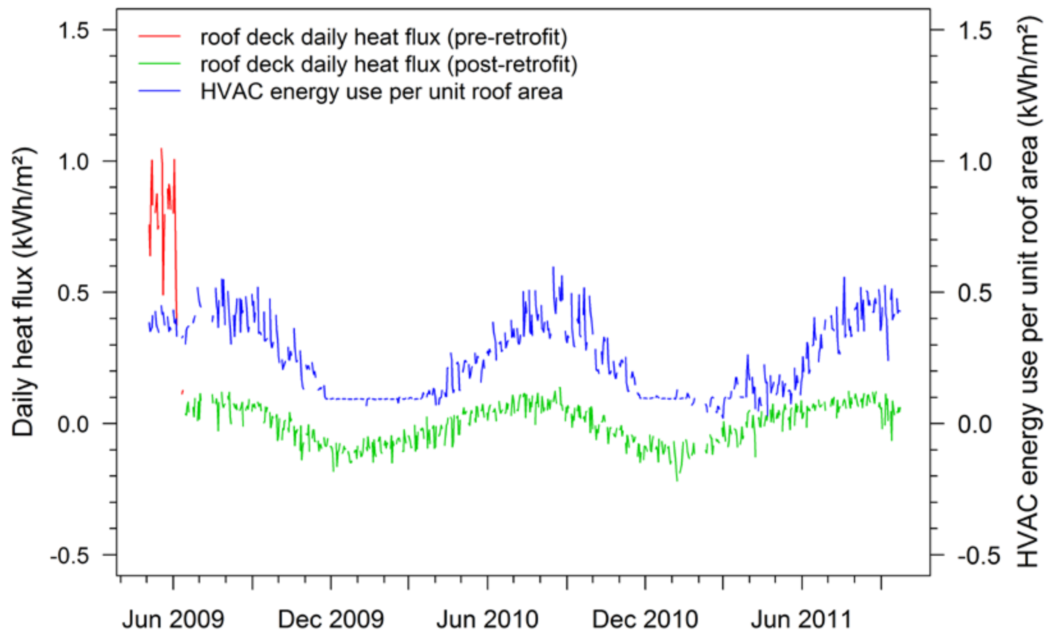

Figure-35: Daily, weekday heat flux through roof deck in the pre and post-BIPV roof phases and A/C energy use at Site III (MCAS Yuma).

While temperature and heat flux measurements can be used to calculate the air conditioning impact to a facility, the measured energy consumption of particular equipment will help to determine the real-world effects. Figure-36 shows the energy use of various air conditioning components and Figure-37 shows the total energy consumption of the A/C system, building and plug loads. Weekend data are excluded. Daily mean temperature and energy consumption were also plotted against cooling degree days and are shown in the DOE LBNL report [1].

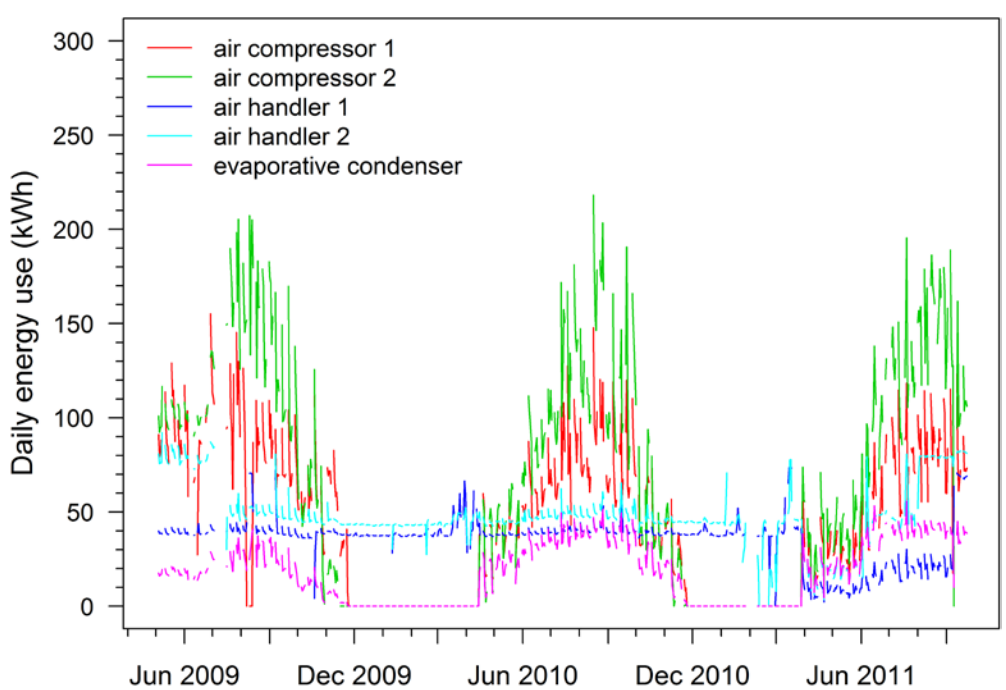

Figure-36: Daily, weekday energy use of the five A/C components at Site III (MCAS Yuma).

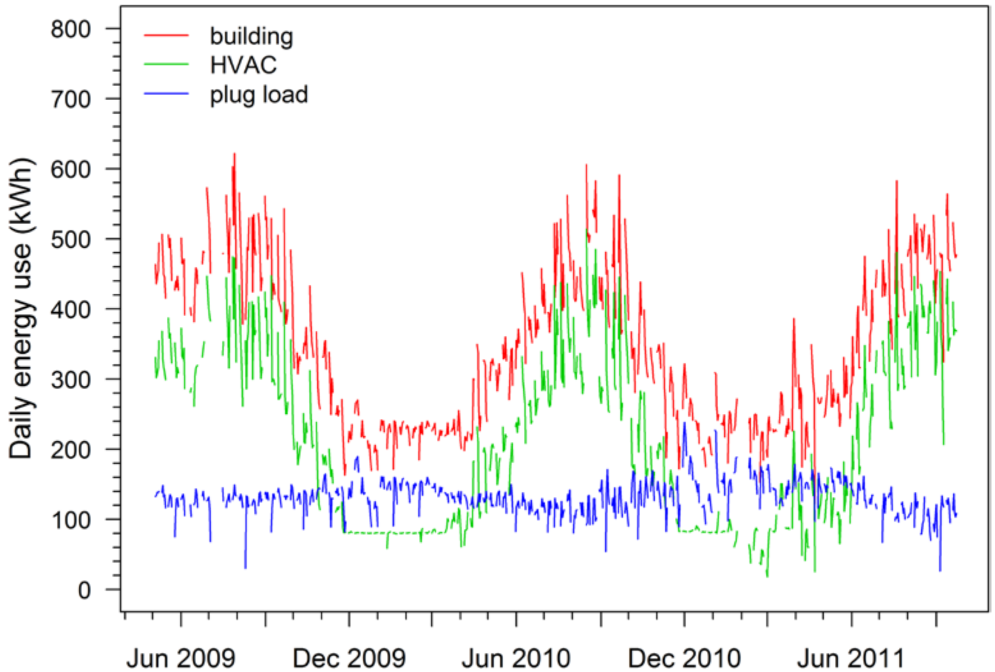

Figure-37: Daily, weekday total energy use the A/C system, plug load, and building at Site III (MCAS Yuma).

Figures-38 through -41 show the performance of the PV in terms of energy production, conversion efficiency and power production with respect to various factors.

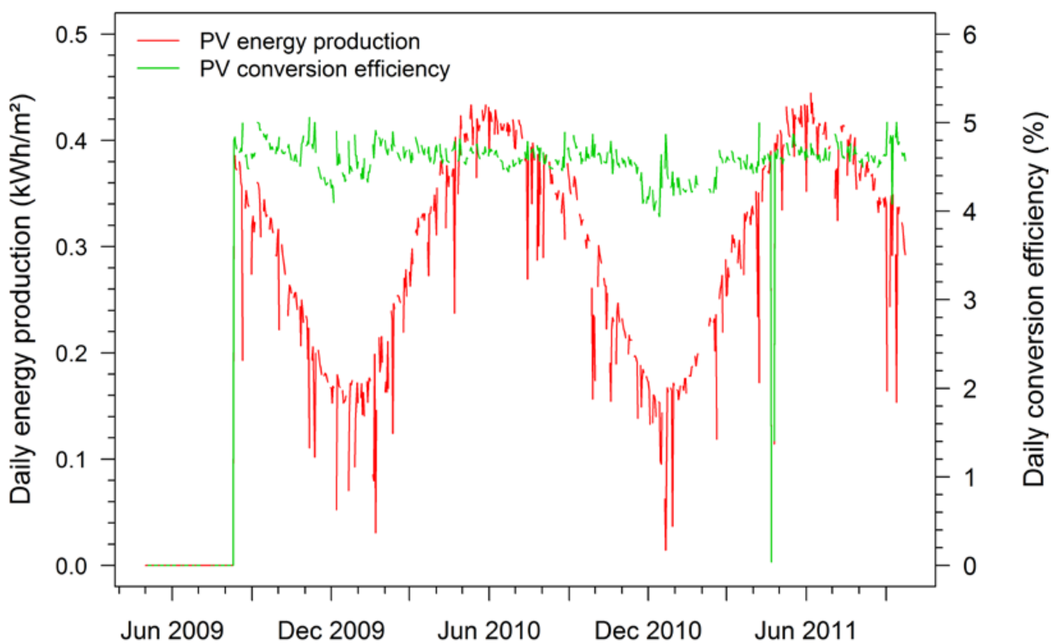

Figure-38: Daily PV energy production per unit PV surface area and mean PV conversion efficiency over time at Site III (MCAS Yuma).

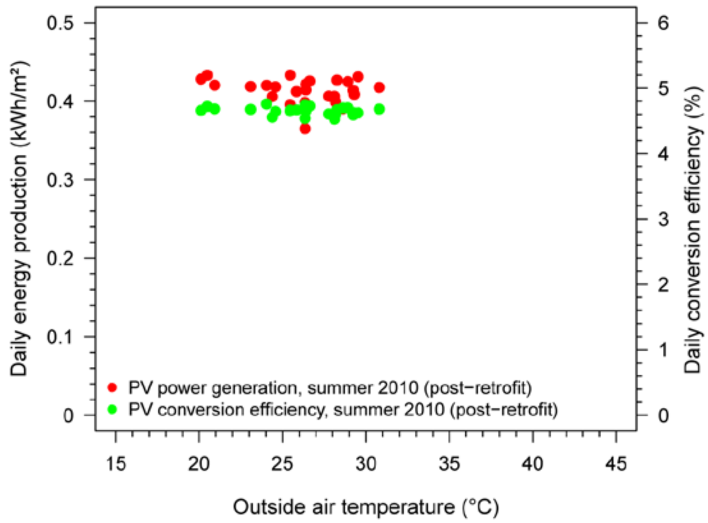

Figure-39: Daily PV energy production per unit PV surface area and mean PV conversion efficiency versus outside air temperature Site III (MCAS Yuma).

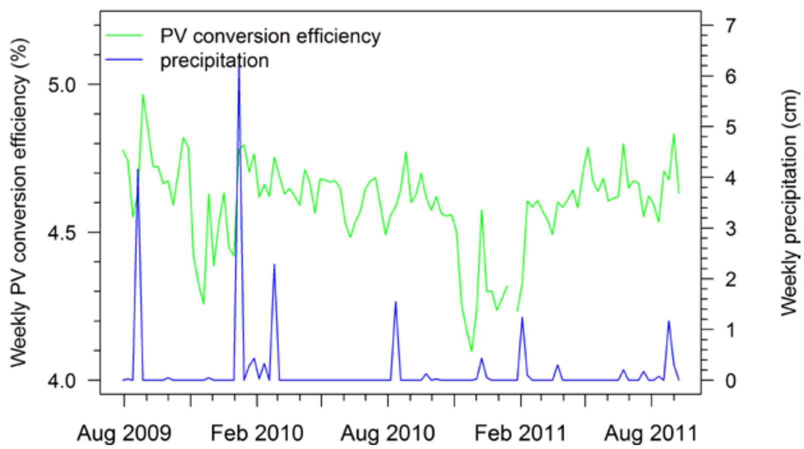

Figure-40: Weekly PV conversion efficiency and precipitation over time at Site III (MCAS Yuma).

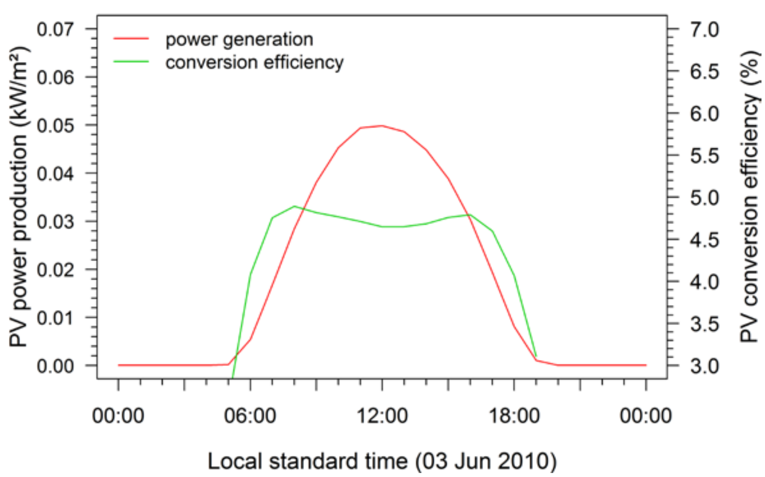

Figure-41: A typical summer diurnal cycle for hourly mean PV power production per unit PV area and conversion efficiency at Site III (MCAS Yuma).

ROOFER results are shown in Table-7 (Appendix J). PV and PVC reflectance results are shown in Tables-8 and -9, respectively (Appendix K). The "with patch" indices are a result of the samples taken from the roof for the laboratory testing discussed later. ROOFER indices without the patch, as if the samples were not taken, were also generated for comparison. October 2011 reflectance values were not attained due to the removal of the ladder needed to safely transport the instrument onto the roof. Since soiling is the largest contributor to reflectivity, visible conditions indicated that the reflectance of the roof had improved in October 2011 when compared to December 2010. This determination is further supported by the PV conversion efficiency analysis, that will be presented in the next section, which shows atypically low efficiency values in Winter 2010. Despite the soiling, the Site III (MCAS Yuma) BIPV roof appeared to have aged the best when compared to the other two sites (Figure-42).

Table-7: Condition indices results from ROOFER surveys at Site III (MCAS Yuma)

	RCI	MCI	FCI
DEC 2010	95	98	94
OCT 2011 without patch	95	98	94
OCT 2011 with patch	89	85	94

Table-8: Average PVC membrane reflectance value at Site III (MCAS Yuma)

	Albedo	Vs. Spec
Original Gray Capsheet	0.25	
Original PVC Spec	0.83	
MAY 2010 PVC – soiled	0.77	- 7 %

Table-9: Average PV reflectance value at Site III (MCAS Yuma)

	Albedo	Vs. Cleaned
MAY 2010 PV – cleaned	0.24	
MAY 2010 PV – soiled	0.17	- 29%

Figure-42: Photo of Site III (MCAS Yuma) in October 2011, 16 months after installation.

Figures-43 and -44 show the problem with the flashing not exceeding the six-inch height requirement, which reduced the overall FCI. The flashing height requirement is to prevent water penetrating the roof through rooftop equipment, such as exhaust vents.

Figure-43: Photo of Site III (MCAS Yuma) exhaust vent with insufficient flashing height.

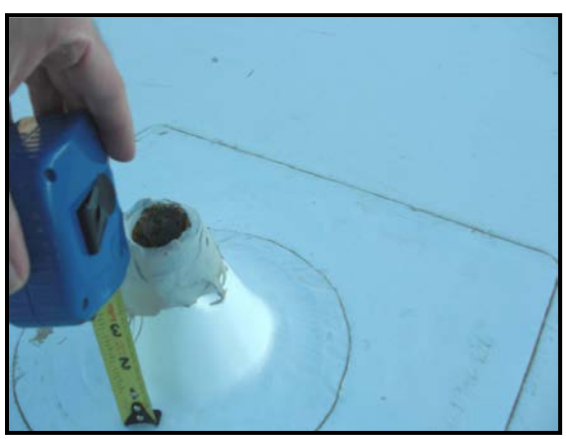

Figure-44: Photo of Site III (MCAS Yuma) air vent with insufficient flashing height.

There were concerns that the higher temperature of the PV modules would prematurely degrade the PVC membrane by heating it up, so PVC samples were taken from Site III (MCAS Yuma) underneath the PV modules and from the open area near the PV modules for laboratory testing. These samples were field weathered from June 2009 to October 2010, which exposed them to two Arizona summers, prior to being collected for laboratory testing. Both samples were put through a number of tests under ASTM D-4434, a PVC membrane standard, to see if they yielded significantly different results and if they failed any of the tests (Table-10). The test results that are close to not meeting the requirements are highlighted in yellow and the results that failed the requirements are highlighted in orange. MD stands for tests in the machine direction and XMD stands for tests in the cross machine direction. The laboratory test reports are in Appendix L.

Table-10: Results of select ASTM D-4434 tests used to evaluate PVC membranes. Highlighted scores indicate results where the PVC sample either failed (orange) or were close to failing (yellow).

Test	Requirement	PVC under PV	PVC in Open Area
Breaking Strength per ASTM D751 A -Grab Method - MD	min. 35 kN/m (200 lbf/in)	363 lbf/in	363 lbf/in
Breaking Strength per ASTM D751 A -Grab Method - XMD	min. 35 kN/m (200 lbf/in)	299 lbf/in	299 lbf/in
Change in Weight after Immersion in Water per ASTM D570 (168 hrs @ 70°C)	max. ± 3.0	0.63%	0.68%
Dynamic Puncture Resistance per ASTM D5635	Pass at min. 20 J (7.3 ft-lb)	22.6 Joules	22.6 Joules
Elongation at Break per ASTM D751, A -Grab Method -MD	min. 15%	119.6%	115.6%
Elongation at Break per ASTM D751, A -Grab Method -XMD	min. 15%	79.8%	82.4%
Linear Dimensional Change per ASTM D1204 (6 hrs @ 80 °C) XMD	max. 0.5%	-0.05%	0.00%
Linear Dimensional Change per ASTM D1204 (6 hrs @ 80°C) MD	max. 0.5%	-0.015%	-0.25%
Low Temperature Bend per ASTM D2136 @ -40°C	No Cracking	No Cracking	No Cracking
Overall Thickness per ASTM D751	min. 1.14 mm (0.045 in.)	.046 in	.0483 in
Overall Thickness per ASTM D751 MD	min. 1.14 mm (0.045 in.)	.0463 in	.0479 in
Post Heat Aged Breaking Strength per ASTM D751, A -Grab Method -MD	min. 90% of original	378 lbf	367 lbf
Post Heat Aged Breaking Strength per ASTM D751 , A -Grab Method -XMD	min. 90% of original	348 lbf	344 lbf
Post Heat Aged Elongation per ASTM D751, A -Grab Method -MD	min. 90% of original	131%	128%
Post Heat Aged Elongation per ASTM D751 , A - Grab Method -XMD	min. 90% of original	92%	90%
Seam Strength per ASTM D751, A - Grab Method	min. 75% of breaking strength (150 lbf/in)	180.2 lbf/in	156.5 lbf/in
Static Puncture Resistance per at ASTM D5602	Pass at min. 15 kg (33 lbf)	No puncture at 80 lb	No puncture at 75 lb
Tearing Strength per ASTM D751 , B -Tongue Tear Method (8x8) -MD	min. 200 N (45.0 lbf)	37 lbf	35 lbf
Tearing Strength per ASTM D751, B -Tongue Tear Method (8x8) -XMD	min . 200 N (45.0 lbf)	52 lbf	54 lbf

Microbial/mold growth is also a concern as was discussed for Site II (NAS Patuxent) River. The test standard for this topic utilizes ASTM G21 and consists of detecting spore growth. The results are shown in Table-11 and the score descriptions follow in Table-12. A copy of the laboratory report is in Appendix M.

Table-11: Results from ASTM G21 on the assessment of microbial growth.

	Incubation Time and Score			
Sample	Day 7	Day 14	Day 21	Day 28
Under Panel	1	1	1	2
Field Membrane	1	1	1	2
Negative Control	0	0	0	0
Positive Control	4	4	4	4

Table-12: Microbial growth score descriptions.

Score	Description
0	No Growth Detected on Surface of Sample
1	Traces of Growth Detected on Sample (<10%)
2	Light Growth Detected on Sample (10%-30%)
3	Medium Growth Detected on Sample (30%-60%)

Qualitative inspections were also made at other existing federal locations with this type of BIPV roof using leveraged funding. While there are areas where this type of BIPV roof aged well, some of the more significant deficiencies are identified as areas of concern, which is not necessarily due to the presence of a PV system, but poor roof construction and practices. Figure-45 shows another water ponding concern, but this was likely a result of the application of the tape as it now appears to prevent proper water drainage. While this is significant, it could be avoidable if the PV modules were oriented along the slope of the roof instead. What is also notable about this site is the significant mold growth that can be seen in the upper right corner of Figure-45. These issues impact overall roof reflectivity, PV performance and roof longevity.

Figure-45: Water ponding due to the failing tape and PV module orientation. Mold growth in the upper right corner.

The discoloration in Figure-46 indicates that the encapsulation of the PV laminate has been compromised. This occurred only in areas where there was significant water ponding, but it is possible that the damage was actually due to snow build-up and the exposure of the encapsulation to freezing temperatures. Interestingly, the tape solution appeared to be unaffected.

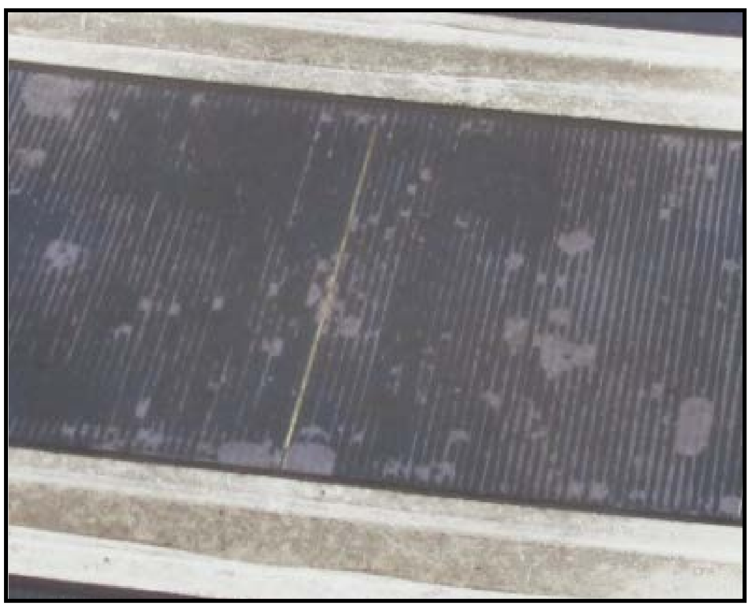

Figure-46: Evidence of PV delamination.

Figure-47 shows another BIPV location where mold growth was localized. This location experiences less rainfall than the sites shown in Figures 45 and 46, but the localized mold growth is much more severe due to water ponding before it reaches the drains. This could have been prevented with better roof construction quality control. The tape solution appears to be performing well.

Figure-47: Severe, localized mold growth due to water ponding before it reaches the drains.

6.0 PERFORMANCE ASSESSMENT

6.1 ROOF INTEGRITY – ROOFER EMS

Using the ROOFER EMS checklist shown in Appendix C and the ROOFER EMS protocols, the roof surveyor can consistently generate an overall roof condition index. The indices and the rate of decrease of the indices over time will be compared to that of other flat roofs common to DoD to determine if the deterioration of the BIPV roof is at an acceptable rate. Figure-48 is an example of the predictive life curves available from ROOFER EMS for a certain roof type. The bolded line shows the standard roof deterioration curve. A new roof should have a RCI of 100. It is expected that the RCI of the roof should not drop below 90 until about year eight of its life. If the RCI at year eight is below 90, then the roof is expected to perform below the standard unless maintenance and repair efforts improve the condition of the roof to a RCI of 90 or greater. If the RCI at year eight is greater than 90, then the roof is expected to perform above the standard. The ROOFER EMS software that generates the condition indices automatically accesses the values of the curves to estimate expected roof life. Note that the ROOFER software has these curves built-in and handles the projected life calculations much more precisely.

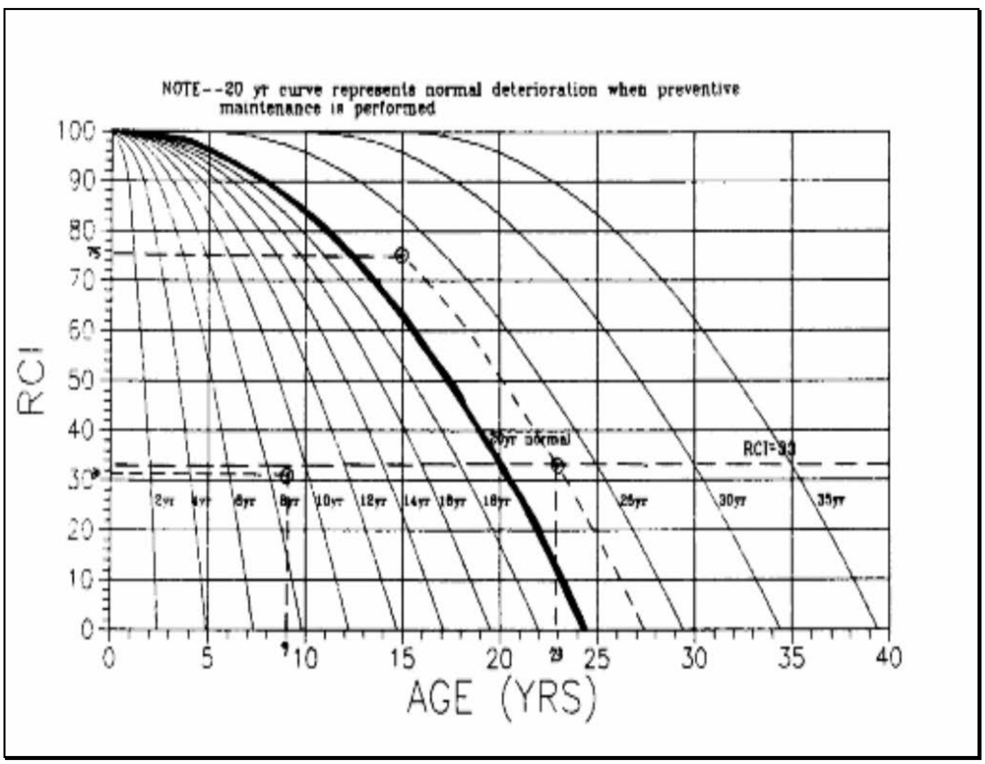

Figure-48: Roof deterioration curves used to predict the remaining life of the roof.

The data presented in Section 5 shows that none of the three BIPV roofs achieved condition indices of 100 even soon after construction was completed due to how ROOFER treats less than ideal roof characteristics as defects. For example, a roof vent that did not have sufficient flashing height was automatically considered a defect when it is initially installed. However, the rate of roof degradation is what determines its life, so how fast the indices drop over time is critical. Site I (Luke AFB) and Site III (MCAS Yuma) both showed very little-to-no change to their indices over time, whereas Site II (NAS Patuxent River) showed a significant reduction in its MCI due to extensive mold growth on the PVC membrane. Note that while Site I (Luke AFB) experienced significant soiling due to dirt build-up and failure of the PV adhesive, those factors do not impact the roof integrity, which is why Site I (Luke AFB) has consistently high condition indices. In general, the performance objective was not met, but the issues resulting from design mistakes, such as the insufficient flashing height, could be remedied in future systems.

6.2 ROOF INTEGRITY – ACCELERATED WEATHER TESTING

Since ROOFER EMS requires a longer period of time in order to better predict the life of the BIPV roof, an independent laboratory tested the roof membrane under accelerated conditions using field weather PVC samples. Test methods listed in ASTM D 4434 addresses conditioning, overall thickness, tensile strength at break, breaking strength, elongation at break, seam strength, heat aging, tear resistance, tearing strength, low temperature bend test, and accelerated weathering. Refer to the documents listed in ASTM D 4434 for the details on the actual test methods used to assess each test category.

Site III (MCAS Yuma) was chosen as the site to retrieve the PVC material from due to the concern that high temperature conditions and solar exposure would have the most impact to the material. The results of the tests were not significantly different for the PVC under the PV material and for the PVC in the open area so it is inconclusive to whether the different environmental conditions significantly shorten the life of the PVC membrane. It is also possible that the higher temperature conditions on one PVC sample had the same effect as the higher solar exposure had on the other. Longer field weathering may also provide more significantly different test results, but due to the project length and the amount of time needed to run some of the accelerated weathering tests, the tested samples were only able to be field weathered for two desert summers. However, without more testing, it is difficult to make definitive conclusions.

6.3 RENEWABLE ENERGY GENERATION

As was discussed in Section 5.6, data for Site I (Luke AFB) was severely limited due to problems with the data collection system and the ESPC contract termination. The two months of data shows that the maximum daily output was often between 200 kW and 300 kW. While the installed capacity is rated at 375 kW, recall that the system should only be expected to produce a power output at that level under standard test conditions. To properly assess the performance, the output was compared to the available solar insolation. Using the data shown in Figure-43, the PV system was determined to be producing only about 80% of what it was expected to from April 1, 2011 to May 12, 2011. Starting on May 13, which is when the energy production significantly increased, the PV system was performing as expected. This was likely due to soiling of the PV modules. However, without detailed weather data, it was not possible to correlate actual weather events. While Site I (Luke AFB)'s data was limited, the performance objective was determined to have been met since the PV system was able perform to expectations.

Data for Site II (NAS Patuxent River) is much more extensive, in spite of minor issues with data collection and certain sensor malfunctions during the monitoring period. With two years of data, it was possible to see how the energy and power output changed over time (see Figures-23 and -24). As expected, the output was lower in the winter seasons. Furthermore, during the monitoring period, the PV system mainly experienced partly cloudy to mostly cloudy weather conditions. However, when comparing the energy output against the available solar insolation, the BIPV system performed above expectations, thus, meeting the performance objective (Figure-49). This can be accredited to the fact that thin film PV material tends to perform relatively well in diffuse sunlight when compared to crystalline PV material and this data provides evidence that the characteristic should be considered when developing future PV systems in similar climates. Note that at times when the performance appeared exceptionally high, such as over 150% of the expectation, this often occurred when the solar insolation was very low, such as early or late in the day or during heavy rainfall, so it does not have a major impact on the overall energy production.

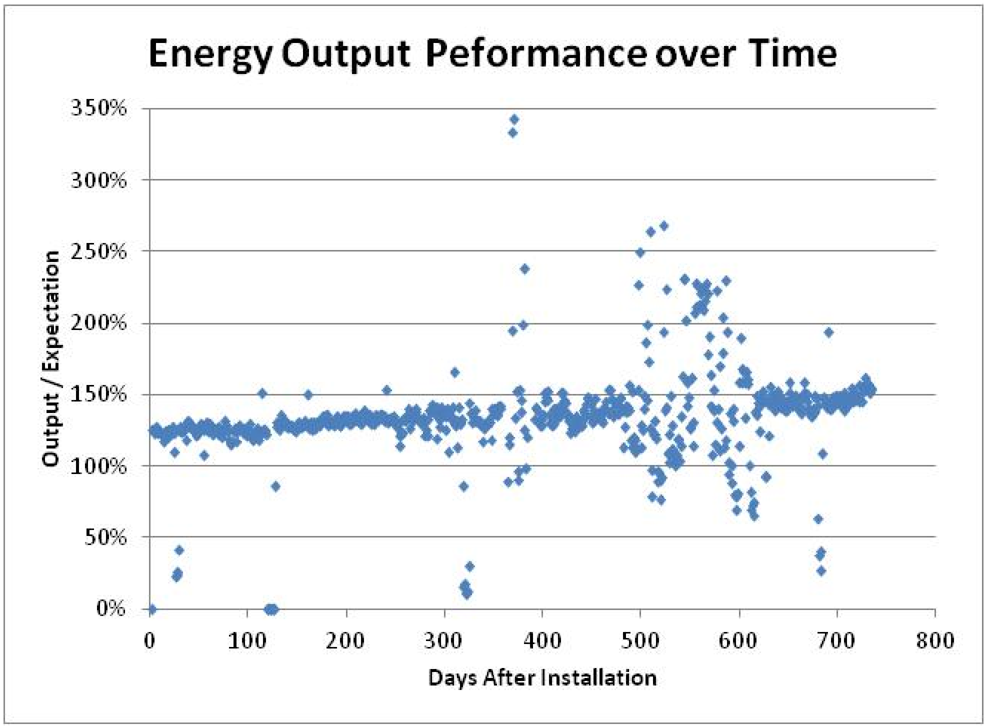

Figure-49: Site II (NAS Patuxent River) performance compared to estimates based on available solar resource.

Figures-25 and -27 show PV performance at Site II (NAS Patuxent River) against various parameters, such as wind speed, temperature, insolation, and precipitation. Wind speed was not seen to have made a definite impact to the temperature of the PV module and did not show any correlation to the available solar irradiance. Regardless of the irradiance, power output performance was initially seen to increase with PV module temperature, but this increase was likely due to more direct sunlight. An attempt was made to identify trends in the data using regression curves and grouping of data based on ranges of irradiance, but the R^2 value shows that the equations do not fit well. It should be noted that PV manufacturer data sheet shows that the power output decreases linearly at a rate of -0.21% per degree Celsius above 25°C at standard test conditions of 1000 W/m^2 irradiance and an air mass of 1.5. Even knowing this, the data is too spread out under these real world conditions to verify that effect.

The amount of precipitation had a definite impact to the power output as the weather would be cloudy and water hinders the transmission of sunlight to the PV modules. As expected, the Site II (NAS Patuxent River) PV system produced more power when the rainfall was lowest. However, rain often helps remove soiling from a PV system. Unfortunately, the data did not show any noticeable change in power output before and after a rain event and is likely due to residual water and the pool of water that is shown in Figure-29. There was a lack of snow events, so snow impacts could not be quantitatively determined, but it is expected that snow retention on the roof will significantly reduce the PV power output more than the water retention.

Instrumentation at Site III (MCAS Yuma) was even more extensive than at Site II (NAS Patuxent River) due to the A/C study being performed. Figure-30 shows that the solar irradiance and the mean wind speed are slightly in sync as the measured values rise and fall. This was easier to see at this site due to the drier weather conditions, but it is still not a strong correlation. Figure-38 shows the energy production rise and fall as expected, with the output lower in the winter seasons. However, the PV conversion efficiency was relatively constant throughout the year. Several visual inspections of the Site III (MCAS Yuma) BIPV roof shows that soiling due to desert sand is a recurring problem, so it was likely that the increased number of rain events in the winter season, when the available solar irradiance is lower and there is less direct sunlight, helped the PV system maintain its efficiency by keeping the modules cleaner. When compared to Site I (Luke AFB), the Site III (MCAS Yuma) BIPV roof is much prone to soiling because of its relatively simple roof shape and small size.

Looking at the energy generation and PV conversion efficiency under a smaller time-scale makes it easier to see how PV output performance correlates to outside air temperature, Figure-39 shows that both values are fairly constant, which shows that this type of PV module performs fairly well in hot, desert conditions.

Weekly PV conversion efficiency was analyzed to see how it changed over time as it related to precipitation events. Figure-40 shows that each time a major rain event occurred, the conversion efficiency increased temporarily. The improvements were not constant and were likely due to the magnitude of the soiling problem prior to the rainfall.

PV power output and conversion efficiency was also of interest. A typical summer day was chosen for Figure-41. The data shows that the power output increase steadily over time before peaking around noon before decreasing almost symmetrically. However, the PV conversion efficiency was more even throughout the day, with a slight local minimum point around noon. As with most objects exposed to the sun, the PV module is typically at a higher temperature shortly after solar noon, which would reduce its conversion efficiency and explains the drop in efficiency. The conversion efficiency data also shows confirms the manufacturer’s claim that this type of thin film PV module works well with diffused sunlight as is evident by a relatively flat efficiency curve and the PV system reaching its expected operational efficiency as early as 0700 and maintaining it as late as 1700. In summary, Site III (MCAS Yuma) met the performance objective.

6.4 INCREASED ENERGY EFFICIENCY – ROOF REFLECTIVITY

Roof reflectivity/albedo was originally planned to be measured for only Site III (MCAS Yuma), but since there were different soiling/aging/degradation conditions at all three sites, roof albedo measurements were made when it resulted in a minor incremental effort to the ROOFER assessments. Albedo data for Site I (Luke AFB) in Table-3 shows that the PVC membrane became significantly less reflective during the course of the study. Visual observations confirmed that this was due to natural soiling by desert dust and dirt. The PV modules also experienced the similar soiling effects. While the albedo value in 2011 is much lower than in 2010, it is not expected that this rate of albedo decrease is constant due to precipitation events. The impact of precipitation events on PV efficiency was evident for Site III (MCAS Yuma) and this was directly tied to how soiled the PV modules are. As can be seen in Figure-22, the dirt build-up is uneven and visual observations of the soiling pattern indicate that precipitation and how it drains off the roof have definite impacts on which parts of the BIPV roof is soiled and which parts are not. Based on the complex layout of the roof, it does not appear that precipitation will ever completely remove the soiling. This short term data indicates that the BIPV roof albedo will likely be roughly 5-30% lower than what it was when it was assembled.

As of July 2011, which is about 31 months after the BIPV roof installation at Site II (NAS Patuxent River), the albedo of the PVC membrane was measured to be 24% less than what the manufacturer reported in the product specification. Since Site II (NAS Patuxent River) experiences frequent precipitation events, the reduction is much more due to mold growth on the PVC instead of soiling due to dust and dirt. Unfortunately, since mold is not easily removed without being likely to damage to the roof, the albedo value is expected to get progressively lower over time. Based on the one data point, the PVC albedo value reduced by about 9% a year. However, the exposed PVC membrane is the only part of the roof that is experiencing the wet environment, so the portion covered by the PV modules should be unaffected. Also, as mentioned earlier, it was not possible to accurately measure the reflectance of the PV modules due to the water ponding at the time of the measurement.

The original aged, built-up roof at Site III (MCAS Yuma) was measured to have an albedo of 0.25. For comparison, the spatial average of the new BIPV roof is 0.59. In about a year after installation, the PVC portion lost 7% of its reflectivity and the PV modules lost 29% of their reflectivity (Tables-8 and -9). The reflectivity of the PV modules appear to have significantly degraded, but when looking at the reflectively values, the PV reflectivity was reduced by only 0.07 whereas the PVC membrane reflectivity was reduced by 0.06 from their conditions as new. Note that the Site III (MCAS Yuma) roof is relatively simple compared to the Site I (Luke AFB) roof in that it is small and had a constant slope from a single ridge line, which allowed the PVC at Site III (MCAS Yuma) to remain relatively clean. The change in albedo values reduces the spatial average to 0.53, which is about a 10% reduction in the overall albedo value.

For comparison, one past study performed by DOE Oak Ridge National Laboratory at their site in Tennessee, shows that the white thermoplastic-olefin (TPO) membrane roof they tested started with a reflectance value of 70.5 and experienced a 12.3% reduction in reflectivity in its first year then fluctuated around a 14% reduction for the following two years[2]. The mean annual reduction in reflectance value was 5.7%. Their report did not indicate any issues with mold growth. In comparison to that DOE study in regards to roof reflectance, Site I (Luke AFB) performs worse due to dirt/dust build-up at certain times of the year, Site II (NAS Patuxent River) performed worse due to the mold growth, and Site III (MCAS Yuma) performed the same. Regarding the criteria established for this performance objective, the three BIPV roofs were determined to have met the performance requirement since the overall reflectivity of the BIPV roofs were still high even after the degradation.

6.5 INCREASED ENERGY EFFICIENCY – A/C LOADS

As originally planned, the building envelope and thermal impacts were studied at Site III (MCAS Yuma) because of the concern about potential heat gain due to the PV modules and actual benefit of the cool roof portion due to the PVC membrane. For a desert climate, the greatest thermal impact is normally in the summer when the temperature is highest. Therefore, in order to maximize the performance monitoring period, only the energy baseline during the cooling season was determined for the facility. Daily building energy use data shows that the energy consumption during the summer was 2.5 times that of the winter.

Figures-31 through -33 shows various temperature measurements during the pre and post-BIPV roof retrofit periods, but the BIPV roof impact is not very clear by just looking at the graphs. However, Figures-34 through -35 shows a significant heat flux change after the BIPV roof was installed. For comparison, standard heat transfer equations using spatial average roof temperatures at different locations of the roof assembly, the estimated thermal resistance of the original roof is 0.20 m^2-K/W whereas it is 0.47 m^2-K/W for the BIPV roof. Note that since the Site III (MCAS Yuma) BIPV roof was installed on top of the original roof, the thermal resistance for the final roof assembly is actually a sum of the two and is estimated to be 0.67 m^2-K/W. Actual heat transfer dynamics is much more complicated than just comparing the thermal resistance values, but the data shows that a significant reductions in the heat flux through the roof surface and deck occurred as expected. The actual thermal resistance of the ceiling and heat flux through the ceiling are unknown and the poor condition of the attic, as described earlier, would not have resulted in the heat flux through the ceiling to be closely correlated to the heat transfer from the roof.

The assessment of the impact to the A/C system is even more complex and the change is not evident in Figures-36 through -37 and complicated by repairs made to the A/C equipment soon after the BIPV roof installation. The majority of the A/C energy consumption during the cooling season was due to the compressors. They were not used during the winter season, which resulted in air handling units (AHU) making up the majority of the A/C energy consumption during that time. Building heat was provided by a natural-gas fueled boiler and, thus, did not contribute to the building electricity use.

Early July 2009 data showed decreases in daily energy consumption for AHU2 and increases for compressor 2, but these changes were more likely due to A/C repairs performed three weeks after the BIPV roof installation. Attempts were made to quantify the effect of the repair on the A/C energy consumption by correlating energy use before and after the repair and by using energy use data from the non-repaired equipment as an energy use basis for the repaired equipment, but it still was not possible to appropriately quantify the change due to the BIPV roof because the energy use of AHU1 and AHU2 appear to be independent based on the available data. To further complicate the situation, the heat flux through the ceiling was only minimally affected by the BIPV roof, which suggests that the observed decreases in A/C energy use were mostly attributed to the A/C repairs. This means that the assessment of the A/C impact was inconclusive when solely using the energy consumption data.

To continue with the A/C assessment, DOE-2.1E was used to simulate building energy usage of a 455 m^2 prototypical office building and estimate the electricity savings for the cooling season and the natural gas savings for the heating season. Long term weather data was not available for Yuma, so data for Phoenix was used. The results showed an annual cooling energy savings of 9.6 kWh/m^2 (34.6 MJ/m^2), annual heating energy savings of 2.9 MJ/m^2 (0.010 therm/m^2) and a source energy savings of 107.1 MJ/m^2 (101 kBTU/m^2). Source energy savings refers to the fuel energy saved. For example, if it takes 3 kWh of energy content of coal to produce 1 kWh of useful electrical energy at the point of use (e.g., at the compressor), the source energy is the 3 kWh of coal.

Similar estimates were made using DOE-2.1E for other locations to assess DoD-wide applicability of BIPV roofs and the results are shown in the following table.

Table-13: Simulated HVAC impact at various locations throughout the U.S. ΔC (kWh/m^2) is the annual cooling savings; ΔH (MJ/m^2) is the annual heating energy savings; ΔS (MJ/m^2) is the annual net source (a.k.a. primary) energy savings a prototypical office building after installation of the BIPV system.

San Diego, CA			Seattle, WA			Norfolk, VA			Jacksonville, FL		
ΔC	ΔH	ΔS	ΔC	ΔH	ΔS	ΔC	ΔH	ΔS	ΔC	ΔH	ΔS
6.2	2.2	68.8	3.7	17.8	57.8	5.3	13.3	71.1	7.3	5.1	83.5

6.6 OPERATIONS AND MAINTENANCE

Site I (Luke AFB) was the only site out of the three where maintenance and repair was performed. The PV bonding failure resulted in the May 2010 tape fix shown in Figure-21. While the bonding failure did not occur throughout the PV system, the PVL manufacturer applied the tape solution on the entire PV system as a preventive measure. However, as can be seen in the photograph, some of the tape deteriorated later that year, so the tape needed to be reapplied. In addition, Site I (Luke AFB) required the replacement of one BIPV panel (i.e., an entire set of PVLs bonded to one carrier PVC sheet) because at least two of the PVLs were corroding due to water penetrating the encapsulation.

Site II (NAS Patuxent River) did require some maintenance due to a pin-size hole in the PV, but there was difficulty in finding local personnel to perform the maintenance due to the need to operate a small flame to patch the hole (Figure-50). Corrosion is expected to spread to the rest of the cell. Fortunately, the PVL includes bypass diodes connected across each cell, which allows the rest of the cells in the PVL to continue to produce power. The mold growth that was shown earlier is also a concern, but as it was stated earlier, an attempt to remove the mold will likely cause more damage to the roof. The only way to stop additional mold growth is to keep the roof dry, which is impractical, so the only remaining practical course of action is to ensure that the roof remains water tight, such as by surveying the roof every one-to-two years, and replacing the roof at its end of life. The tape solution was not applied to this site due to the lack of the PV bonding problem and the desire to study the BIPV roof as it was originally designed.

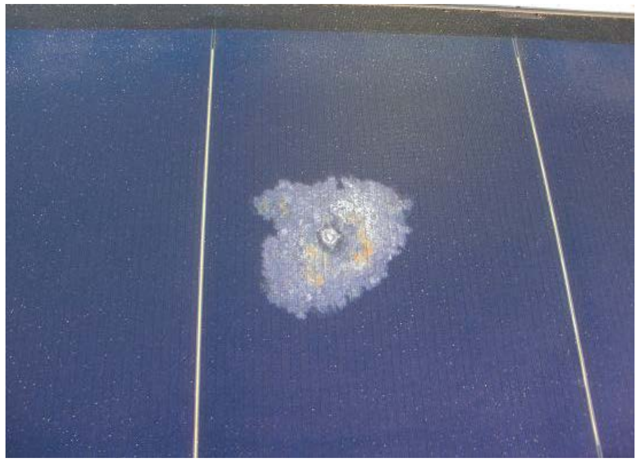

Figure-50: Corrosion of PV material due to a pin-size hole at Site II (NAS Patuxent River).

Out of the nine roofs that were visited during this study, the Site III (MCAS Yuma) BIPV roof was the one in the most pristine condition. However, it is also one of the newest of the nine. The last time the BIPV roof was surveyed was about 2.5 years after the installation. The PV bonding problem at Site I (Luke AFB) was not noticed until about 4 years after the installation. The tape solution was not applied to Site III (MCAS Yuma) due to the lack of the PV bonding problem and the desire to study the BIPV roof as it was originally designed.

Other sites that were visited included BIPV roofs at General Services Administration Waltham, Marine Corps Base Hawaii Kaneohe Bay (two BIPV roofs at this location), Camp Shields in Okinawa, Naval Base Guam, and NAS North Island. Only the BIPV system at Camp Shields was reported to have experienced the PV bonding problem, but all of the above sites received the tape fix as a pre-emptive measure. Sandia National Laboratory's BIPV roof was not visited, but the site point-of-contact confirmed that they did not experience any PV bonding problems. Unfortunately, at one of the visited sites, the tape caused additional water ponding and soiling due to the orientation of the tape being perpendicular to the direction of water drainage off the roof (Figure-46). One site did experience a problem with an inverter, but it failed within warranty and was scheduled for replacement.

Several non-government BIPV system owners were contacted to request information on the O&M for their systems, but there was difficulty in finding knowledgeable facility personnel to interview. The few that claimed that their system was working fine were unclear on the level of investigation that was performed. It is unlikely that typical facilities personnel will perform roof surveys as detailed as the ones dictated by ROOFER EMS.

BIPV roof systems appear to require little maintenance, but the systems in coastal/humid environments generally experienced mild-to-severe mold growth on the PVC membrane. Water ponding and improper water drainage significantly contributed to this problem (Figure-47). This is expected to require a major roof repair/replacement effort years from now, but prior to the end of the advertised product life, which makes the type of PVC membrane used in the BIPV system inappropriate for humid environments.

7.0 COST ASSESSMENT

7.1 COST MODEL

The warranty on the PVC membrane was 20 years and on the PV modules was 25 years. Since it is possible that major A/C equipment can have a product life of 20 years and that the HVAC equipment is not part of roof construction, the A/C operational cost factor was assumed to remain constant for 20 years. The life cycle cost elements was then evaluated using the savings to investment ratio (SIR) equation,

$$SIR = \frac{(3) + (4) - (5) - (7)}{(1) - (2)}(8) \quad ,$$

where the numbers refer to the cost evaluation factors in the table below. If (6) and (8) result in a different estimate product life, the period for the life-cycle-cost-analysis used the lower of the two values. Estimated energy and O&M cost escalation rates were also be assumed based on available government data to better predict the life cycle operational costs. A calculation where escalation rates are not considered was also performed. Additionally, the cost of a BIPV roof was compared to that of conventional roof top PV systems with similar power output capacity to compare the implementation cost of a BIPV roof versus a conventional roof with a conventional rack-mounted rooftop PV system.

The installation costs of a BIPV roof included the costs for design, construction mobilization, and commissioning of the integrated roof system. Based on discussions with the manufacturer, this is the primary cost of a BIPV roof system since the expected maintenance cost is minimal.

Table-14: Cost factors to consider in assessing cost/benefit of BIPV roofs.

COST EVALUTION FACTORS	
Cost Factor	**Data Tracked During the Demonstration**
(1) Installation Costs of BIPV Roofs	Labor and material required to install
(2) Conventional Re-roofing Costs	Cost to re-roof using conventional roofing products
(3) A/C Operational Cost	Energy usage reduction post BIPV roof installation vs. baseline
(4) Renewable Energy Generation	System lifetime cost savings based on energy produced by the PV system
(5) PV System Maintenance/Repair	Frequency of required maintenance/repair, if any Labor and material per maintenance/repair action, if any Energy not produced due to roof or PV system maintenance
(6) PV System Lifetime	Estimate based on components degradation during demonstration
(7) Roof Maintenance/Repair	Frequency of required maintenance/repair, if any Labor and material per maintenance/repair action, if any
(8) PVC Roof Membrane System Lifetime	Estimate based on components degradation during demonstration

Only the incremental cost of the PV system in a BIPV roof should be considered when evaluating the technology's economics. When a facility is in need of a new roof or a re-roof, conventional roofing products are typically used. Accounting for this avoided cost in a BIPV roof installation better represents the incremental cost of a BIPV roof over a conventional roof.

Different roof types may result in different building thermal envelopes. When a BIPV roof instead of a conventional roof is utilized, the effect on the energy consumption of the A/C system is unknown. Since the PVC roof membrane is Energy Star-rated as a cool roof material, the cost in powering the A/C system is expected to decrease. However, the dark-colored PV panels may result in additional heat gain. This energy cost difference needs to be accounted for to evaluate a BIPV roof's effect on energy efficiency. The energy efficiency impact of the BIPV panels on top of the cool roof was measured and analyzed. The energy efficiency impact of just the cool roof may be estimated using the measured heat flux through the cool roof material.

The PV system in a BIPV roof will generate renewable energy and reduce energy purchased from the local utility, which results in an energy savings. Since this system has potential DoD-wide application, the annual energy production was recorded and the cost savings was shown for various electricity rates.

Costs associated with maintaining or repairing the system were recorded, but not when repairs were covered by the warranty. Since the measured energy production already accounted for any potential PV system downtime, the lost energy was not part of the BIPV roof economic analysis. Also, it is worth noting that due to the integrated aspect of the PV panels, there is no air flow beneath the panels as there is in rack-mounted PV systems. This may increase the temperature of the panels and either reduce the efficiency of the PV panels or result in component failures. Any reduction in energy production from this effect was also automatically captured from the energy output measurements.

The manufacturer claimed that only periodic washing of the roof is necessary under dirty weather conditions. It is not DoD's facility management practice to wash roofs as part of their maintenance duties, so this expense was not expected to occur. However, in the event that this maintenance or repair was necessary, the cost was recorded. It is worth noting that any roof maintenance or repair effort may require the PV system to be temporarily disabled until the roof maintenance is completed. This loss in energy production was also noted, if occurred. As mentioned earlier, the measured annual energy production of the system would have already accounted for this loss.

The PVC roof membrane system has a 20-year warranty, but based on past facility management practices, this may be difficult to attain. Most DoD installations do not have a roof maintenance program in place, but since the roof requires minimal-to-no maintenance and some existing single-ply roof membranes have exceeded their advertised lifetime, it is possible that the BIPV roof can meet its 20 year product life. Experienced Navy roof surveyors completed the evaluation and independently estimated the potential lifetime of the roof.

The monitoring effort is a significant portion of the project costs. However, labor and materials costs for the data acquisition system design, installation, and analysis of the BIPV roof was not included in calculating the payback period of the technology since these costs are not typically included in a re-roofing or PV installation project.

7.2 COST DRIVERS

The existing roof condition can be a significant cost driver. The roof repairs required for Site II (NAS Patuxent River) to be able to utilize the BIPV roof made up nine percent of the total installation cost. The roof at Site III (MCAS Yuma) was in decent condition (i.e., heat transfer properties are similar to when it was constructed), which allowed for the BIPV roof be installed on top of the existing roof and did not result in any noticeable cost increase.

Economy of scale can also affect the cost when looking at a per Watt or per square foot basis. A sales representative stated that the system becomes very cost effective for roofs exceeding 200,000 sq. ft. in size. On small-scale systems, such as the two BIPV roofs funded by ESTCP, the installation cost of a BIPV roof was highly dependent on the size of the PV system because the high expense of the PV modules. Site II (NAS Patuxent River) costs $13.50 per Watt or $22.70 per square foot when including the cost of roof repair. Without the roof repair, the cost is $12.30/W or $20.80/sq. ft. Site III (MCAS Yuma) costs $12.30/W or $27.40/sq. ft., not including the utility rebate for the PV. Since the BIPV manufacturer was located in Los Angeles, the costs were slightly affected by the distance from the manufacturing plant, but the roof at Site II (NAS Patuxent River) is 73% larger than the roof at Site III (MCAS Yuma) and has a larger, though proportionally smaller PV component, which helps explain why the two cost benchmarks for the two sites do not provide a simple way to accurately estimate the installation cost. Exact cost data is not available from the non-ESTCP BIPV roof sites, but data for some locations were available from press releases. The largest known rooftop system was a $13M, 2 MW system that consists of two roofs with a combined roof area of 640,000 sq. ft. That system costs $6.50/W or $20.31/sq. ft. Quantitatively, the proportion of the PV component of the 2MW system yields an installed capacity of 3.1 W/sq. ft., whereas Site I (Luke AFB) is 2.6 W/sq. ft., Site II (NAS Patuxent River) is 1.7 W/sq. ft., and Site III (MCAS Yuma) is 2.2 W/sq. ft. The proportionally larger PV component is likely to have further helped reduce the cost. Note that the proportion of the PV component at the ESTCP-funded sites were primarily limited by funding, but the distribution of area covered by the PV modules at those sites were chosen to enable a better study of the BIPV system.

Solar PV incentive programs are a significant cost driver because available incentives can significantly reduce the cost of a PV system. There is currently a federal incentive, called the Business Energy Investment Tax Credit (ITC) that allows a corporate owner of a solar energy system to claim a credit on their tax filing valued at 30% of the installed cost of the solar PV system. Since the ESTCP-funded systems are government-owned, this study did not qualify for the ITC. However, this study was able to make use of the Arizona Public Service (APS) utility rebate program for Site III (MCAS Yuma), which reduced the cost of the BIPV system by 17 %. It is worth noting that the APS PV rebate program at that time did not differentiate between thin film PV and crystalline PV modules, specifically the aspect that thin film PV power output is less impacted by the incident angle of solar radiation than crystalline PV. Therefore, APS reduced the rebate amount by almost 14% because half of the low-slope roof faced north. Another significant consideration about incentives is the change of terms over time. The rebate for Site III (MCAS Yuma) PV rebate request, the rebate was $2.50/W. The same program now only offers $0.60/W for grid-tied, non-residential PV systems up to 30 kW.

7.3 COST ANALYSIS AND COMPARISON

Based on past press releases related to this form of BIPV roof system, it appears that the cost of the system without incentives had originated at around $20/W and steadily decreased to $12.30/W, which is the cost benchmark generated from this study based on the prices paid in the 2008 contract award. With the lowest reported installed cost at $6.50/W, it is conceivable that the cost could steadily decline to that price point for small-scale systems over time.

Note that earlier in this section, only the cost and benefit of a BIPV system has been evaluated against the cost of a conventional roof. That helped determine the value of the incremental cost of a BIPV system. For those that are considering rooftop PV system regardless of the return on investment, a more useful comparison would be between a BIPV system and a conventional roof with a conventional rooftop-mounted PV system. While the size and cost of the roof and PV system can both vary, the comparison is further complicated by the wide variety of commercially available, conventional rooftop PV products. Statistical data will be used to address this variation issue. Figure-51 is from an National Renewable Energy Laboratory (NREL) report [3]and shows that the installed cost of various PV systems in 2010 dollars and shows that commercial rooftop PV systems cost roughly between $4 and $4.60 per Watt (DC). Figure-52 is a graph from the State of California’s Solar Statistics website (www.californiasolarstatistics.ca.gov) and shows that the 2012 installed cost average of a high number of non- residential systems is roughly between $4 and $7.50 per Watt (DC). Note that the data does not make a distinction between ground and roof mounted systems, but it is generally uncommon for non-utility systems be to ground mounted, so the cost range will be assumed to be representative of commercial, roof mounted PV systems. Also, since it has only been two years from 2010 as of this report and inflation has not changed significantly, it will be assumed that the range from the NREL data is still accurate in today’s dollars. Therefore, the range that will be used for the comparison in this report will be $4 to $7.50 per Watt. Additionally, to simplify the comparison, the same roof and PV system sizes from this study will be used. Table-15 shows how the actual BIPV roof costs compare against the estimated costs.

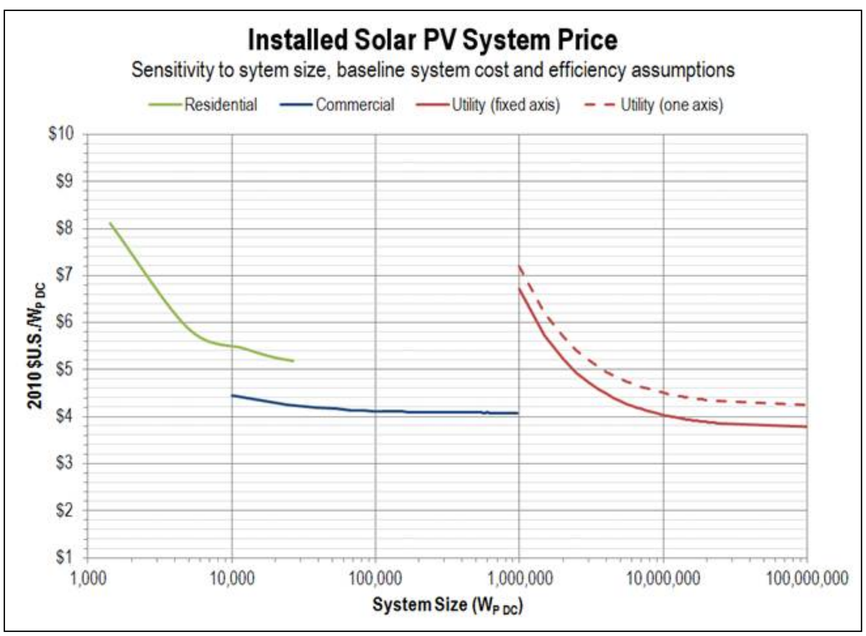

Figure-51: Graph from NREL report showing the installed cost of various PV systems against the system size [3].

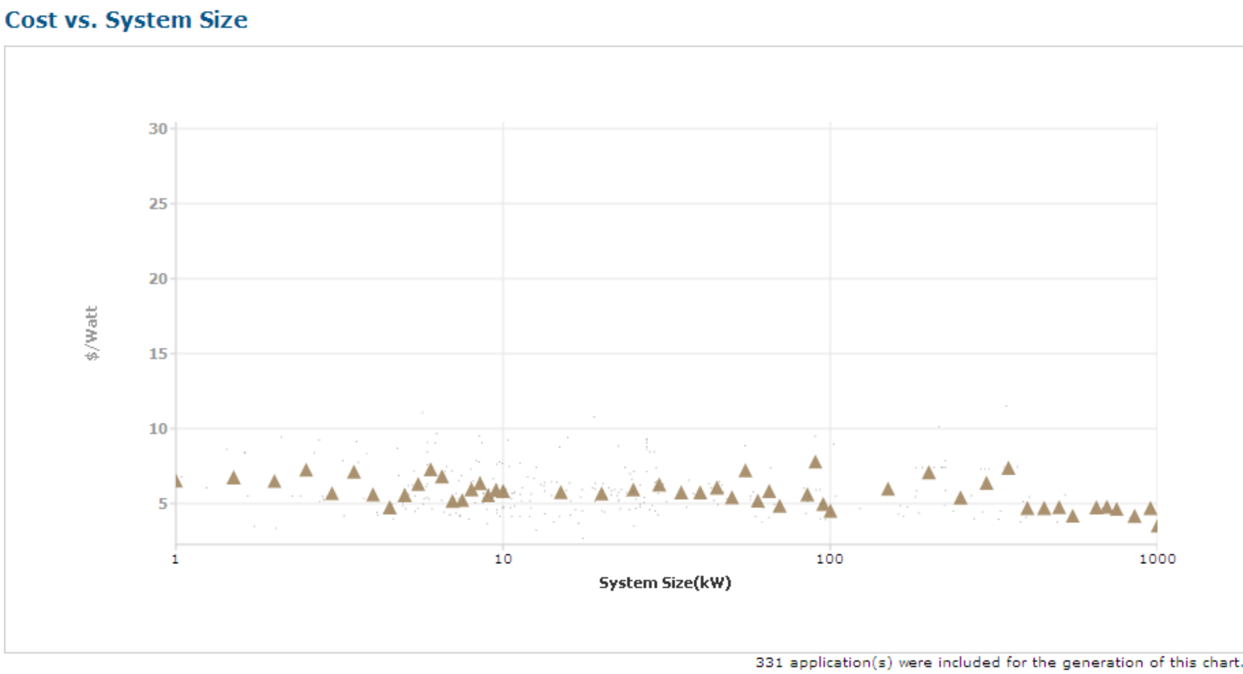

Figure-52: Graph from California Solar Statistics website showing the installed cost of non-residential PV systems against the system size for 2012.

Table-15: Estimated capital costs for conventional roofs and PV systems compared to actual BIPV costs.

	BIPV Cost at time of Award	Conventional Roof @ $5/sq.ft. and PV @ $4/W	Conventional Roof @ $5/sq.ft. and PV @ $7.5/W	Conventional Roof @ $20/sq.ft. and PV @ $4/W	Conventional Roof @ $20/sq.ft. and PV @ $7.5/W
Site I (Luke AFB)	$6M	$2.2M	$3.5M	$4.4M	$5.7M
Site II (Patuxent River)	$363K w/ roof repairs; $332K w/o	$188K	$282K	$428K	$522K
Site III (MCAS Yuma)	$254K w/o rebate	$129K	$201K	$268K	$340K

In each scenario, Site I (Luke AFB)'s actual BIPV roof cost is greater than the combined estimated cost of the conventional systems. The other ESTCP-funded sites have only a lower capital cost when the conventional roofing cost is high. However, these comparisons do not account for market conditions. The installation of the BIPV roof at Site I (Luke AFB) started in 2005, which was when the product was still relatively new and conventional PV systems using rigid PV modules were still more costly. Figure-53 shows the 2007 California Solar Statistics average installed cost in present value (i.e., adjusted for inflation) is closer to $7 – $10 per Watt. Unfortunately, that website lacks data for systems prior to 2007. For a more accurate comparison, the contract for the installation of the BIPV roofs at Site II (NAS Patuxent River) and Site III (MCAS Yuma) was awarded in 2008 and the California Solar Statistics website shows the average installed cost in 2008 dollars to be roughly $7.5-$10 per Watt (Figure-54).

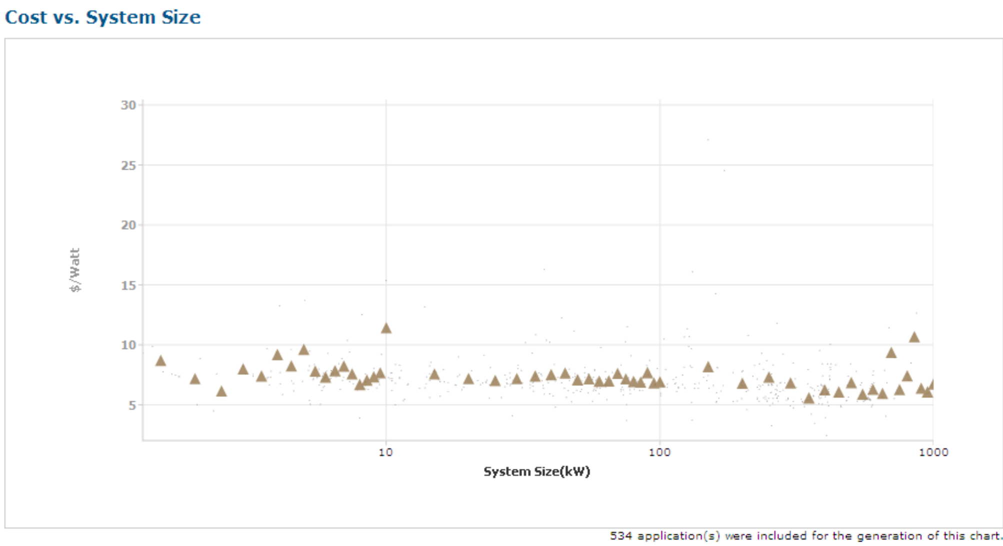

Figure-53: Graph from California Solar Statistics website showing the installed cost of non-residential PV systems against the system size for just 2007.

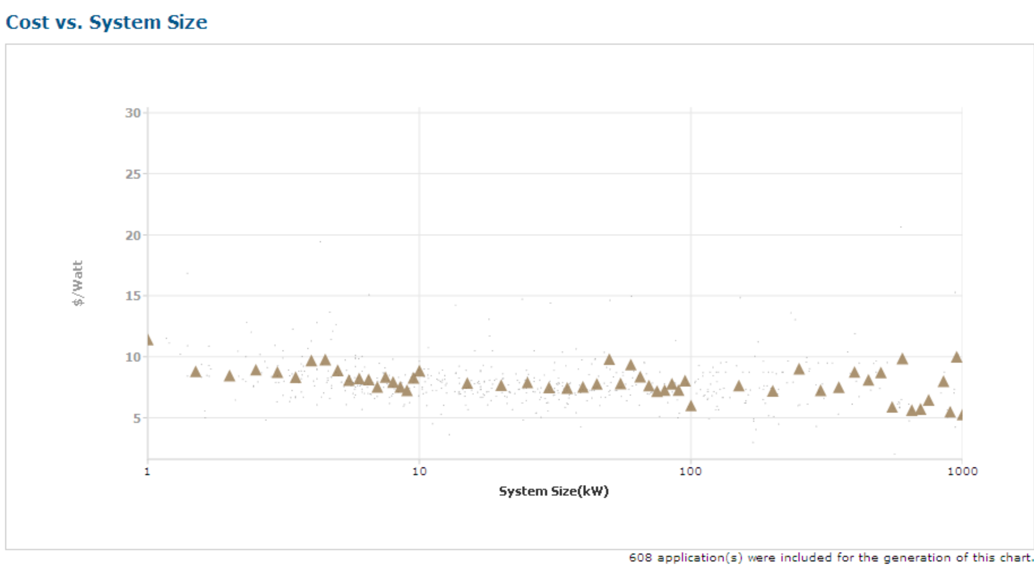

Figure-54: Graph from California Solar Statistics website showing the installed cost of non-residential PV systems against the system size for just 2008.

Table-16 shows how the actual BIPV roof costs compare against the estimated costs from the 2008 data. Site I (Luke AFB) still does not appear to be have a more advantageous capital cost, but recall that it was one of the earlier systems in place and the cost range for conventional PV systems in 2005 is likely to be greater than shown here. However, for the Site II (NAS Patuxent River) and Site III (MCAS Yuma), it is evident that these BIPV roofs are more competitive and, in certain scenarios, require a lower capital investment than the conventional approach.

Table-16: Estimated 2008 costs for conventional roofs and PV systems compared to actual BIPV costs.

	BIPV Cost at time of Award	Conventional Roof @ $5/sq.ft. and PV @ $7.5/W	Conventional Roof @ $5/sq.ft. and PV @ $10/W	Conventional Roof @ $20/sq.ft. and PV @ $7.5/W	Conventional Roof @ $20/sq.ft. and PV @ $10/W
Site I (Luke AFB)	$6M	$3.5M	$4.5M	$5.7M	$6.6M
Site II (Patuxent River)	$363K w/ roof repairs; $332K w/o	$282K	$349K	$522K	$589K
Site III (MCAS Yuma)	$254K w/o rebate	$208K	$252K	$340K	$391K

While this analysis in this section thus far shows that the BIPV roof studied could be competitive when looking at the capital cost, the operations and maintenance cost and service life also need to be considered. Conventional rooftop PV systems have a much longer history than BIPV roofs and generally require little-to-no maintenance as long as the roof attachment method does not compromise the roof. Since both BIPV and conventional PV systems utilize the same inverters and both the PV modules have similar warranty periods, these factors can be eliminated from the comparison. The remaining primary component is the roofing system and the PV attachment mechanism. Adhesive issues and mold growth can make this form of BIPV roof unlikely to reach its advertised 20-year life.

Site I (Luke AFB) was installed in 2006 via an ESPC, so the exact installation cost for the BIPV roof is not entirely separable from other costs, such as shared overhead costs, in that contract. Press releases reported that the system cost $6 million. Conventional re-roofing costs $5-$20 per square foot depending on the chosen roof quality and type. HVAC operational costs were not studied for this site. The limited energy production data shows that the system generates a mean of 1,812 kWh per day. The latest electricity rate for this site is unavailable, but NREL's PV Watts program reports the state average to be $0.085 per kWh, which results in an estimated annual savings of $56,217. PV system repairs were performed to address the PV adhesion problem, but the effort was covered by the warranty, so it is unclear what it cost to perform the work. Since the government did not have to expend funds to perform the repair work, the repair costs are considered zero. As long as the PV modules are not significantly displaced from their original locations, the modules should continue to generate power as intended, so it will be assumed that the PV system will continue to perform to the BIPV roof's advertised 20-year life. A one-time PV inverter replacement is assumed at a total cost of $0.75/W. Maintenance on the PVC roof membrane was not performed and appeared to remain in good condition, so it will be assumed that this component will also achieve its advertised system life. Note that ROOFER EMS results predicted the BIPV roof life to be 11-19 years. The reason for the range is because the roof is so large that the assessment was separated into four sections. The simplified (i.e., escalation and inflation rates are ignored) formula for calculating the SIR provides results ranging from 0.16 to 0.27 when using the avoided conventional re-roofing cost range of $5-$20 per square foot. Even when making optimistic assumptions, the BIPV system is not a cost effective investment. Fortunately, installations costs have been reduced since the installation of Site I (Luke AFB).

Site II (NAS Patuxent River) was installed in 2009 and cost $363,187, with $31,151 of that associated with necessary roof removal and repairs to support the BIPV roof. The $5-$20 per sq.ft. conventional re-roofing cost range also applies here. The HVAC system was not studied for this site. The mean daily energy production from two years worth of data is 81.9 kWh per day. The reported FY10 blended electricity rate is $0.127 per kWh, resulting in an annual cost savings of $3,796. No PV maintenance or repair was needed during the study period. Roof maintenance was not performed. The 2011 ROOFER assessment projected that the roof will only last until 2013 if left alone and until 2020 if repairs are made. The estimated cost for repairs is $20,933. If we assume that the repairs will be made and the roof performs to 2020, the SIR values are estimated to be 0.074 to 0.48 depending on the avoided conventional re-roofing cost. With this 11 year system life, there is little concern about including the PV inverter replacement cost in the calculation. However, note that the 2013 date does not imply that the roof will fail for certain. It is an indication that the roof needs to be regularly surveyed because of the potential for significant failure. If repairs are not needed and the system lasts 11 years, the SIR range improves to 0.15-0.97. For an ideal 20 year system, and an assumed one-time PV inverter replacement at $0.75/W, the SIR range would be 0.20-1.29.

The installed cost for Site III (MCAS Yuma) was $253,945 when not including the $44,000 rebate. The $5-$20 per sq.ft. conventional re-roofing cost range also applies here. The HVAC impact is assumed to be zero for this particular facility because of the inconclusive results. The mean daily energy production from about two years worth of data is 92.7 kWh per day. The reported FY10 blended electricity rate is $0.073 per kWh, resulting in an annual cost savings of $2,470. No PV maintenance or repair was needed during the study period and no degradation of the PV modules or the adhesive was observed. No roof maintenance or repair was needed during the study period and the PVC membrane appears to be in good condition. The 2011 ROOFER results predicted a total system life of 18 years after an estimated repair effort of $1,072. However, as stated earlier, this does not imply that the roof will fail at that time. For instance, the 2009 ROOFER results predicted a total system life of 15 years. The following table shows the SIR values for the various scenarios. All assume a one-time PV inverter replacement at a cost of $0.75/W. Note that the SIR values for the scenarios with HVAC savings assume that there is good thermal coupling between the roof and conditioned space, which means that the estimated savings of 9.89 kWh/m^2 from section 6.5 was used. In other words, the SIR values for the scenarios with HVAC savings reflects a similar, but theoretical facility with a tighter building envelope located in Phoenix, AZ.

Table-17: SIR values of various scenarios based on the Site III (MCAS Yuma) BIPV roof.

	SIR with Avoided Re-roof at $5/sq.ft.	SIR with Avoided Re-roof at $20/sq.ft.	SIR with Avoided Re-roof at $5/sq.ft. & Rebates	SIR with Avoided Re-roof at $20/sq.ft. & Rebates	SIR with Avoided Re-roof at $5/sq.ft. & HVAC Savings	SIR with Avoided Re-roof at $20/sq.ft. & HVAC Savings	SIR with Avoided Re-roof at $5/sq.ft. & HVAC Savings & Rebate	SIR with Avoided Re-roof at $20/sq.ft. & HVAC Savings & Rebate
15-Year Life	0.10	0.30	0.13	0.84	0.14	0.44	0.18	1.22
20-Year Life	0.16	0.48	0.20	1.34	0.22	0.66	0.28	1.85

8.0 IMPLEMENTATION ISSUES

BIPV roof technology and products are still relatively new, so there is a general lack of experience and history with BIPV roofs throughout DoD and even in the private industry. Lessons were learned from the installation and the real world effects on the BIPV roof. Some implementation issues could be overcome now that there is a better understanding of the BIPV roof system, whereas other problems were inherent to the roof's components and did not become apparent until a time after installation was completed.

The Navy and Marine Corps typically utilize construction expertise within the Facilities and Engineering Acquisition Division (FEAD) and Resident Officer in Charge of Construction (ROICC) offices to perform quality assurance during construction efforts. The Army and Air Force utilize similar services. Before the installation of a BIPV roof, ROICC personnel had expressed their need to learn about the BIPV roof system in order to properly review contractor work. It is recommended that DoD personnel in charge of rooftop solar projects, at minimum, consult with a DoD roofing specialist. Ideally, personnel experienced with rooftop solar projects would provide training and/or consultation prior to design and construction phases for each DoD BIPV roof project.

There was a lack of firefighter safety standards and design practices that reduce hazards in the event of a fire. For example, this type of BIPV roof system has the electric conduit embedded in the insulation layer. While this resulted in a very clean appearance, the cables are hidden from firefighters and presents an electric hazard because PV modules continue to function whenever exposed to light even when disconnected from the facility. This is one of the reasons why the BIPV system provider switched to surface mounted conduit a few years ago. Some industry standards like the National Electric Code address fire and electrical safety of PV systems, but the rooftop PV industry is still relatively new and more work needs to be done, especially as new technologies emerge. The Underwriter Laboratories report on *Firefighter Safety and Photovoltaic Installations Research Project* and the California Department of Forestry and Fire Protection *Solar Photovoltaic Installation Guideline* are recommended and free to download for those that desire to know more about PV systems and fire safety.

For the BIPV roofs funded by ESTCP, the contractor designed the BIPV system and Navy personnel reviewed the submittals using the information available prior to this study. The two notable issues that could have been prevented had the results of this study been available include the flashing and the vapor barrier. Recall that the inadequate flashing height results in a higher chance of water penetrating the roof. The most straightforward solution is to establish minimum flashing height requirements explicitly in the statement of work to ensure that objects, such as air vents, have their height raised to meet the requirement. This issue is more likely to occur when using a BIPV roof overlay approach, such as the case with Site III (MCAS Yuma), but can still occur in roof replacement efforts when the new insulation thickness is greater than the original insulation thickness. It is worth noting that the insufficient flashing issue has been seen in other regular roofing renovation projects as well, so it is not limited to BIPV roofs. With respect to the vapor barrier, the missing component caused the roof deck at Site II (NAS Patuxent River) deck to warp because of the humidity and frequent rainfall in that location. The warping was not evident until months after the system was installed and was not considered because the prior roof, a modified bitumen system, did not require one. This problem was not observed in other BIPV roofs in other humid/wet locations surveyed during the course of this study. Future systems should ensure that a vapor barrier be included in the statement of work if a vapor barrier does not exist.

Mold growth appeared in many of the larger systems because either the climate was humid, causing the roof to remain generally wet for a long period of time, and/or there was insufficient drainage, causing water to form small ponds. While mold growth on PVC roof membranes are tested under an ASTM standard and certain mold may not be malignant to roof longevity, the energy efficiency benefits are greatly reduced due to the reduction in roof reflectivity, which can negatively impact the economic benefits. Personnel in charge of specifying roof requirements should ensure that both the workmanship and manufacturer warranties provide resolutions regarding both mold growth and improper roof drainage. Insufficient drainage can be a result of a poor design and/or a poor installer. In the case of a BIPV retrofit, it is possible that the original roof was never properly designed or installed. A properly timed survey within a day or two after a rain event of the existing roof will help identify drainage issues and areas for improvement when the BIPV roof is installed. In addition a BIPV roof assessment prior to the expiration of the workmanship warranty is recommended.

In two of the systems surveyed, the PV adhesive failed. While the system integrator attempted to fix this issue, the results were unfavorable and the tape solution itself generated undesirable conditions, such as water retention and a sticky residue. The manufacturer removed PVC membrane from their list of approved substrates and instead standardized on TPO membranes for this type of BIPV system after this study started. However, both the system integrator and the PVL manufacturer filed for bankruptcy in 2012 and are no longer able to service the BIPV roof, but there is still at least one third-party vendor who has access to some unused PVLs. The PVC membrane manufacturer is still in business and third-party solutions are available to address the adhesive issue, but may void the remaining warranty on the PVC membrane, so the PVC membrane manufacturer should be engaged before proceeding with a repair effort.

When the PV adhesive fails, it is possible to remove the affected PVLs or a group of PVLs on the same carrier sheet. Removing an individual PVL may leave adhesive residue that is difficult to remove and a clean PVC membrane surface is necessary if a replacement PVL is desired. Replacing individual PVLs is not recommended because there is no guarantee/warranty that the new PVL will not experience the same adhesive failure and there has not been much research into finding a reliable adhesive for adhering PV to the PVC membrane. If the PVL is removed, but not replaced, then the carrier sheet will need to be patched with additional PVC membrane material to ensure water does not flow to the other PVLs or into the roof. The patching of a PVC membrane utilizes a no-flame, heat welding approach and is a standard roofing industry task so the PVC membrane warranty could be maintained as long as the PVC manufacturer's requirements are met. Removing a group of PVLs on the same carrier sheet requires cutting into the carrier sheet and disconnecting the BIPV panel. If replacement PVLs are undesired, then the roof can be patched with a new PVC sheet slightly larger than the carrier sheet that was removed. If replacing the PVLs, the BIPV system owner should consider the use of a TPO membrane as the carrier sheet. While TPO can not be heat welded to PVC, mechanical fasteners will likely be necessary and the actual approach will be left to the third-party solution provider. However, it is unknown whether or not this approach will void the PVC membrane warranty, so the PVC roof membrane manufacturer should be consulted prior to starting this repair effort. Regardless of the approach, when one or more PVLs are removed or replaced, an electrical engineer or a PV designer should be consulted to determine how the change may impact the system's electrical performance and identify any mitigation techniques.

A UFGS was to be developed if this system performed successfully, but due to the various issues and the bankruptcy of the PV and systems integrator, a specification would not help with the adoption of this technology. In addition, the emergence of new CIGS and CdTe PV modules and vendors have led to a much more diverse group of designs since this study started and it is not possible to simply write one guide specification to address these new and varied options. Instead it is recommended that the lessons learned from this study be applied to the acquisition planning, design, and construction process.

The technical areas of concerns may be mitigated in various ways depending on the acquisition vehicle used. When upfront capital is invested, such as through the Military Construction (MILCON) program, maintenance is typically not included in the cost. DoD will be responsible for maintaining and repairing the BIPV system after the warranty period is over. Therefore, the acquisition workforce needs to be careful with the solicitation requirements and fully understand the details of the workmanship and manufacturer warranty associated with the proposal. When a financed, performance contract is used, such as an Energy Savings Performance Contract (ESPC), maintenance of the system may be included in the contract. In addition, risks associated with BIPV system ownership can be mitigated by adequately addressing the performance requirements that the energy service company must meet in order to comply with the contract. In the case of an ESPC, the Measurement & Verification (M&V) plan is the core to performance measurement and, in general, the more thorough the M&V plan, the more expensive the effort, but results in a lower risk to the government. In addition, the energy service company will need to be comfortable with guaranteeing the performance of BIPV roofs or else another rooftop PV system may be proposed instead. Risk management will need to be applied by both the government and contractor to find the best balance for the project. A third, more radical and more complex method of acquiring BIPV roofs would be to utilize an approach similar to how the large PV arrays were installed at Nellis AFB and NAWCWD China Lake which are similar in concept to an Enhanced Use Lease (EUL) in conjunction with a Power Purchase Agreement (PPA). An EUL can be used to lease out roofs as real estate. While this does not preclude the lessee to do something else with the roof space, its uses are extremely limited. Also, as it was with an ESPC, the lessee will need to be comfortable with BIPV roofs or it will propose a different rooftop PV system. A PPA is used to purchase the power. Standard EUL and PPA require full and open competition and they may have different contract durations, which adds to the complexity. However, if achieved, the lessee will own and operate the roofs and PV systems and eliminates most, if not all, of the risks to DoD.

The exact BIPV system studied is no longer commercially available, but adhered PV systems are still in use and the lessons learned from this study can also be applied to other rooftop systems that use an adhered PV approach as they can experience similar issues. Risks associated with BIPV systems can be mitigated by applying sound roofing practices, being aware of potential failure points, and utilizing the proper acquisition vehicle. It is recommended that DoD revisit the BIPV roofs in this study several years from now, maintain a list of adhered PV systems, identify their basic PV and roof components, and survey a sample set every few years to identify performance and durability trends of the different components.

9.0 REFERENCES

[1] Ban-Weiss, G., Wray, C., Delp, W., Ly, P., Akbari, H., Levinson, R., *Electricity Production and Cooling Energy Savings from Installation of a Building-Integrated Photovoltaic Roof on an Office Building.* Energy & Buildings, Volume 56, January 2013.

[2] Desjarlais, A., Petrie, T., Atchley, J., Gillenwater, R., Roodvoets, D., *Evaluating the Energy Performance of Ballasted Roof Systems*. ORNL Report Number UF-04-396, April 2008.

[3] Goodrich, A., James, T., Woodhouse, M., *Residential, Commercial, and Utility-Scale Photovoltaic (PV) System Prices in the United States: Current Drivers and Cost-Reduction Opportunities*. NREL/TP-6A20-53347, February 2012.

Appendix A
Points of Contact

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Nathan Finch	NAVFAC EXWC CI 1100 23rd Avenue Port Hueneme, CA 93043	P: 805-982-6630 nathan.finch@navy.mil	Roof Specialist
Mark deOgburn	NAVFAC Atlantic PW Building 13 Charleston, SC 29405	P: 843-296-1923 mark.deogburn@navy.mil	Roof Subject Matter Expert
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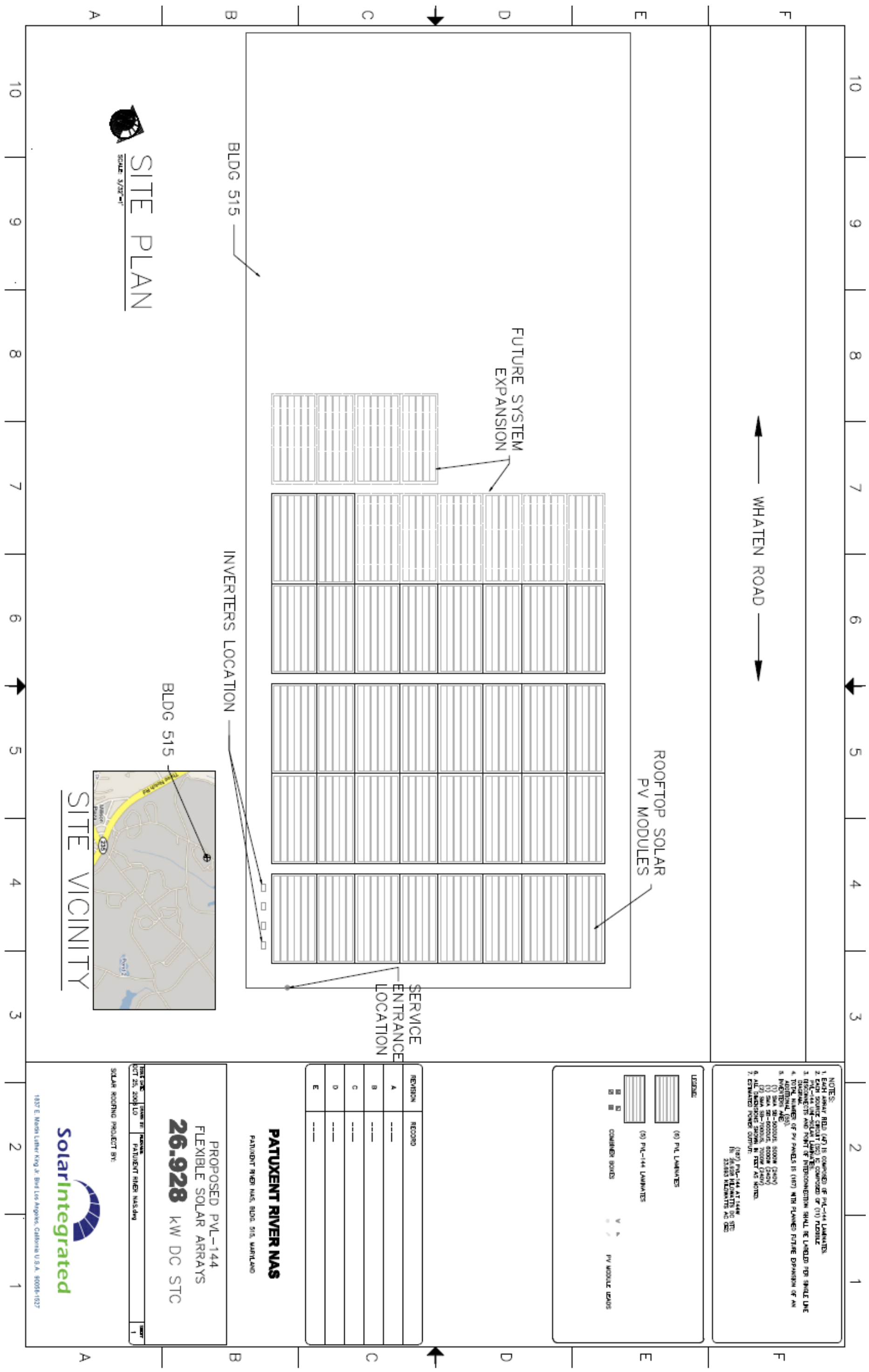
Hashem Akbari, Ph.D.[1]	Concordia University, Department of Building, Civil, and Environmental Engineering, 1455 De Mainsonneuve Blvd W., Montreal, QC H3G 1M8, Canada	P: 514-848-2424 x3201 HAkbari@ENCS.Concordia.CA	HVAC Analysis Expert
Craig Wray, P.E.	Lawrence Berkeley National Laboratory, Environmental Energy Technologies Division, 1 Cyclotron Road MS 90R2000 Berkeley, CA 94720	P: 510-486-4021 CPWray@lbl.gov	Measurement Expert
Woody Delp	Lawrence Berkeley National Laboratory, 1 Cyclotron Road MS 90R3058 Berkeley, CA 94720	P: 510-486-5864 F: 510-486-6658 wwdelp@lbl.gov	Measurement Expert
SEI Group, Inc.	303 Williams Ave SW, Suite 135, Huntsville, AL 35801	256-533-0500 mark.kelly@seigroupinc.com	Contractor

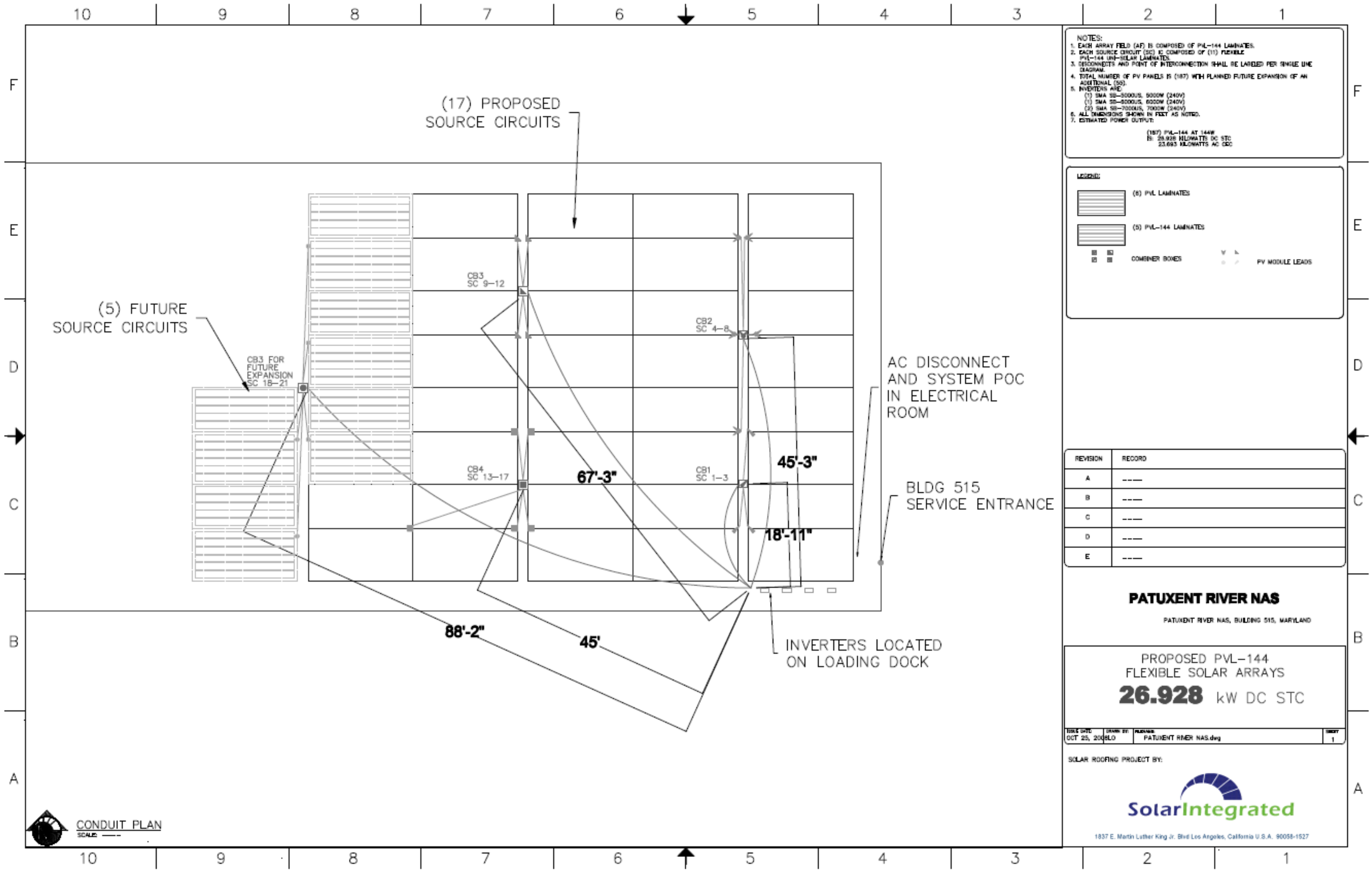
[1]Dr. Akbari was originally part of the LBNL Heat Island Group at the beginning of this study.

Appendix B
Design Drawings

Site I (Luke AFB) installation was not funded by this ESTCP study, so design drawings are unavailable.

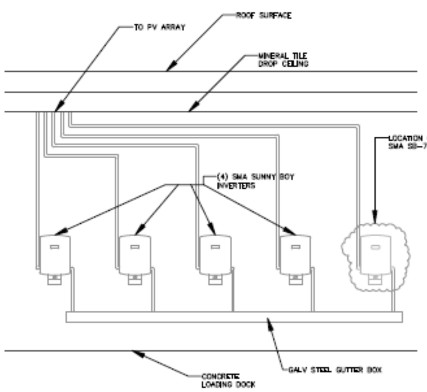
Site II (NAS Patuxent River)



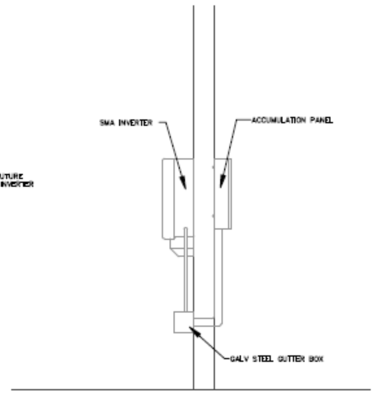


(17) PROPOSED SOURCE CIRCUITS
(5) FUTURE SOURCE CIRCUITS
CB3 FOR FUTURE EXPANSION SC 18–21
CB3 SC 9–12
CB2 SC 4–8
CB4 SC 13–17
CB1 SC 1–3
67'-3"
45'-3"
18'-11"
88'-2"
45'
AC DISCONNECT AND SYSTEM POC IN ELECTRICAL ROOM
BLDG 515 SERVICE ENTRANCE
INVERTERS LOCATED ON LOADING DOCK
CONDUIT PLAN
NOTES:
1. EACH ARRAY FIELD (AF) IS COMPOSED OF PVL–144 LAMINATES.
2. EACH SOURCE CIRCUIT (SC) IS COMPOSED OF (11) FLEXIBLE PVL–144 UNI–SOLAR LAMINATES.
3. DISCONNECTS AND POINT OF INTERCONNECTION SHALL BE LABELED PER SINGLE LINE DIAGRAM.
4. TOTAL NUMBER OF PV PANELS IS (187) WITH PLANNED FUTURE EXPANSION OF AN ADDITIONAL (56).
5. INVERTERS ARE:
(1) SMA SB–5000US, 5000W (240V)
(1) SMA SB–6000US, 6000W (240V)
(2) SMA SB–7000US, 7000W (240V)
6. ALL DIMENSIONS SHOWN IN FEET AS NOTED.
7. ESTIMATED POWER OUTPUT:
(187) PVL–144 AT 144W
IS: 26.928 KILOWATTS DC STC
23.693 KILOWATTS AC CEC
LEGEND:
(8) PVL LAMINATES
(5) PVL–144 LAMINATES
COMBINER BOXES
PV MODULE LEADS
REVISION
RECORD
A ---
B ---
C ---
D ---
E ---
PATUXENT RIVER NAS
PATUXENT RIVER NAS, BUILDING 515, MARYLAND
PROPOSED PVL–144 FLEXIBLE SOLAR ARRAYS
26.928 kW DC STC
ISSUE DATE
OCT 25, 2008
DRAWN BY:
BLO
FILENAME:
PATUXENT RIVER NAS.dwg
SHEET
1
SOLAR ROOFING PROJECT BY:
SolarIntegrated
1837 E. Martin Luther King Jr. Blvd Los Angeles, California U.S.A. 90058-1527

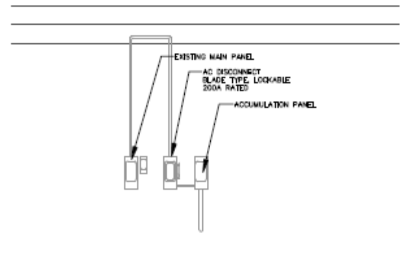
INVERTER DETAIL NOTES:
1. ALL DISCONNECTS & BREAKERS TO BE LABELED PER SINGLE LINE DIAGRAM.
2. INVERTER EQUIPMENT MUST BE LOCATED IN DESIGNATED AREA AS SHOWN BUT MAY BE REPOSITIONED TO FACILITATE INSTALLATION.



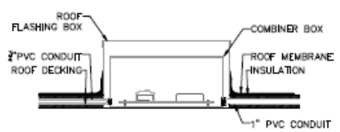
INVERTER DETAIL:
LOADING DOCK AT SW CORNER OF BLDG. 515
SCALE: 1:32



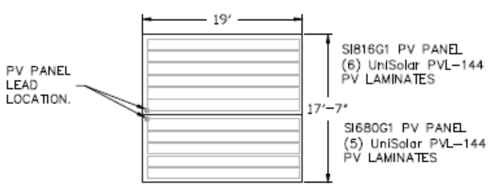
INVERTER/AC DISCONNECT WALL SECTION
SCALE: 1:16



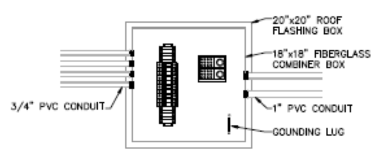
SYSTEM INTERCONNECTION DETAIL:
BUILDING 515 MAIN LOCATED AGAINST SOUTH WALL AT WEST END.
SCALE: 1:32



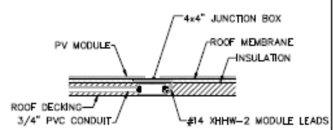
COMBINER BOX SIDE DETAIL
SCALE: 1 1/2" = 1'



SI816G1 PV PANEL DETAIL
SCALE: 1" = 8'



COMBINER BOX FRONT DETAIL
SCALE: 1 1/2" = 1'



MODULE LEAD BOX DETAIL
SCALE: 1 1/2" = 1'

NOTES:
1. EACH ARRAY FIELD (AF) IS COMPOSED OF PVL-144 LAMINATES.
2. EACH SOURCE CIRCUIT (SC) IC COMPOSED OF (11) FLEXIBLE PVL-144 UNI-SOLAR LAMINATES.
3. DISCONNECTS AND POINT OF INTERCONNECTION SHALL BE LABELED PER SINGLE LINE DIAGRAM.
4. TOTAL NUMBER OF PV PANELS IS (187) WITH PLANNED FUTURE EXPANSION OF AN ADDITIONAL (55).
5. INVERTERS ARE:
   (1) SMA SB-5000US, 5000W (240V)
   (1) SMA SB-6000US, 6000W (240V)
   (2) SMA SB-7000US, 7000W (240V)
6. ALL DIMENSIONS SHOWN IN FEET AS NOTED.
7. ESTIMATED POWER OUTPUT:

(187) PVL-144 AT 144W
IS: 26.928 KILOWATTS DC STC
23.893 KILOWATTS AC CEC

REVISION	RECORD
A	---
B	---
C	---
D	---
E	---

PATUXENT RIVER NAS

PATUXENT RIVER NAS, BUILDING 515, MARYLAND

PROPOSED PVL-144
FLEXIBLE SOLAR ARRAYS
26.928 kW DC STC

ISSUE DATE	DRAWN BY	FILENAME	SHEET
OCT 25, 200	SLO	SIT-BIPV PAX RIVER.dwg	1

SOLAR ROOFING PROJECT BY:

SolarIntegrated

1837 E. Martin Luther King Jr. Blvd Los Angeles, California U.S.A. 90058-1527

70

NOTES:
1. EACH ARRAY FIELD (AF) IS COMPOSED OF PVL-144 LAMINATES.
2. EACH SOURCE CIRCUIT (SC) IS COMPOSED OF (11) FLEXIBLE PVL-144 UNI-SOLAR LAMINATES.
3. DISCONNECTS AND POINT OF INTERCONNECTION SHALL BE LABELED PER SINGLE LINE DIAGRAM.
4. TOTAL NUMBER OF PV PANELS IS (187) WITH PLANNED FUTURE EXPANSION OF AN ADDITIONAL (55).
5. INVERTERS ARE:
   (1) SMA SB-5000US, 5000W (240V)
   (1) SMA SB-6000US, 6000W (240V)
   (2) SMA SB-7000US, 7000W (240V)
6. ALL DIMENSIONS SHOWN IN FEET AS NOTED.
7. ESTIMATED POWER OUTPUT:

(187) PVL-144 AT 144W
IS: 26.928 KILOWATTS DC STC
23.893 KILOWATTS AC CEC

GENERAL SINGLE LINE DIAGRAM NOTES:

1. THE PV SYSTEM CONSISTS OF:
   (11) UISOLAR PVL-144 PV MODULES IN SERIES TO FORM A SOURCE CIRCUIT (SC).
2. THE SYSTEM CONSISTS OF:
   (17) SC
   (1) SMA SB 5000US INVERTER
   (1) SMA SB 6000US INVERTERS
   (2) SMA SB 7000US INVERTER
   26.928 kW STC
   23.893 kW AC (CEC)
3. ALL CONDUCTORS ARE COPPER.
4. ALL CONNECTORS AND COUPLERS ARE SETSCREW TYPE UNLESS OTHERWISE NOTED.
5. ALL BELOW ROOF CONDUIT IS TO BE SCHEDULE 40 RIGID PVC. ALL ABOVE ROOF CONDUIT IS TO BE RIGID METAL CONDUIT.
6. ALL ENCLOSURES ARE NEMA 3R UNLESS OTHERWISE NOTED.
7. EQUIPMENT SHALL BE INSTALLED IN ACCORDANCE WITH THE NEC AND ALL APPLICABLE REQUIREMENTS OF THE SERVING ELECTRICAL UTILITY COMPANY AND OF THE LOCAL AUTHORITY HAVING JURISDICTION.
8. CONDUCTORS AND ELECTRICAL EQUIPMENT ARE SIZED TO ACCOMODATE AN ADDITIONAL (4) SC FOR A FUTURE SYSTEM EXPANSION.
9. INVERTERS ARE LISTED TO UL 1741 & IEEE 1547 COMPLIANT.

TABLE 1: COMBINER BOX & OUTPUT CONDUCTORS:

BOX	NUMBER OF SC	DISTANCE (ft.)	AWG	CONDUIT	Vdrop
1	3	18	#12	(1) ¾" PVC	0.26%
2	5	45	#8	(1) ¾" PVC	0.43%
3	4	65	#10	(1) ¾" PVC	0.79%
4	5	45	#8	(1) ¾" PVC	0.43%
5	RESERVED FOR EXPANSION: INSTALL EMPTY CB AND COUDUIT ONLY				
	0	65	N/A	(1) ¾" PVC	N/A

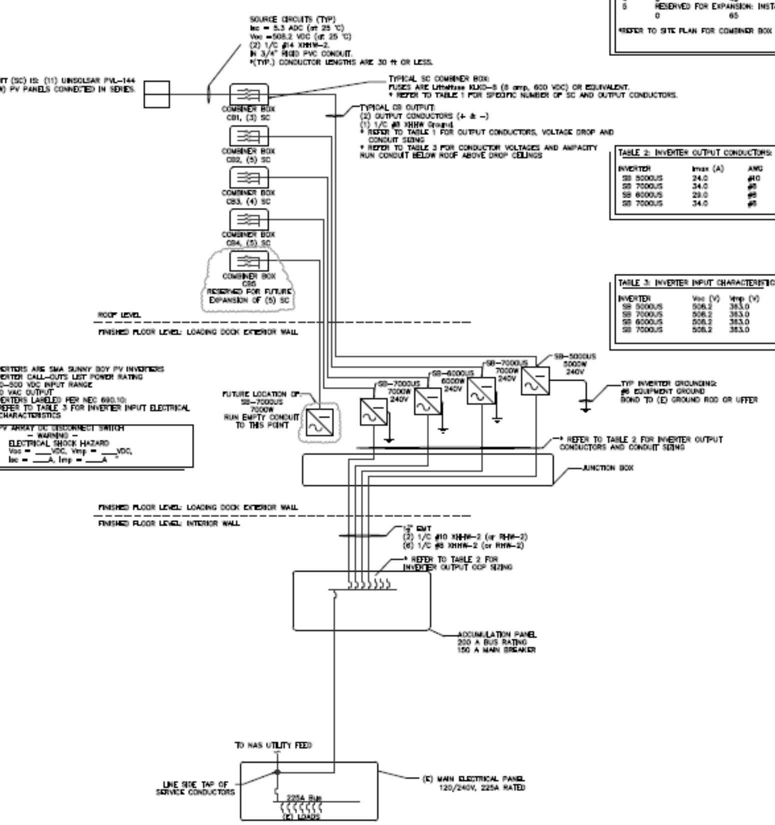
*REFER TO SITE PLAN FOR COMBINER BOX LOCATIONS

TABLE 2: INVERTER OUTPUT CONDUCTORS:

INVERTER	Imax (A)	AWG	CONDUIT	BREAKER OCP (A)
SB 5000US	24.0	#10	(1) ¾" EMT	30
SB 7000US	34.0	#8	(1) 1" EMT	45
SB 6000US	29.0	#8	(1) 1" EMT	40
SB 7000US	34.0	#8	(1) 1" EMT	45

TABLE 3: INVERTER INPUT CHARACTERISTICS FOR DC DISCONNECT

INVERTER	Voc (V)	Vmp (V)	Isc (A)	Imp (A)
SB 5000US	508.2	383.0	15.90	13.08
SB 7000US	508.2	383.0	26.50	21.80
SB 6000US	508.2	383.0	21.20	17.44
SB 7000US	508.2	383.0	26.50	21.80



POINT OF INTERCONNECTION:

1. TAP CONDUCTORS FEEDING MAIN BREAKER ON THE SERVICE SIDE OF THE BREAKER.
2. LABEL UTILITY DISCONNECT SWITCH PER FOLLOWING:

" PV SYSTEM DISCONNECT SWITCH
− WARNING −
ELECTRICAL SHOCK HAZARD
DO NOT TOUCH TERMINALS
TERMINALS ON BOTH THE LINE AND THE LOAD SIDE OF THE SWITCH MAYBE ENERGIZED IN THE OPEN POSITION "

ELECTRICAL SINGLE LINE DIAGRAM

SCALE: NTSC

REVISION	RECORD
A	———
B	———
C	———
D	———
E	———

PATUXENT RIVER NAS

PATUXENT RIVER NAS, BUILDING 515, MARYLAND

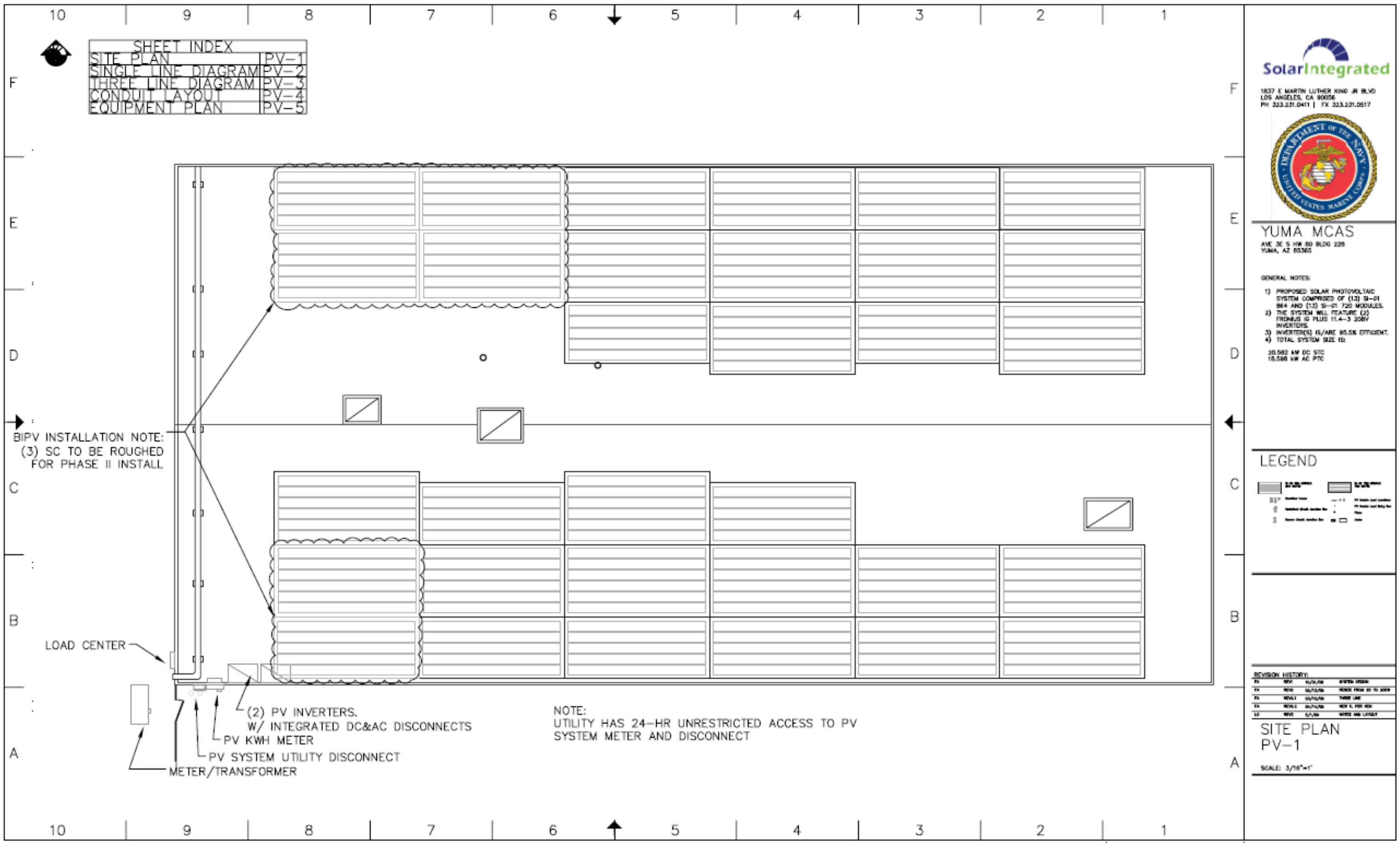
PROPOSED PVL-144
FLEXIBLE SOLAR ARRAYS
26.928 kW DC STC

ISSUE DATE	DRAWN BY	FILENAME	SHEET
OCT 25, 200	SLO	PATUXENT RIVER NAS.dwg	1

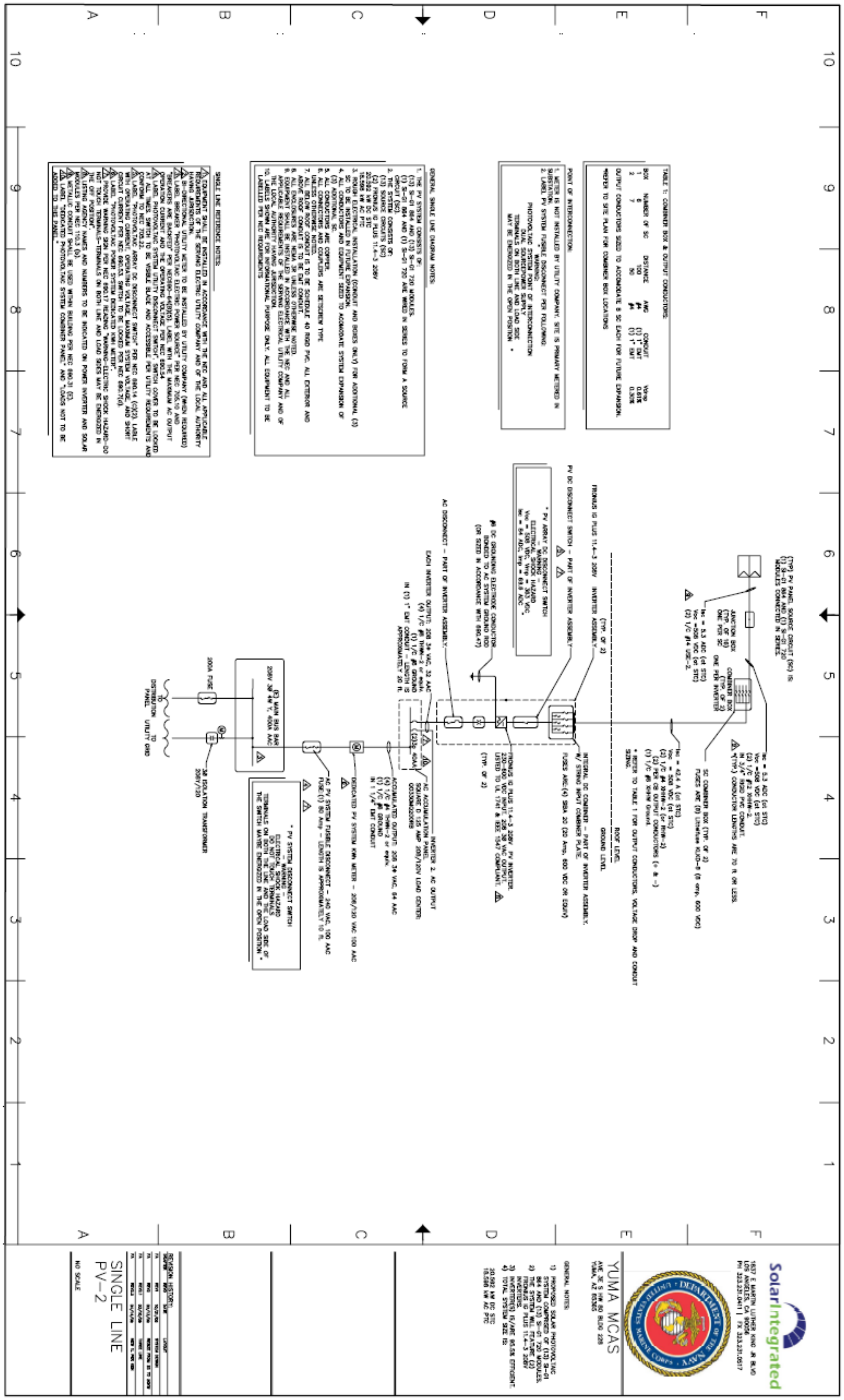
SOLAR ROOFING PROJECT BY:

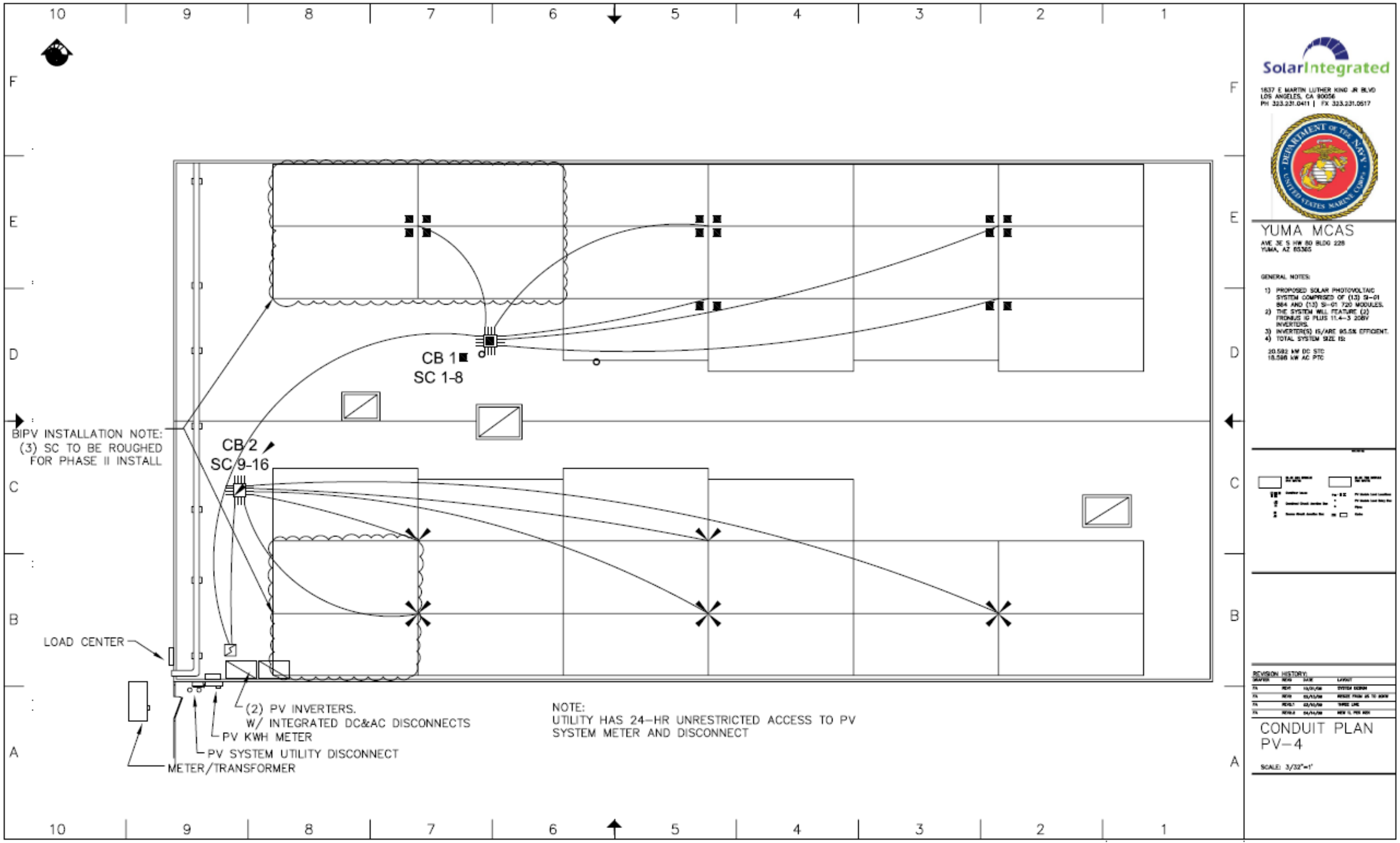
SolarIntegrated

1837 E. Martin Luther King Jr. Blvd Los Angeles, California U.S.A. 90058-1527

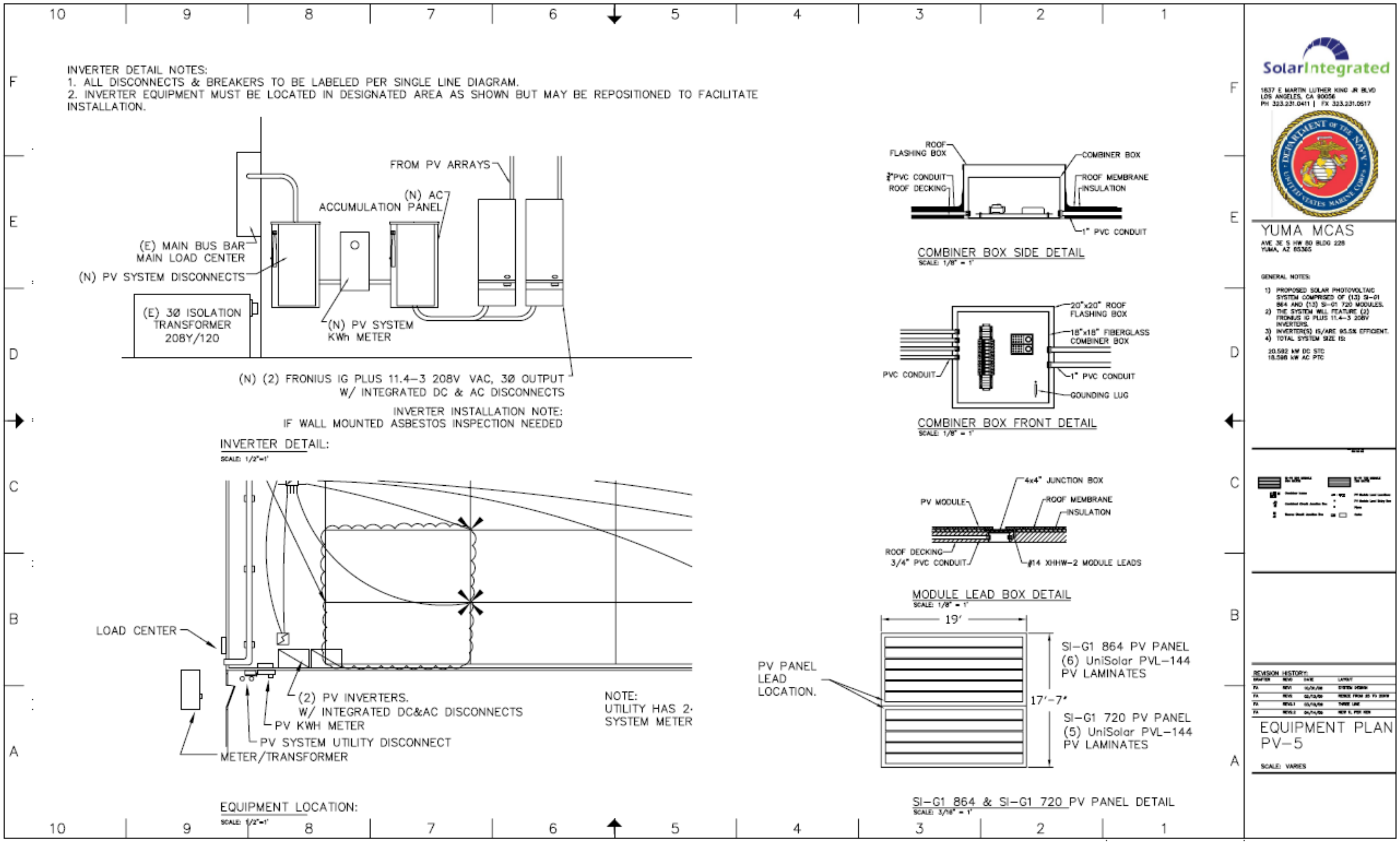


Site III (MCAS Yuma)


SolarIntegrated
YUMA MCAS
SINGLE LINE
PV-2
NO SCALE



SolarIntegrated
1837 E MARTIN LUTHER KING JR BLVD
LOS ANGELES, CA 90058
PH 323.231.0411 | FX 323.231.0517
YUMA MCAS
AVE 3E S HW 80 BLDG 228
YUMA, AZ 85365
GENERAL NOTES:
1) PROPOSED SOLAR PHOTOVOLTAIC SYSTEM COMPRISED OF (13) SI-01 884 AND (13) SI-01 720 MODULES.
2) THE SYSTEM WILL FEATURE (2) FRONIUS IG PLUS 11.4-3 208V INVERTERS.
3) INVERTER(S) IS/ARE 95.5% EFFICIENT.
4) TOTAL SYSTEM SIZE IS:
20.582 kW DC STC
18.598 kW AC PTC
CB 1
SC 1-8
CB 2
SC 9-16
BIPV INSTALLATION NOTE:
(3) SC TO BE ROUGHED
FOR PHASE II INSTALL
LOAD CENTER
(2) PV INVERTERS.
W/ INTEGRATED DC&AC DISCONNECTS
PV KWH METER
PV SYSTEM UTILITY DISCONNECT
METER/TRANSFORMER
NOTE:
UTILITY HAS 24-HR UNRESTRICTED ACCESS TO PV SYSTEM METER AND DISCONNECT
REVISION HISTORY:
CONDUIT PLAN
PV-4
SCALE: 3/32"=1'


INVERTER DETAIL NOTES:
1. ALL DISCONNECTS & BREAKERS TO BE LABELED PER SINGLE LINE DIAGRAM.
2. INVERTER EQUIPMENT MUST BE LOCATED IN DESIGNATED AREA AS SHOWN BUT MAY BE REPOSITIONED TO FACILITATE INSTALLATION.
FROM PV ARRAYS
(N) AC ACCUMULATION PANEL
(E) MAIN BUS BAR MAIN LOAD CENTER
(N) PV SYSTEM DISCONNECTS
(E) 3Ø ISOLATION TRANSFORMER 208Y/120
(N) PV SYSTEM KWh METER
(N) (2) FRONIUS IG PLUS 11.4-3 208V VAC, 3Ø OUTPUT W/ INTEGRATED DC & AC DISCONNECTS
INVERTER INSTALLATION NOTE: IF WALL MOUNTED ASBESTOS INSPECTION NEEDED
INVERTER DETAIL:
SCALE: 1/2"=1'
LOAD CENTER
(2) PV INVERTERS. W/ INTEGRATED DC&AC DISCONNECTS
PV KWH METER
PV SYSTEM UTILITY DISCONNECT
METER/TRANSFORMER
NOTE: UTILITY HAS 2 SYSTEM METER
EQUIPMENT LOCATION:
SCALE: 1/2"=1'
ROOF FLASHING BOX
COMBINER BOX
PVC CONDUIT
ROOF DECKING
ROOF MEMBRANE
INSULATION
1" PVC CONDUIT
COMBINER BOX SIDE DETAIL
SCALE: 1/8" = 1'
20"x20" ROOF FLASHING BOX
18"x18" FIBERGLASS COMBINER BOX
PVC CONDUIT
1" PVC CONDUIT
GOUNDING LUG
COMBINER BOX FRONT DETAIL
SCALE: 1/8" = 1'
4x4" JUNCTION BOX
PV MODULE
ROOF MEMBRANE
INSULATION
ROOF DECKING
3/4" PVC CONDUIT
#14 XHHW-2 MODULE LEADS
MODULE LEAD BOX DETAIL
SCALE: 1/8" = 1'
19'
17'-7"
PV PANEL LEAD LOCATION.
SI-G1 864 PV PANEL (6) UniSolar PVL-144 PV LAMINATES
SI-G1 720 PV PANEL (5) UniSolar PVL-144 PV LAMINATES
SI-G1 864 & SI-G1 720 PV PANEL DETAIL
SCALE: 3/16" = 1'
SolarIntegrated
1837 E MARTIN LUTHER KING JR BLVD
LOS ANGELES, CA 90056
PH 323.231.0411 | FX 323.231.0517
YUMA MCAS
AVE 3E S HW 80 BLDG 228
YUMA, AZ 85365
GENERAL NOTES:
1) PROPOSED SOLAR PHOTOVOLTAIC SYSTEM COMPRISED OF (13) SI-G1 864 AND (13) SI-G1 720 MODULES.
2) THE SYSTEM WILL FEATURE (2) FRONIUS IG PLUS 11.4-3 208V INVERTERS.
3) INVERTER(S) IS/ARE 95.5% EFFICIENT.
4) TOTAL SYSTEM SIZE IS:
20.592 kW DC STC
18.586 kW AC PTC
REVISION HISTORY:
EQUIPMENT PLAN
PV-5
SCALE: VARIES

Appendix C
ROOFER EMS Check List

BC L 1	Loss of protective coating or light corrosion.
BC L 2	Distortion of joint covers.
BC L 3	Top of flashing is less than 6 inches above roof surface
BC L 4	Exposed fastener
BC M 1	Joint cover is unbonded to metal BF, but does not allow water to penetrate
BC M 2	Coated metal BF fastener are loose
BC M 3	Coated metal BF has pulled away from wall or curb has lifted up but top termination is watertight.
BC M 4	Crazing or eroding of the joint cover material that has not worn through and does not allow water to penetrate.
BC M 5	Coated metal BF has repairs made with dissimilar materials.
BC H 1	Holes in metal BF
BC H 2	Hole in joint cover or unbonding of joint cover from metal BF, allowing water to penetrate.
BC H 3	Exposed gaps at top termination of BF
BC H 4	Coated metal BF has pulled away from wall or curb or has lifted up, allowing water to penetrate.

BF L 1	Light crazing or eroding of the BF
BF L 2	Top of BF is less than 6 inches above the roof surface.
BF L 3	Nailing strip or flashing batten with exposed fastener is <6 in above roof surface.
BF L 4	Seam or side lap is open less than .5 inch
BF L 5	Flashing has temporary repairs.
BF M 1	Crazing or eroding of BF that has worn through to a reinforcement or scrim sheet or down to another layer of different color, or has resulted in loss of sheet thickness.
BF M 2	Slippage, wrinkling, blistering, pulling, unbonding, or bridging of BF that does not allow water to penetrate.
BF M 3	Grease, solvent, or oil drippings on the BF with deterioration of BF but does not allow water to penetrate

BF M 4	Flashing has repairs made with dissimilar materials.
BF M 5	Seam or side lap is open more than .5 inch, but does not allow water to penetrate.
BF M 6	Loose or missing termination bar where no counterflashing is used.
BF M 7	Loose or missing nailing strip
BF H 1	Crazing or eroding of BF that has worn through the flashing allowing water to penetrate.
BF H 2	Holes, splits, or tears in flashing caused by deterioration or physical damage.
BF H 3	Exposed gaps at the top of the BF.
BF H 4	Seam or side lap is open through its entire width, allowing water to penetrate.
BF H 5	Holes through the BF caused by solvents, oils, or other chemicals.

DR L 1	Field seam within 1 ft of drain or roof level scupper
DR L 2	Stripping material or membrane is open less than 1/2 inch
DR M 1	Stripping material is crazing, checked or cracked
DR M 2	Stripping material or membrane is open 1/2 inch or more, but does not allow water to penetrate.
DR M 3	Strainer is broken or missing.
DR M 4	Scupper shows loss of protective coating or start of metal corrosion
DR M 5	Drain has a field seam in the clamping ring
DR H 1	Stripping material has holes, cuts, or tears, allowing water to penetrate
DR H 2	Stripping material or membrane is open, allowing water to penetrate
DR H 3	Clamping ring is loose or missing from drain or bolts are missing
DR H 4	Drain is clogged
DR H 5	Scupper is broken or contains holes
DR H 6	Holes, cuts, tears, or abrasions through the membrane within 2 feet of drain or scupper

DS L 1	Missing lap sealant at field seam (EPDM and PVC membranes only)
DS L 2	Missing lap sealant at field seam which has exposed reinforcement material at seam edge.
DS L 3	Seam is open less than 1/2 inch

DS L 4	Wrinkling at seam that is watertight.
DS L 5	Seam intersections on EPDM that do not have a patch covering them
DS L 6	Blisters within the seam
DS M 1	Seam is open 1/2 inch or more, but does not allow water to penetrate
DS M 2	Pinch wrinkle at seam
DS H 1	Seam is open through its entire depth, allowing water to penetrate
DS H 2	Fishmouths, wrinkles, or bunches at the seam that allow water to penetrate.

DV M 1	Evidence of vegetation, but not penetrating the felts.
DV M 2	Grease solvent or oil drippings on roof which show no degradation of the roof membrane.
DV M 3	The collection of foreign objects which are not removed from the roof during the inspection.
DV H 1	Vegetation roots that have penetrated the felts.
DV H 2	Grease solvent or oil drippings on roof which have caused degradation of the roof membrane allowing water to penetrate

EM L 1	Loss of protective coating or light corrosion
EM L 2	Termination battons have exposed fastener
EM L 3	Stripping material is open less than 1/2 inch
EM L 4	Distortion of joint covers
EM L 5	For coated metal edge flashings that are not stripped in, membrane is open < 1/2 in
EM M 1	Joint cover is unbonded to embedded edge material, but does not allow water to penetrate
EM M 2	Nails under the stripping felts are backing out.
EM M 3	Stripping material is crazing, checked or cracked
EM M 4	Stripping material is open more than 1/2 inch, but metal fasteners not exposed
EM M 5	Loose or lifted metal with deterioration of stripping material
EM M 6	Embrittled joint stripping material
EM M 7	The entire length of interior gutter is rated medium as a minimum due to leak potential

EM M 8	For coated metal edge flashings that are not stripped in, membrane is open more than 1/2 inch but does not allow water to penetrate
EM H 1	Stripping material is missing or open and edge metal fastener are exposed, or stripping material has holes, cuts or tears, allowing water penetrate.
EM H 2	Hole in joint cover or unbonding of joint cover from embedded edge metal, allowing water to penetrate.
EM H 3	Holes have occurred through the metal.
EM H 4	Holes associated with loose or lifted embedded edge metal
EM H 5	Holes in interior gutter
EM H 6	For coated metal edge flashings that are not stripped in, membrane is open allowing water to penetrate

EQ L 1	All improper EQ supports are rated low as a minimum due to maintenance problems.
EQ M 1	Movement of the support has caused displacement of the roof surfacing but has not damaged the membrane.
EQ M 2	The equipment is bolted through the membrane but the bolts appear to be sealed.
EQ H 1	The support has caused damage to the roof membrane.
EQ H 2	The equipment is bolted through the membrane but the bolts appear not to be sealed.

FP L 1	Flashing sleeve is deformed.
FP L 2	Stripping material, boot, or membrane is open less than 1/2 inch
FP L 3	Opening in the penetration or flashing is less than 6 inches above the roof surface.
FP M 1	Stripping material is crazing, checked or cracked
FP M 2	Stripping material, boot, or membrane is open more than 1/2 inch but does not allow water to penetrate flashing
FP M 3	Top of flashing sleeve or boot is not sealed or is not rolled down into the existing plumbing vent
FP M 4	Clamping band is loose or missing (where required)
FP M 5	Umbrella is open or no umbrella is present (where required)
FP M 6	Corrosion of metal or delamination of coating.

FP H 1	Stripping material has holes, cuts or tears
FP H 2	Stripping material, boot, or membrane is open, allowing water to penetrate
FP H 3	Holes, cuts, or tears in flashing sleeve or metal curb
FP H 4	No flashing sleeve is present
FP H 5	Incompatible flashing material has been used

HL L 1	Surface scratches or abrasions with no significant loss of membrane thickness
HL M 1	Cuts, gouges, or abrasions with loss of membrane thickness but not fully penetrating the membrane
HL H 1	Holes, cuts, gouges, or abrasions that penetrate the membrane
HL H 2	Holes through the membrane caused by underlying mechanical fastener.

MC L 1	Loss of protective coating or corrosion without holes
MC L 2	Top of counterflashing or metal coping is deformed and allows water to pond on top
MC L 3	Metal cap flashing is deformed but still performing its function
MC L 4	MC has been sealed to the base flashing
MC M 1	Corrosion holes have occurred through the metal on a vertical surface.
MC M 2	Metal coping cap has loose fasteners, failure of soldered or sealed joints, open joints, or loss of attachment.
MC M 3	MC has rough edges that are in contact with base flashing
MC H 1	Metal coping cap or counterflashing is missing or displaced from its original position.
MC H 2	Corrosion holes have occurred through the metal on a horizontal surface.
MC H 3	Metal coping cap has open joints or missing joint covers where they were originally installed
MC H 4	Sealant at reglet or top of counterflashing is missing or no longer functional, allowing water to channel behind it.
MC H 5	Counterflashing is loose at the top allowing water to channel behind it
MC H 6	MC does not extend over top of BF

MD L 1	Light crazing of membrane surface

MD M 1	Crazing or eroding of the membrane surface that has worn through to a reinforcement or scrim sheet or down to another layer of different color, or loss of sheet thickness
MD H 1	Crazing or eroding of the membrane surface that has worn through the membrane allowing water to penetrate.

MS L 1	Membrane tension caused by warping or bowing of substrate
MS L 2	Uneven joints or gaps more than 1/2 inch wide, but less than 2 inches b/w insulation boards.
MS M 1	Uneven joints or gaps more than 2 inches wide b/w insulation boards or absence of substrate support for width of 2 inches or more.
MS M 2	For ballasted systems, insulation boards have been displaced
MS M 3	Lumps indicating presence of foreign material between membrane and substrate.

PA L 1	All patches not made with similar materials as of original construction are rated low as a minimum.
PA M 1	All patches made with temporary materials (duct tape, caulkings) are rated medium
PA H 1	Ruptures or other membrane distresses are present within the patched areas.

PD L 1	General ponding is rated low due to maintenance problems.
PD M 1	Ponding caused by wrinkles or folds in membrane that block drainage
PD M 2	Ponding caused by warping or bowing of the substrate beneath the membrane

PP L 1	Low severity due to maintenance problems.
PP M 1	Stripping material is crazing, checked or cracked
PP M 2	Stripping material or membrane is open more than 1/2 inch but does not allow water to penetrate.
PP M 3	Loss of protective coating or corrosion of metal
PP M 4	For EPDM and Hypalon, stripping material is not covering the top of the metal pan or does not terminate below the sealer
PP H 1	Stripping material has holes, cuts, or tears allowing water to penetrate through

PP H 2	Edge of stripping material or membrane is open, allowing water to penetrate
PP H 3	Sealer is below the metal rim, allowing ponding in pan
PP H 4	Sealer has cracked or separated from the pan or penetration
PP H 5	Corrosion through the metal pan

RG L 1	All ridges are rated low as a minimum
RG H 1	Open breaks have developed in the ridge allowing water to penetrate.

SC L 1	Color of underlying membrane can be seen through the coating or membrane has lost coating protection.
SC M 1	Membrane area has lost the sand or mineral matter portion of the coating protection.

SP H 1	An unrepaired split or a repaired split which has started to reopen.

SS L 1	For fully adhered systems, an area of unattached membrane or substrate of 2 sf or less
SS L 2	For ballasted systems, a bare area of 4 sf or less
SS M 1	For fully adhered systems, an area of unattache membrane or substrate greater than 2 sf but less than 100 sf
SS M 2	For mechanically attached systems, an isolated mechanical fastener that has lost its attachment capability or backed out causing bridging of the membrane
SS M 3	For partially adhered systems, an isolated point of attachmen that has lost adherence
SS M 4	For ballasted systems, a bare area of greater than 4 but less than 100 sf
SS H 1	For fully adhered systems, an area of unattached membrane or substrate 100 sf or greater
SS H 2	For mechanically attached systems, adjacent mechanical fastener that have lost their attachmen capabilities or backed out causing bridging of the membrane
SS H 3	For partially adhered systems, adjacent points of attachment that have lost adherence
SS H 4	For ballasted systems, a bare area of 100 sf or greater.

Appendix D
Site III (MCAS Yuma) Energy Usage Monitoring Points

For the energy monitoring at Site III, data will be collected for both the control and test conditions as described as follows:

MONITORING POINTS			
No.	*Name*	*Purpose*	*Location*
1	TR-1	Roof surface temperature	Location 1 on the roof
2	TR-2	Roof surface temperature	Location 2 on the roof
2a	TR-2a	BIPV surface temperature	Location 2 on the BIPV surface
3	TR-3	Roof surface temperature	Location 3 on the roof
3a	TR-3a	BIPV surface temperature	Location 3 on the BIPV surface
4	TR-4	Roof surface temperature	Location 4 on the roof
4a	TR-4a	BIPV surface temperature	Location 4 on the BIPV surface
5	TU-1	Roof underside temperature	Location 1 inside the attic
6	TU-2	Roof underside temperature	Location 2 inside the attic
7	TU-3	Roof underside temperature	Location 3 inside the attic
8	TU-4	Roof underside temperature	Location 4 inside the attic
9	TP-1	Plenum air temperature	Location 1 inside the attic
10	TP-2	Plenum air temperature	Location 2 inside the attic
11	TP-3	Plenum air temperature	Location 3 inside the attic
12	TP-4	Plenum air temperature	Location 4 inside the attic
13	TI-1	Interior air temperature	Location 1 six inches from the ceiling
14	TI-2	Interior air temperature	Location 2 six inches from the ceiling
15	TI-3	Interior air temperature	Location 3 six inches from the ceiling
16	TI-4	Interior air temperature	Location 4 six inches from the ceiling
17	HF-1	Heat flux through roof	Location 1 installed under the roof in the attic
18	HF-2	Heat flux through roof	Location 2 installed under the roof in the attic
18a	HF-2a	Heat flux through BIPV	Location 2 installed under the BIPV over the roof

19	HF-3	Heat flux through roof	Location 3 installed under the roof in the attic
19a	HF-3a	Heat flux through BIPV	Location 3 installed under the BIPV over the roof
20	HF-4	Heat flux through roof	Location 4 installed under the roof in the attic
20a	HF-4a	Heat flux through BIPV	Location 4 installed under the BIPV over the roof
21	WAC-1	A/C 1 power	Air conditioning 1, Central panel
22	WAC-2	A/C 2 power	Air conditioning 2, Central panel
23	WAH-1	A/H 1 power	Air handler 1, Central panel
24	WAH-2	A/H 2 power	Air handler 2, Central panel
25	WCT-1	Cooling Tower 1 power	Cooling tower 1, Central panel
26	WCT-2	Cooling Tower 1 power	Cooling tower 1, Central panel
27	WLIT	Lights power	Central panel
28	WTOT	Total building power	Central panel
29	WBIPV-1	BIPV-1 power	Central panel
30	WBIPV-2	BIPV-2 power	Central panel
31	WBIPV-3	BIPV-3 power	Central panel
32	TAO	Outdoor dry bulb temperature	Weather tower on the roof
33	RHO	Outdoor relative humidity	Weather tower on the roof
34	HSOL	Total horizontal insolation	Weather tower on the roof

Appendix E
Site I (Luke AFB) ROOFER Survey Results

2008 ROOFER Assessment

2008 Section A

Maintenance, Repair & Replacement Analysis

Building:	1 - Base Exchange	Area Cost Index:	$2.00
Section:	A	Roof Replacement Cost:	$25.00 per SF
Section Area:	33180	Insulation Replacement Cost:	$10.00 per SF
Roofing Type:	SINGLE-PLY: PVC		

Originally Constructed/Last Replaced:	2006	Visual Inspection Date:	7/21/2008
Current Age: 3 Year(s)		Insulation Inspection Date:	--------

Predicted Year of Replacement (w/o repairs):		2013					
Additional Service Life (w/repairs):		13	Year(s)			Current	Improved
Predicted Year of Replacement (w/repairs):		2026			RCI	95	98
					FCI	95	100
Cost for Repairs:	$	4580.00	352.31	$/year	MCI	94	97
Cost for Replacement:	$	829500.00	41475.00	$/year	100	100	

Adjusted Repair/Replace Ratio = 0.04 Recommendation: Repair

Corrective Action Requirement Sheet

Major Repair

(Note: Attach a copy of this form, along with a copy of the Roof Inspection Worksheet to DA Form 4283

Agency/Inst.:	COMM - Commissary	Facility No:	1
Bldg No./Sec:	1 A	Bldg Name:	Base Exchange
Bldg Use:		Inspection Date:	Jul/2008
Membrane:	SINGLE-PLY: PVC	Area (SF):	33180
Surfacing:	None	Age (Yrs):	3
Vapor Ret:	NONE	Deck Type:	STEEL
Insulation:	POLYISOCYANURATE	Est. Repair Cost:	$ 4580.00

CORRECTIVE ACTION RECOMMENDED: Maintenance, Repair and/or Partial Replacement

JUSTIFICATION: An economic analysis of the roof condition, including age, indicates that it is more cost effective to accomplish the necessary maintenance, repairs and/or partial replacement of the roofing components rather than replace the roofing system. Therefore, accomplish the following actions for the above roof section.

[Note: numbers refer to identification numbers of distresses corresponding with the Roof Inspection Worksheet]

1. MC-M-1 1 LF — Clean and patch holes in metal cap flashing and coat surface with corrosion resistant paint. [1]

2. BF-M-2 3 LF — Prepare surface of base flashing, peel back and re-glue. Fasten top edge. [2]

4. SS-M-1 50 SF — Cut unadhered membrane, clean and prepare surface, readhere and install membrane patch over repair area. [4]

6. PD-M-2 20 SF — Cut membrane over underlying bowed insulation, remove insulation and replace. Clean and prepare surface and patch repair with new membrane. [6]

Economic Evaluation Worksheet for a Single-Ply Roofing System

Agency/Inst: COMM - Commissary | Building/Section: 1 A | Area: 33180 SF | Age: 3

Total Repair Costs / Additional Service Life	$ 4580 / 13 Yrs		Replacement Cost @ $25.00/SF	$	829500
Total Repair Cost/ Additional Service Life	$ 352.31	$/Yr	Replacement Cost/20 Years	$	41475 $/Yr

Cost Analysis — Generated: Feb/03/2009

Ratio = Repair Cost/Year / Replace Cost/Year = 0.01

Adjusted Ratio = Ratio + (0.01 * Age) = 0.04

Adjusted Ratio	Recommended Action
0 - 0.8	Repair
0.8 - 1.2	Marginal
> 1.2	Replace

Membrane

DIS-SL-DF	Unit Cost	Qty	Total Cost	DIS-SL-DF	Unit Cost	Qty	Total Cost
DS-H-1	29.18			MS-M-1	33.60		
DS-H-2	35.42			MS-M-2	39.42		
DS-M-1	24.74			MS-M-3	26.18		
DS-M-2	35.42			PA-H-1	33.98		
DV-H-1	42.66			PA-M-1	33.98		
DV-H-2	42.66			PD-M-1	32.22		
DV-M-1	5.86			PD-M-2	59.54	20	$ 1190.80
DV-M-2	42.66			RG-H-1	24.10		
DV-M-3	5.86			SC-M-1	19.88		
EQ-H-1	89.92			SP-H-1	24.10		
EQ-H-2	81.94			SS-H-1	35.96		
EQ-M-1	41.90			SS-H-2	27.58		
EQ-M-2	81.94			SS-H-3	27.72		
HL-H-1	66.54			SS-H-4	5.68		
HL-H-2	29.52			SS-M-1	35.96	50	$ 1798.00
HL-M-1	14.30			SS-M-2	27.58		
MD-H-1	25.04			SS-M-3	27.72		
MD-M-1	14.46			SS-M-4	5.68		

Economic Evaluation Worksheet for a Single-Ply Roofing System

Agency/Inst: COMM - Commissary | Building/Section: 1 A | Area: 33180 SF | Age: 3

Flashing

DIS-SL-DF	Unit Cost	Qty	Total Cost	DIS-SL-DF	Unit Cost	Qty	Total Cost
BC-H-1	51.76			EM-H-1	19.24		
BC-H-2	47.78			EM-H-2	70.76		
BC-H-3	20.84			EM-H-3	36.18		
BC-H-4	152.08			EM-H-4	31.10		
BC-M-1	47.78			EM-H-5	39.50		
BC-M-2	29.90			EM-H-6	21.44		
BC-M-3	20.84			EM-M-1	21.44		
BC-M-4	47.78			EM-M-2	30.00		
BC-M-5	44.36			EM-M-3	10.76		
BF-H-1	36.54			EM-M-4	17.34		
BF-H-2	36.54			EM-M-5	32.06		
BF-H-3	19.16			EM-M-6	32.82		
BF-H-4	34.32			EM-M-7	39.50		
BF-H-5	62.26			EM-M-8	20.20		
BF-M-1	11.10			FP-H-1	28.70		
BF-M-2	24.88	3	$ 74.64	FP-H-2	17.34		
BF-M-3	62.26			FP-H-3	118.22		
BF-M-4	39.80			FP-H-4	105.32		
BF-M-5	35.62			FP-H-5	118.22		
BF-M-6	19.16			FP-M-1	10.76		
BF-M-7	43.94			FP-M-2	17.34		
DR-H-1	58.66			FP-M-3	5.74		
DR-H-2	76.62			FP-M-4	16.24		
DR-H-3	88.44			FP-M-5	49.16		
DR-H-4	86.08			FP-M-6	43.40		
DR-H-5	187.54			MC-H-1	15.20		
DR-H-6	190.94			MC-H-2	15.20		
DR-M-1	10.76			MC-H-3	18.84		
DR-M-2	17.34			MC-H-4	13.24		
DR-M-3	64.14			MC-H-5	18.92		
DR-M-4	39.10			MC-H-6	9.78		
DR-M-5	174.08			MC-M-1	15.52	1	$ 15.52

Economic Evaluation Worksheet for a Single-Ply Roofing System

Agency/Inst: COMM - Commissary | Building/Section: 1 A | Area: 33180 SF | Age: 3

Flashing

DIS-SL-DF	Unit Cost	Qty	Total Cost	DIS-SL-DF	Unit Cost	Qty	Total Cost
MC-M-2	7.10						
MC-M-3	9.98						
PP-H-1	58.66						
PP-H-2	76.62						
PP-H-3	73.42						
PP-H-4	107.86						
PP-H-5	264.70						
PP-M-1	10.76						
PP-M-2	17.34						
PP-M-3	43.40						
PP-M-4	264.70						

Insulation: 0.00 NONE

Repair SetUp Charge = $ 1500

2008 Section B

Maintenance, Repair & Replacement Analysis

Building:	1 - Base Exchange	Area Cost Index:	$2.00
Section:	B	Roof Replacement Cost:	$25.00 per SF
Section Area:	39900	Insulation Replacement Cost:	$10.00 per SF
Roofing Type:	SINGLE-PLY: PVC		

Originally Constructed/Last Replaced:	2006	Visual Inspection Date:	7/21/2008
Current Age:	3 Year(s)	Insulation Inspection Date:	--------

Predicted Year of Replacement (w/o repairs):			2010				
Additional Service Life (w/repairs):			16	Year(s)		Current	Improved
Predicted Year of Replacement (w/repairs):			2026		RCI	86	98
					FCI	81	99
Cost for Repairs:	$	3444.00	215.25	$/year	MCI	97	97
Cost for Replacement:	$	997500.00	49875.00	$/year	100	100	

Adjusted Repair/Replace Ratio = 0.03 Recommendation: Repair

Corrective Action Requirement Sheet

Major Repair

(Note: Attach a copy of this form, along with a copy of the Roof Inspection Worksheet to DA Form 4283

Agency/Inst.:	COMM - Commissary	Facility No:	1
Bldg No./Sec:	1 B	Bldg Name:	Base Exchange
Bldg Use:		Inspection Date:	Jul/2008
Membrane:	SINGLE-PLY: PVC	Area (SF):	39900
Surfacing:	None	Age (Yrs):	3
Vapor Ret:	NONE	Deck Type:	STEEL
Insulation:	POLYISOCYANURATE	Est. Repair Cost:	$ 3444.00

CORRECTIVE ACTION RECOMMENDED: Maintenance, Repair and/or Partial Replacement

JUSTIFICATION: An economic analysis of the roof condition, including age, indicates that it is more cost effective to accomplish the necessary maintenance, repairs and/or partial replacement of the roofing components rather than replace the roofing system. Therefore, accomplish the following actions for the above roof section.

[Note: numbers refer to identification numbers of distresses corresponding with the Roof Inspection Worksheet]

2.	DV-M-1 4 SF	Clean membrane surface of dirt and vegetation. [2]
3.	DR-M-3 10 LF	Replace broken drain strainer with new strainer. [3]
5.	DV-M-2 30 SF	Remove chemically damaged membrane, clean and prepare surface and install membrane patch over repair area. [5]

Economic Evaluation Worksheet for a Single-Ply Roofing System

Agency/Inst: COMM - Commissary	Building/Section: 1 B	Area: 39900 SF	Age: 3

Total Repair Costs Additional Service Life	$ 3444 16 Yrs	Replacement Cost @ $25.00/SF	$ 997500
Total Repair Cost/ Additional Service Life	$ 215.25 $/Yr	Replacement Cost/20 Years	$ 49875 $/Yr

Cost Analysis

Generated: Feb/03/2009

$$\text{Ratio} = \frac{\text{Repair Cost/Year}}{\text{Replace Cost/Year}} = 0.00$$

Adjusted Ratio = Ratio + (0.01 * Age) = 0.03

Adjusted Ratio	Recommended Action
0 - 0.8	Repair
0.8 - 1.2	Marginal
> 1.2	Replace

Membrane

DIS-SL-DF	Unit Cost	Qty	Total Cost
DS-H-1	29.18		
DS-H-2	35.42		
DS-M-1	24.74		
DS-M-2	35.42		
DV-H-1	42.66		
DV-H-2	42.66		
DV-M-1	5.86	4	$ 23.44
DV-M-2	42.66	30	$ 1279.80
DV-M-3	5.86		
EQ-H-1	89.92		
EQ-H-2	81.94		
EQ-M-1	41.90		
EQ-M-2	81.94		
HL-H-1	66.54		
HL-H-2	29.52		
HL-M-1	14.30		
MD-H-1	25.04		
MD-M-1	14.46		
MS-M-1	33.60		
MS-M-2	39.42		
MS-M-3	26.18		
PA-H-1	33.98		
PA-M-1	33.98		
PD-M-1	32.22		
PD-M-2	59.54		
RG-H-1	24.10		
SC-M-1	19.88		
SP-H-1	24.10		
SS-H-1	35.96		
SS-H-2	27.58		
SS-H-3	27.72		
SS-H-4	5.68		
SS-M-1	35.96		
SS-M-2	27.58		
SS-M-3	27.72		
SS-M-4	5.68		

Economic Evaluation Worksheet for a Single-Ply Roofing System

Agency/Inst: COMM - Commissary	Building/Section: 1 B	Area: 39900 SF	Age: 3

Flashing

DIS-SL-DF	Unit Cost	Qty	Total Cost
BC-H-1	51.76		
BC-H-2	47.78		
BC-H-3	20.84		
BC-H-4	152.08		
BC-M-1	47.78		
BC-M-2	29.90		
BC-M-3	20.84		
BC-M-4	47.78		
BC-M-5	44.36		
BF-H-1	36.54		
BF-H-2	36.54		
BF-H-3	19.16		
BF-H-4	34.32		
BF-H-5	62.26		
BF-M-1	11.10		
BF-M-2	24.88		
BF-M-3	62.26		
BF-M-4	39.80		
BF-M-5	35.62		
BF-M-6	19.16		
BF-M-7	43.94		
DR-H-1	58.66		
DR-H-2	76.62		
DR-H-3	88.44		
DR-H-4	86.08		
DR-H-5	187.54		
DR-H-6	190.94		
DR-M-1	10.76		
DR-M-2	17.34		
DR-M-3	64.14	10	$ 641.40
DR-M-4	39.10		
DR-M-5	174.08		
EM-H-1	19.24		
EM-H-2	70.76		
EM-H-3	36.18		
EM-H-4	31.10		
EM-H-5	39.50		
EM-H-6	21.44		
EM-M-1	21.44		
EM-M-2	30.00		
EM-M-3	10.76		
EM-M-4	17.34		
EM-M-5	32.06		
EM-M-6	32.82		
EM-M-7	39.50		
EM-M-8	20.20		
FP-H-1	28.70		
FP-H-2	17.34		
FP-H-3	118.22		
FP-H-4	105.32		
FP-H-5	118.22		
FP-M-1	10.76		
FP-M-2	17.34		
FP-M-3	5.74		
FP-M-4	16.24		
FP-M-5	49.16		
FP-M-6	43.40		
MC-H-1	15.20		
MC-H-2	15.20		
MC-H-3	18.84		
MC-H-4	13.24		
MC-H-5	18.92		
MC-H-6	9.78		
MC-M-1	15.52		

Economic Evaluation Worksheet for a Single-Ply Roofing System

Agency/Inst: COMM - Commissary	Building/Section: 1 B	Area: 39900 SF	Age: 3

Flashing

DIS-SL-DF	Unit Cost	Qty	Total Cost
MC-M-2	7.10		
MC-M-3	9.98		
PP-H-1	58.66		
PP-H-2	76.62		
PP-H-3	73.42		
PP-H-4	107.86		
PP-H-5	264.70		
PP-M-1	10.76		
PP-M-2	17.34		
PP-M-3	43.40		
PP-M-4	264.70		

Insulation: 0.00 NONE

Repair SetUp Charge = $ 1500

2008 Section C

Maintenance, Repair & Replacement Analysis

Building:	1 - Base Exchange	Area Cost Index:	$2.00
Section:	C	Roof Replacement Cost:	$25.00 per SF
Section Area:	35340	Insulation Replacement Cost:	$10.00 per SF
Roofing Type:	SINGLE-PLY: PVC		

Originally Constructed/Last Replaced:	2006	Visual Inspection Date:	7/21/2008
Current Age:	3 Year(s)	Insulation Inspection Date:	--------

Predicted Year of Replacement (w/o repairs):		2015					
Additional Service Life (w/repairs):		11	Year(s)			Current	Improved
Predicted Year of Replacement (w/repairs):		2026			RCI	97	98
					FCI	100	100
Cost for Repairs:	$	1535.00	139.55	$/year	MCI	96	97
Cost for Replacement:	$	883500.00	44175.00	$/year	100	100	

Adjusted Repair/Replace Ratio = 0.03 Recommendation: Repair

Major Repair

(Note: Attach a copy of this form, along with a copy of the Roof Inspection Worksheet to DA Form 4283

Agency/Inst.:	COMM - Commissary	Facility No:	1
Bldg No./Sec:	1 C	Bldg Name:	Base Exchange
Bldg Use:		Inspection Date:	Jul/2008
Membrane:	SINGLE-PLY: PVC	Area (SF):	35340
Surfacing:	None	Age (Yrs):	3
Vapor Ret:	None	Deck Type:	STEEL
Insulation:	POLYISOCYANURATE	Est. Repair Cost:	$ 1535.00

CORRECTIVE ACTION RECOMMENDED: Maintenance, Repair and/or Partial Replacement

JUSTIFICATION: An economic analysis of the roof condition, including age, indicates that it is more cost effective to accomplish the necessary maintenance, repairs and/or partial replacement of the roofing components rather than replace the roofing system. Therefore, accomplish the following actions for the above roof section.

[Note: numbers refer to identification numbers of distresses corresponding with the Roof Inspection Worksheet]

1. DV-M-1 6 SF Clean membrane surface of dirt and vegetation. [1]

Economic Evaluation Worksheet for a Single-Ply Roofing System

Agency/Inst: COMM - Commissary	Building/Section: 1 C	Area: 35340 SF	Age: 3

Total Repair Costs	$	1535	Replacement Cost @ $25.00/SF	$	883500
Additional Service Life		11 Yrs			
Total Repair Cost/ Additional Service Life	$	139.55 $/Yr	Replacement Cost/20 Years	$	44175 $/Yr

Cost Analysis — Generated: Feb/03/2009

Ratio = Repair Cost/Year / Replace Cost/Year = 0.00

Adjusted Ratio = Ratio + (0.01 * Age) = 0.03

Adjusted Ratio	Recommended Action
0 - 0.8	Repair
0.8 - 1.2	Marginal
> 1.2	Replace

Membrane

DIS-SL-DF	Unit Cost	Qty	Total Cost	DIS-SL-DF	Unit Cost	Qty	Total Cost
DS-H-1	29.18			MS-M-1	33.60		
DS-H-2	35.42			MS-M-2	39.42		
DS-M-1	24.74			MS-M-3	26.18		
DS-M-2	35.42			PA-H-1	33.98		
DV-H-1	42.66			PA-M-1	33.98		
DV-H-2	42.66			PD-M-1	32.22		
DV-M-1	5.86	6	$ 35.16	PD-M-2	59.54		
DV-M-2	42.66			RG-H-1	24.10		
DV-M-3	5.86			SC-M-1	19.88		
EQ-H-1	89.92			SP-H-1	24.10		
EQ-H-2	81.94			SS-H-1	35.96		
EQ-M-1	41.90			SS-H-2	27.58		
EQ-M-2	81.94			SS-H-3	27.72		
HL-H-1	66.54			SS-H-4	5.68		
HL-H-2	29.52			SS-M-1	35.96		
HL-M-1	14.30			SS-M-2	27.58		
MD-H-1	25.04			SS-M-3	27.72		
MD-M-1	14.46			SS-M-4	5.68		

Economic Evaluation Worksheet for a Single-Ply Roofing System

Agency/Inst: COMM - Commissary	Building/Section: 1 C	Area: 35340 SF	Age: 3

Flashing

DIS-SL-DF	Unit Cost	Qty	Total Cost	DIS-SL-DF	Unit Cost	Qty	Total Cost
BC-H-1	51.76			EM-H-1	19.24		
BC-H-2	47.78			EM-H-2	70.76		
BC-H-3	20.84			EM-H-3	36.18		
BC-H-4	152.08			EM-H-4	31.10		
BC-M-1	47.78			EM-H-5	39.50		
BC-M-2	29.90			EM-H-6	21.44		
BC-M-3	20.84			EM-M-1	21.44		
BC-M-4	47.78			EM-M-2	30.00		
BC-M-5	44.36			EM-M-3	10.76		
BF-H-1	36.54			EM-M-4	17.34		
BF-H-2	36.54			EM-M-5	32.06		
BF-H-3	19.16			EM-M-6	32.82		
BF-H-4	34.32			EM-M-7	39.50		
BF-H-5	62.26			EM-M-8	20.20		
BF-M-1	11.10			FP-H-1	28.70		
BF-M-2	24.88			FP-H-2	17.34		
BF-M-3	62.26			FP-H-3	118.22		
BF-M-4	39.80			FP-H-4	105.32		
BF-M-5	35.62			FP-H-5	118.22		
BF-M-6	19.16			FP-M-1	10.76		
BF-M-7	43.94			FP-M-2	17.34		
DR-H-1	58.66			FP-M-3	5.74		
DR-H-2	76.62			FP-M-4	16.24		
DR-H-3	88.44			FP-M-5	49.16		
DR-H-4	86.08			FP-M-6	43.40		
DR-H-5	187.54			MC-H-1	15.20		
DR-H-6	190.94			MC-H-2	15.20		
DR-M-1	10.76			MC-H-3	18.84		
DR-M-2	17.34			MC-H-4	13.24		
DR-M-3	64.14			MC-H-5	18.92		
DR-M-4	39.10			MC-H-6	9.78		
DR-M-5	174.08			MC-M-1	15.52		

Economic Evaluation Worksheet for a Single-Ply Roofing System

Agency/Inst: COMM - Commissary	Building/Section: 1 C	Area: 35340 SF	Age: 3

Flashing

DIS-SL-DF	Unit Cost	Qty	Total Cost	DIS-SL-DF	Unit Cost	Qty	Total Cost
MC-M-2	7.10						
MC-M-3	9.98						
PP-H-1	58.66						
PP-H-2	76.62						
PP-H-3	73.42						
PP-H-4	107.86						
PP-H-5	264.70						
PP-M-1	10.76						
PP-M-2	17.34						
PP-M-3	43.40						
PP-M-4	264.70						

Insulation:				
0.00	NONE	Repair SetUp Charge =	$	1500

2008 Section D

Maintenance, Repair & Replacement Analysis

Building:	1 - Base Exchange	Area Cost Index:	$2.00
Section:	D	Roof Replacement Cost:	$25.00 per SF
Section Area:	30020	Insulation Replacement Cost:	$10.00 per SF
Roofing Type:	SINGLE-PLY: PVC		

Originally Constructed/Last Replaced:	2006	Visual Inspection Date:	7/21/2008
Current Age:	3 Year(s)	Insulation Inspection Date:	--------

Predicted Year of Replacement (w/o repairs):		2018					
Additional Service Life (w/repairs):		8	Year(s)		Current	Improved
Predicted Year of Replacement (w/repairs):		2026		RCI	98	98
				FCI	100	100
Cost for Repairs:	$	1523.00	190.38 $/year	MCI	97	97
Cost for Replacement:	$	750500.00	37525.00 $/year	100	100	

Adjusted Repair/Replace Ratio = 0.04 Recommendation: Repair

Corrective Action Requirement Sheet

Major Repair

(Note: Attach a copy of this form, along with a copy of the Roof Inspection Worksheet to DA Form 4283

Agency/Inst.:	COMM - Commissary	Facility No:	1
Bldg No./Sec:	1 D	Bldg Name:	Base Exchange
Bldg Use:		Inspection Date:	Jul/2008
Membrane:	SINGLE-PLY: PVC	Area (SF):	30020
Surfacing:	NONE	Age (Yrs):	3
Vapor Ret:	NONE	Deck Type:	STEEL
Insulation:	POLYISOCYANURATE	Est. Repair Cost:	$ 1523.00

CORRECTIVE ACTION RECOMMENDED: Maintenance, Repair and/or Partial Replacement

JUSTIFICATION: An economic analysis of the roof condition, including age, indicates that it is more cost effective to accomplish the necessary maintenance, repairs and/or partial replacement of the roofing components rather than replace the roofing system. Therefore, accomplish the following actions for the above roof section.

[Note: numbers refer to identification numbers of distresses corresponding with the Roof Inspection Worksheet]

1. DV-M-1 4 SF — Clean membrane surface of dirt and vegetation. [1]

Economic Evaluation Worksheet for a Single-Ply Roofing System

Agency/Inst: COMM - Commissary	Building/Section: 1 D	Area: 30020 SF	Age: 3

Total Repair Costs	$	1523		Replacement Cost @ $25.00/SF	$	750500
Additional Service Life		8	Yrs			
Total Repair Cost/ Additional Service Life	$	190.38	$/Yr	Replacement Cost/20 Years	$	37525 $/Yr

Cost Analysis

Generated: Feb/03/2009

$$\text{Ratio} = \frac{\text{Repair Cost/Year}}{\text{Replace Cost/Year}} = 0.01$$

Adjusted Ratio = Ratio + (0.01 * Age) = 0.04

Adjusted Ratio	Recommended Action
0 - 0.8	Repair
0.8 - 1.2	Marginal
> 1.2	Replace

Membrane

DIS-SL-DF	Unit Cost	Qty	Total Cost	DIS-SL-DF	Unit Cost	Qty	Total Cost
DS-H-1	29.18			MS-M-1	33.60		
DS-H-2	35.42			MS-M-2	39.42		
DS-M-1	24.74			MS-M-3	26.18		
DS-M-2	35.42			PA-H-1	33.98		
DV-H-1	42.66			PA-M-1	33.98		
DV-H-2	42.66			PD-M-1	32.22		
DV-M-1	5.86	4	$ 23.44	PD-M-2	59.54		
DV-M-2	42.66			RG-H-1	24.10		
DV-M-3	5.86			SC-M-1	19.88		
EQ-H-1	89.92			SP-H-1	24.10		
EQ-H-2	81.94			SS-H-1	35.96		
EQ-M-1	41.90			SS-H-2	27.58		
EQ-M-2	81.94			SS-H-3	27.72		
HL-H-1	66.54			SS-H-4	5.68		
HL-H-2	29.52			SS-M-1	35.96		
HL-M-1	14.30			SS-M-2	27.58		
MD-H-1	25.04			SS-M-3	27.72		
MD-M-1	14.46			SS-M-4	5.68		

Economic Evaluation Worksheet for a Single-Ply Roofing System

Agency/Inst: COMM - Commissary	Building/Section: 1 D	Area: 30020 SF	Age: 3

Flashing

DIS-SL-DF	Unit Cost	Qty	Total Cost	DIS-SL-DF	Unit Cost	Qty	Total Cost
BC-H-1	51.76			EM-H-1	19.24		
BC-H-2	47.78			EM-H-2	70.76		
BC-H-3	20.84			EM-H-3	36.18		
BC-H-4	152.08			EM-H-4	31.10		
BC-M-1	47.78			EM-H-5	39.50		
BC-M-2	29.90			EM-H-6	21.44		
BC-M-3	20.84			EM-M-1	21.44		
BC-M-4	47.78			EM-M-2	30.00		
BC-M-5	44.36			EM-M-3	10.76		
BF-H-1	36.54			EM-M-4	17.34		
BF-H-2	36.54			EM-M-5	32.06		
BF-H-3	19.16			EM-M-6	32.82		
BF-H-4	34.32			EM-M-7	39.50		
BF-H-5	62.26			EM-M-8	20.20		
BF-M-1	11.10			FP-H-1	28.70		
BF-M-2	24.88			FP-H-2	17.34		
BF-M-3	62.26			FP-H-3	118.22		
BF-M-4	39.80			FP-H-4	105.32		
BF-M-5	35.62			FP-H-5	118.22		
BF-M-6	19.16			FP-M-1	10.76		
BF-M-7	43.94			FP-M-2	17.34		
DR-H-1	58.66			FP-M-3	5.74		
DR-H-2	76.62			FP-M-4	16.24		
DR-H-3	88.44			FP-M-5	49.16		
DR-H-4	86.08			FP-M-6	43.40		
DR-H-5	187.54			MC-H-1	15.20		
DR-H-6	190.94			MC-H-2	15.20		
DR-M-1	10.76			MC-H-3	18.84		
DR-M-2	17.34			MC-H-4	13.24		
DR-M-3	64.14			MC-H-5	18.92		
DR-M-4	39.10			MC-H-6	9.78		
DR-M-5	174.08			MC-M-1	15.52		

Economic Evaluation Worksheet for a Single-Ply Roofing System

Agency/Inst: COMM - Commissary	Building/Section: 1 D	Area: 30020 SF	Age: 3

Flashing

DIS-SL-DF	Unit Cost	Qty	Total Cost	DIS-SL-DF	Unit Cost	Qty	Total Cost
MC-M-2	7.10						
MC-M-3	9.98						
PP-H-1	58.66						
PP-H-2	76.62						
PP-H-3	73.42						
PP-H-4	107.86						
PP-H-5	264.70						
PP-M-1	10.76						
PP-M-2	17.34						
PP-M-3	43.40						
PP-M-4	264.70						

Insulation:

0.00 NONE

Repair SetUp Charge = $ 1500

2010 ROOFER Assessment

2010 Section A

Date: MAR/26/2010	Visual Inspection Summary	Page 1

Installation: COMM - Commissary

Date Inspected:	03/18/2010	
Building:	1 - Base Exchange	
Section:	A - SE Section	
Roof Type:	Membrane	
Category Code:	44271	Supply Facilities Storage - Covered - Installation, and Organizational General Storage, Family Housing
Roof Section Area:	33180 SqFt	

Flashing Length:	414 Ft	Perimeter:	344 Ft	Curb:	70 Ft

FCI of Section:	96	Rating: Excellent
MCI of Section:	96	Rating: Excellent
ICI of Section:	None	Rating: None
RCI of Section:	97	Rating: ROUTINE MAINTENANCE ONLY

Flashing Distresses

Distress Type		Severity	Quantity	Density	Deduct
FP	FLASHED PEN	L	1	0.24	2.6
MC	METAL CAP	M	1	0.24	3.3

Membrane Distresses

Distress Type		Severity	Quantity	Density	Deduct
EQ	EQ SUPPORTS	L	10	0.03	2.2
PD	PONDING	L	20	0.06	2.6
SS	SYS. SECUREMENT	L	30	0.09	0.9

Remarks

2nd inspection done with cooler temperatures, the wrinkling was significantly reduced.

2010 Section B

Date: MAR/26/2010	**Visual Inspection Summary**	Page 1

Installation: COMM - Commissary

Date Inspected:	03/18/2010
Building:	1 - Base Exchange
Section:	B - SW Section
Roof Type:	Membrane

Category Code: 44271 Supply Facilities
Storage - Covered - Installation, and Organizational
General Storage, Family Housing

Roof Section Area: 39900 SqFt

Flashing Length: 580 Ft Perimeter: 400 Ft Curb: 180 Ft

FCI of Section:	95	Rating:	Excellent
MCI of Section:	97	Rating:	Excellent
ICI of Section:	None	Rating:	None
RCI of Section:	96	Rating:	ROUTINE MAINTENANCE ONLY

Flashing Distresses

Distress Type		Severity	Quantity	Density	Deduct
DR	DRAIN & SCUPPER	M	1	0.17	4.9
FP	FLASHED PEN	L	1	0.17	2.4
MC	METAL CAP	L	2	0.34	1.1

Membrane Distresses

Distress Type		Severity	Quantity	Density	Deduct
DV	DEBRIS & VEG	M	4	0.01	0.0
EQ	EQ SUPPORTS	L	10	0.03	1.7
PD	PONDING	L	20	0.05	2.5

2010 Section C

Date: MAR/26/2010	Visual Inspection Summary	Page 1

Installation: COMM - Commissary

Date Inspected:	03/18/2010	
Building:	1 - Base Exchange	
Section:	C - NW Section	
Roof Type:	Membrane	
Category Code:	44271	Supply Facilities Storage - Covered - Installation, and Organizational General Storage, Family Housing
Roof Section Area:	35340 SqFt	

Flashing Length:	556 Ft	Perimeter:	376 Ft	Curb:	180 Ft

FCI of Section:	100	Rating: Excellent
MCI of Section:	100	Rating: Excellent
ICI of Section:	None	Rating: None
RCI of Section:	100	Rating: ROUTINE MAINTENANCE ONLY

Flashing Distresses

Distress Type	Severity	Quantity	Density	Deduct
None				

Membrane Distresses

Distress Type	Severity	Quantity	Density	Deduct
DV DEBRIS & VEG	M	10	0.03	1.1

Date: MAR/26/2010	Visual Inspection Summary	Page 1

Installation: COMM - Commissary

Date Inspected:	03/18/2010	
Building:	1 - Base Exchange	
Section:	D - NE Section	
Roof Type:	Membrane	
Category Code:	44271	Supply Facilities Storage - Covered - Installation, and Organizational General Storage, Family Housing
Roof Section Area:	30020 SqFt	

Flashing Length:	408 Ft	Perimeter:	348 Ft	Curb:	60 Ft

FCI of Section:	100	Rating: Excellent
MCI of Section:	96	Rating: Excellent
ICI of Section:	None	Rating: None
RCI of Section:	97	Rating: ROUTINE MAINTENANCE ONLY

Flashing Distresses

Distress Type	Severity	Quantity	Density	Deduct
None				

Membrane Distresses

Distress Type		Severity	Quantity	Density	Deduct
DV	DEBRIS & VEG	M	8	0.03	1.1
PD	PONDING	L	60	0.20	2.8

2011 ROOFER Assessment

2011 Section A

Date: OCT/18/2011	**Visual Inspection Summary**	Page 1

Installation: COMM - Commissary

Date Inspected: 10/11/2011
Building: 1 - Base Exchange
Section: A - SE Section
Roof Type: Membrane

Category Code: 44271 Supply Facilities
Storage - Covered - Installation, and Organizational
General Storage, Family Housing

Roof Section Area: 33180 SqFt

Flashing Length: 414 Ft Perimeter: 344 Ft Curb: 70 Ft

FCI of Section:	94	Rating: Excellent
MCI of Section:	94	Rating: Excellent
ICI of Section:	None	Rating: None
RCI of Section:	95	Rating: ROUTINE MAINTENANCE ONLY

Flashing Distresses

Distress Type		Severity	Quantity	Density	Deduct
FP	FLASHED PEN	L	8	1.93	5.5
MC	METAL CAP	M	1	0.24	3.3

Membrane Distresses

Distress Type		Severity	Quantity	Density	Deduct
PD	PONDING	L	65	0.20	2.8
SS	SYS. SECUREMENT	M	50	0.15	3.9
SS	SYS. SECUREMENT	L	30	0.09	0.9

Maintenance, Repair & Replacement Analysis

Building:	1 - Base Exchange	Area Cost Index:	$2.00
Section:	A	Roof Replacement Cost:	$8.00 per SF
Section Area:	33180	Insulation Replacement Cost:	$12.00 per SF
Roofing Type:	SINGLE-PLY: PVC		

Originally Constructed/Last Replaced: 2006 Visual Inspection Date: 10/11/2011
Current Age: 5 Year(s) Insulation Inspection Date: --------

Predicted Year of Replacement (w/o repairs): 2024
Additional Service Life (w/repairs): 2 Year(s)
Predicted Year of Replacement (w/repairs): 2026

	Current	Improved
RCI	95	96
FCI	94	95
MCI	94	96
100	100	

Cost for Repairs:	$	2814.00	1407.00	$/year
Cost for Replacement:	$	265440.00	13272.00	$/year

Adjusted Repair/Replace Ratio = 0.16 Recommendation: Repair

2011 Section B

Date: OCT/18/2011	Visual Inspection Summary	Page 1

Installation: COMM - Commissary

Date Inspected:	10/11/2011	
Building:	1 - Base Exchange	
Section:	B - SW Section	
Roof Type:	Membrane	
Category Code:	44271	Supply Facilities Storage - Covered - Installation, and Organizational General Storage, Family Housing
Roof Section Area:	39900 SqFt	

Flashing Length:	580 Ft	Perimeter:	400 Ft	Curb:	180 Ft

FCI of Section:	89	Rating: Excellent
MCI of Section:	92	Rating: Excellent
ICI of Section:	None	Rating: None
RCI of Section:	91	Rating: ROUTINE MAINTENANCE ONLY

Flashing Distresses

Distress Type		Severity	Quantity	Density	Deduct
FP	FLASHED PEN	H	2	0.34	10.7

Membrane Distresses

Distress Type		Severity	Quantity	Density	Deduct
EQ	EQ SUPPORTS	L	170	0.43	6.1
PA	PATCHING	L	40	0.10	3.0
PD	PONDING	M	230	0.58	3.2
PD	PONDING	L	45	0.11	2.8

Maintenance, Repair & Replacement Analysis

Building:	1 - Base Exchange	Area Cost Index:	$2.00
Section:	B	Roof Replacement Cost:	$8.00 per SF
Section Area:	39900	Insulation Replacement Cost:	$12.00 per SF
Roofing Type:	SINGLE-PLY: PVC		

Originally Constructed/Last Replaced:	2006	Visual Inspection Date:	10/11/2011
Current Age:	5 Year(s)	Insulation Inspection Date:	--------

Predicted Year of Replacement (w/o repairs):		2020				
Additional Service Life (w/repairs):		6 Year(s)			Current	Improved
Predicted Year of Replacement (w/repairs):		2026		RCI	91	95
				FCI	89	100
Cost for Repairs:	$ 8446.00	1407.67	$/year	MCI	92	93
Cost for Replacement:	$ 319200.00	15960.00	$/year	100	100	

Adjusted Repair/Replace Ratio = 0.14   Recommendation: Repair

2011 Section C

Date: OCT/18/2011	**Visual Inspection Summary**	Page 1

Installation: COMM - Commissary

Date Inspected:	10/11/2011	
Building:	1 - Base Exchange	
Section:	C - NW Section	
Roof Type:	Membrane	
Category Code:	44271	Supply Facilities Storage - Covered - Installation, and Organizational General Storage, Family Housing
Roof Section Area:	35340 SqFt	

Flashing Length:	556 Ft	Perimeter:	376 Ft	Curb:	180 Ft

FCI of Section:	94	Rating: Excellent
MCI of Section:	96	Rating: Excellent
ICI of Section:	None	Rating: None
RCI of Section:	95	Rating: ROUTINE MAINTENANCE ONLY

Flashing Distresses

Distress Type		Severity	Quantity	Density	Deduct
DR	DRAIN & SCUPPER	M	1	0.18	5.1
FP	FLASHED PEN	M	1	0.18	4.2
FP	FLASHED PEN	L	1	0.18	2.4

Membrane Distresses

Distress Type		Severity	Quantity	Density	Deduct
DS	DEFECTIVE SEAMS	L	10	0.03	2.0
DV	DEBRIS & VEG	M	23	0.07	1.8
PD	PONDING	L	64	0.18	2.8

Maintenance, Repair & Replacement Analysis

Building:	1 - Base Exchange	Area Cost Index:	$2.00
Section:	C	Roof Replacement Cost:	$8.00 per SF
Section Area:	35340	Insulation Replacement Cost:	$12.00 per SF
Roofing Type:	SINGLE-PLY: PVC		

Originally Constructed/Last Replaced:	2006	Visual Inspection Date:	10/11/2011
Current Age:	5 Year(s)	Insulation Inspection Date:	--------

Predicted Year of Replacement (w/o repairs):		2024				
Additional Service Life (w/repairs):		4 Year(s)			Current	Improved
Predicted Year of Replacement (w/repairs):		2028		RCI	95	98
				FCI	94	98
Cost for Repairs:	$ 1248.00	312.00	$/year	MCI	96	97
Cost for Replacement:	$ 282720.00	14136.00	$/year	100	100	

Adjusted Repair/Replace Ratio = 0.07 Recommendation: Repair

2011 Section D

Date: OCT/18/2011	Visual Inspection Summary	Page 1

Installation: COMM - Commissary

Date Inspected:	10/11/2011	
Building:	1 - Base Exchange	
Section:	D - NE Section	
Roof Type:	Membrane	
Category Code:	44271	Supply Facilities Storage - Covered - Installation, and Organizational General Storage, Family Housing
Roof Section Area:	30020 SqFt	

Flashing Length:	408 Ft	Perimeter:	348 Ft	Curb:	60 Ft

FCI of Section:	100	Rating: Excellent
MCI of Section:	96	Rating: Excellent
ICI of Section:	None	Rating: None
RCI of Section:	97	Rating: ROUTINE MAINTENANCE ONLY

Flashing Distresses

Distress Type		Severity	Quantity	Density	Deduct
None					

Membrane Distresses

Distress Type		Severity	Quantity	Density	Deduct
DS	DEFECTIVE SEAMS	L	40	0.13	2.2
EQ	EQ SUPPORTS	L	3	0.01	0.0
PD	PONDING	L	70	0.23	2.8

Maintenance, Repair & Replacement Analysis

Building:	1 - Base Exchange	Area Cost Index:	$2.00
Section:	D	Roof Replacement Cost:	$8.00 per SF
Section Area:	30020	Insulation Replacement Cost:	$12.00 per SF
Roofing Type:	SINGLE-PLY: PVC		

Originally Constructed/Last Replaced:	2006	Visual Inspection Date:	10/11/2011
Current Age:	5 Year(s)	Insulation Inspection Date:	--------

Predicted Year of Replacement (w/o repairs):		2027					
Additional Service Life (w/repairs):		0	Year(s)		Current	Improved
Predicted Year of Replacement (w/repairs):		2027		RCI	97	98
				FCI	100	100
Cost for Repairs:	$	0.00	------ $/year	MCI	96	97
Cost for Replacement:	$	240160.00	12008.00 $/year	100	100	

Adjusted Repair/Replace Ratio = --- Recommendation: Replace

Appendix F
Site I (Luke AFB) Albedo Assessments

2010 Albedo Measurements

- Column 4, PVC right between PV Panels, was only for comparison, but is not accurate because the sample surface area is too small.

Sample Number	**1**	**2**	**3**	**4**	**5**
Sample Description	PV near ladder	PVC near roof center	PV	PVC right between PV Panels	PV
Comments	cleaned panels with new tape	soiled	soiled	soiled	soiled
E1918/E1918A Trial 1					
Clock Time (hh:mm AM/PM)	10:30 AM	10:38 AM	10:45 AM	10:58 AM	11:05 AM
Local Standard Time (decimal)	9.5	9.6	9.8	10.0	10.1
Solar Altitude (degrees above horizon)	59	61	62	65	66
Solar Altitude at least 45 degrees?	TRUE	TRUE	TRUE	TRUE	TRUE
Expected Incident Solar Radiation (W m^{-2})	908	926	941	966	978
Incident Solar Radiation, Initial (W m^{-2})	835	875	935	979	999
Solar Radiation Reflected from Sample + White Mask over Black Mask (W m^{-2})	422	605	448	480	474
Solar Radiation Reflected from Sample + Black Mask (W m^{-2})	125	298	114	123	114
Solar Radiation Reflected from Sample (W m^{-2})	205	629	204	275	210
Incident Solar Radiation, Final (W m^{-2})	855	889	951	995	1017
Absolute Difference in Incident Solar Radiation (W m^{-2})	20	14	16	16	18
E1918 Solar Reflectance (0-1) **(valid only if surface area ≥ 10 m^2)**	0.246	0.719	0.218	0.281	0.210
E1918A Solar Reflectance (0-1) **(describes surface covered by masks)**	0.228	0.762	0.228	0.331	0.226
E1918/E1918A Trial 2					
Clock Time (hh:mm AM/PM)	10:32 AM	10:40 AM	10:47 AM	11:00 AM	11:07 AM
Local Standard Time (decimal)	9.5	9.7	9.8	10.0	10.1
Solar Altitude (degrees above horizon)	60	61	63	65	66
Solar Altitude at least 45 degrees?	TRUE	TRUE	TRUE	TRUE	TRUE
Expected Incident Solar Radiation (W m^{-2})	913	930	945	969	982
Incident Solar Radiation, Initial (W m^{-2})	850	885	942	996	1015
Solar Radiation Reflected from Sample + White Mask over Black Mask (W m^{-2})	430	615	448	482	484
Solar Radiation Reflected from Sample + Black Mask (W m^{-2})	126	300	111	128	119
Solar Radiation Reflected from Sample (W m^{-2})	209	636	207	272	208
Incident Solar Radiation, Final (W m^{-2})	860	896	953	1003	1022
Absolute Difference in Incident Solar Radiation (W m^{-2})	10	11	11	7	7
E1918 Solar Reflectance (0-1) **(valid only if surface area ≥ 10 m^2)**	0.246	0.719	0.220	0.273	0.205
E1918A Solar Reflectance (0-1) **(describes surface covered by masks)**	0.230	0.754	0.238	0.318	0.211
E1918/E1918A Trial 3					
Clock Time (hh:mm AM/PM)	10:34 AM	10:42 AM	10:49 AM	11:02 AM	11:09 AM
Local Standard Time (decimal)	9.6	9.7	9.8	10.0	10.2
Solar Altitude (degrees above horizon)	60	62	63	65	67
Solar Altitude at least 45 degrees?	TRUE	TRUE	TRUE	TRUE	TRUE
Expected Incident Solar Radiation (W m^{-2})	917	934	949	973	985
Incident Solar Radiation, Initial (W m^{-2})	862	900	953	992	1018
Solar Radiation Reflected from Sample + White Mask over Black Mask (W m^{-2})	429	620	451	482	481
Solar Radiation Reflected from Sample + Black Mask (W m^{-2})	117	301	114	129	112
Solar Radiation Reflected from Sample (W m^{-2})	207	643	213	282	206
Incident Solar Radiation, Final (W m^{-2})	876	914	970	1009	1024
Absolute Difference in Incident Solar Radiation (W m^{-2})	14	14	17	17	6
E1918 Solar Reflectance (0-1) **(valid only if surface area ≥ 10 m^2)**	0.240	0.714	0.224	0.284	0.202
E1918A Solar Reflectance (0-1) **(describes surface covered by masks)**	0.240	0.758	0.244	0.336	0.218
E1918 Summary					
Trial 1	0.246	0.719	0.218	0.281	0.210
Trial 2	0.246	0.719	0.220	0.273	0.205
Trial 3	0.240	0.714	0.224	0.284	0.202
Mean	0.244	0.717	0.220	0.279	0.206
Standard Deviation	0.003	0.002	0.003	0.006	0.004
E1918A Summary					
Trial 1	0.228	0.762	0.228	0.331	0.226
Trial 2	0.230	0.754	0.238	0.318	0.211
Trial 3	0.240	0.758	0.244	0.336	0.218
Mean	0.233	0.758	0.237	0.329	0.218
Standard Deviation	0.007	0.004	0.008	0.009	0.008

2011 Albedo Measurements

- Based on the 2010 assessment, Columns 1 and 2 were deemed sufficient to represent the overall roof reflectivity values. Columns 3-7 were taken for comparison, but did not utilize the modified ASTM E1918 approach and, thus, is not as accurate.

Sample Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Sample Description	PVC near center (6)	PV near center (7)	PVC near center (4)	PVC near center (5)	PV near center (3)	PV near center (2)	PVC near center (1)
Comments	soiled	soiled	soiled	soiled	soiled	soiled	soiled
E1918/E1918A Trial 1							
Clock Time (hh:mm AM/PM)	12:01 PM	12:27 PM	11:49 AM	11:51 AM	11:47 AM	11:44 AM	11:40 AM
Local Standard Time (decimal)	11.0	11.5	10.8	10.9	10.8	10.7	10.7
Solar Altitude (degrees above horizon)	73	74	71	72	71	71	70
Solar Altitude at least 45 degrees?	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
Expected Incident Solar Radiation (W m^{-2})	1033	1043	1024	1025	1022	1019	1015
Incident Solar Radiation, Initial (W m^{-2})	808	805	804	802	804	801	797
Solar Radiation Reflected from Sample + White Mask over Black Mask (W m^{-2})	505	400					
Solar Radiation Reflected from Sample + Black Mask (W m^{-2})	210	98					
Solar Radiation Reflected from Sample (W m^{-2})	456	158	355	435	173	179	276
Incident Solar Radiation, Final (W m^{-2})	809	811					
Absolute Difference in Incident Solar Radiation (W m^{-2})	1	6	not computed	not computed	not computed	not computed	not computed
E1918 Solar Reflectance (0-1) **(valid only if surface area ≥ 10 m^2)**	0.564	0.196	0.442	0.542	0.215	0.223	0.346
E1918A Solar Reflectance (0-1) **(describes surface covered by masks)**	0.600	0.181	not computed	not computed	not computed	not computed	not computed
E1918/E1918A Trial 2							
Clock Time (hh:mm AM/PM)	12:06 PM	12:32 PM	11:49 AM	11:52 AM	11:48 AM	11:44 AM	11:40 AM
Local Standard Time (decimal)	11.1	11.5	10.8	10.9	10.8	10.7	10.7
Solar Altitude (degrees above horizon)	73	74	71	72	71	71	70
Solar Altitude at least 45 degrees?	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
Expected Incident Solar Radiation (W m^{-2})	1036	1044	1024	1026	1023	1019	1015
Incident Solar Radiation, Initial (W m^{-2})	807	807	801	801	805	802	797
Solar Radiation Reflected from Sample + White Mask over Black Mask (W m^{-2})	517	401					
Solar Radiation Reflected from Sample + Black Mask (W m^{-2})	217	96					
Solar Radiation Reflected from Sample (W m^{-2})	454	155	354	434	174	180	276
Incident Solar Radiation, Final (W m^{-2})	802	806					
Absolute Difference in Incident Solar Radiation (W m^{-2})	5	1	not computed	not computed	not computed	not computed	not computed
E1918 Solar Reflectance (0-1) **(valid only if surface area ≥ 10 m^2)**	0.563	0.192	0.442	0.542	0.216	0.224	0.346
E1918A Solar Reflectance (0-1) **(describes surface covered by masks)**	0.571	0.178	not computed	not computed	not computed	not computed	not computed
E1918/E1918A Trial 3							
Clock Time (hh:mm AM/PM)	12:11 PM	12:36 PM	11:49 AM	11:55 AM	11:48 AM	11:44 AM	11:40 AM
Local Standard Time (decimal)	11.2	11.6	10.8	10.9	10.8	10.7	10.7
Solar Altitude (degrees above horizon)	73	74	71	72	71	71	70
Solar Altitude at least 45 degrees?	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
Expected Incident Solar Radiation (W m^{-2})	1039	1044	1024	1029	1023	1019	1015
Incident Solar Radiation, Initial (W m^{-2})	802	801	802	799	805	802	797
Solar Radiation Reflected from Sample + White Mask over Black Mask (W m^{-2})	515	395		447			
Solar Radiation Reflected from Sample + Black Mask (W m^{-2})	215	95		349			
Solar Radiation Reflected from Sample (W m^{-2})	459	158	354	435	174	180	276
Incident Solar Radiation, Final (W m^{-2})	807	805		804			
Absolute Difference in Incident Solar Radiation (W m^{-2})	5	4	not computed	5	not computed	not computed	not computed
E1918 Solar Reflectance (0-1) **(valid only if surface area ≥ 10 m^2)**	0.572	0.197	0.441	0.544	0.216	0.224	0.346
E1918A Solar Reflectance (0-1) **(describes surface covered by masks)**	0.587	0.189	not computed	0.629	not computed	not computed	not computed
E1918 Summary							
Trial 1	0.564	0.196	0.442	0.542	0.215	0.223	0.346
Trial 2	0.563	0.192	0.442	0.542	0.216	0.224	0.346
Trial 3	0.572	0.197	0.441	0.544	0.216	0.224	0.346
Mean	0.566	0.195	0.442	0.543	0.216	0.224	0.346
Standard Deviation	0.005	0.003	0.000	0.001	0.001	0.001	0.000
E1918A Summary							
Trial 1	0.600	0.181	not computed	not computed	not computed	not computed	not computed
Trial 2	0.571	0.178	not computed	not computed	not computed	not computed	not computed
Trial 3	0.587	0.189	not computed	0.629	not computed	not computed	not computed
Mean	0.586	0.182	not computed	not computed	not computed	not computed	not computed
Standard Deviation	0.014	0.006	not computed	not computed	not computed	not computed	not computed

Appendix G
Site II (NAS Patuxent River) Monitoring Report

Techval

DEPARTMENT OF THE NAVY

NAVAL FACILITIES ENGINEERING COMMAND

Naval Facilities Engineering Service Center

Final Report

On

Technical Evaluation of Building Integrated Photovoltaic (BIPV)

At

NAS Patuxent River

Contract No. N62473-06-D-3009
Delivery Order # 17

August 2011

1 Executive Summary

Techval determined through this technical evaluation that Building Integrated Photovoltaic (BIPV) is a viable means for energy production under the right circumstances. This report offers guidelines and an assessment tool to help the facility manager determine if this technology is applicable for a candidate facility. If the guidelines and assessment tool indicate the potential for energy savings for the facility, Techval recommends that the facility manager investigate the possibilities of using BIPV as a part of their energy management plans. However, as determined by this study and demonstrated in the report, BIPV is not a cost effective energy technology. To be effective, BIPV roofing systems need to be applied to a facility in need of a new roof and in an area where there is high solar irradiation, high electric utility rates, and a large unobstructed roof area exposed to direct sunlight.

This evaluation was conducted on Building 515 at the NAS Patuxent River. Building 515 is a single story wood framed building with space used as office and warehouse. The installation of the BIPV at Building 515 took nine days.

1.1 What Is the Technology?

A BIPV roof consists of a photovoltaic (PV) material that is attached to a roof in such a way that removal of the photovoltaic material will also result in the removal of the roof. Also, in a BIPV roof, evaluation of the roofing system will require the evaluation of the roofing and PV materials as a whole. This BIPV roof demonstration evaluated the benefits of a membrane roof integrated with thin film PV modules.

1.2 How Does It Save Energy?

Building Integrated Photovoltaics produces energy similarly to other types of photovoltaic systems while providing additional roof insulation which can lead to the reduction of heating and cooling costs. This evaluation did not include the heating and cooling effects to the interior of the facility. The production of energy by the roof reduces the building's consumption of energy from the utility grid.

1.3 Where Should the Navy Apply It?

Techval offers the following guidelines for determining if BIPV technology has the potential for saving energy in a local facility:

- Are there plans to reroof soon?
- Is there a large portion of the roof with few vertical items such as vent stacks and little or no rooftop mechanical equipment?
- Is there little to no shading of the roof an hour after sunrise to an hour before sunset?
- Is the cost of electricity over 20¢/kWh?
- Is the solar resource for the location over 5kWh/m²/day?

If you answered "yes" to all of the questions above, investigate this technology for your facility.

1.4 How Much Does It Cost and How Much Did It Save?

Techval installed 16,000 ft^2 of roofing material and 5,700 ft^2 of BIPV at Building 515 at NAS Patuxent River. This project was installed under a firm fixed price contract of $349,772 which included $305,781 for the roofing material and BIPV installation, $13,991 for the design of the roof and PV systems, and $30,000 for roofing repairs and tear off of the old roofing material. The $349,772 is representative of the cost to a local base, if they contracted directly with the subcontractor. The repairs included repair of 64 ft^2 for roofing deck, replacement of 16 linear feet of fascia trim, and reinforcement of six (6) damaged roofing beams.

The PV produced 60,708 kWh over the demonstration period of two (2) years. That is an annual energy production of 30,354 kWh. A utility rate of $0.11/kWh was given by the POC to be the local utility rate. The BIPV system produced enough renewable energy on average to reduce the utility bill $3,339 annually.

In this case, the simple payback for this technology is 92 years but that does not take into account that the roof was in need of replacement. The payback should be calculated on the difference of the BIPV PVC membrane roofing system and the replacement cost of a traditional granular cap sheet built-up-roof (BUR) roofing system. It is estimated that the replacement costs of a traditional roofing system would be about $112,757 for this building. Based on this estimate, the simple payback is reduced to 58 years.

1.5 What Are the Maintenance Costs / Savings Issues?

There were no maintenance issues with the roof membrane, BIPV, or the inverters during the course of this evaluation.

1.6 What Are the Findings, Conclusions, and Recommendations?

1.6.1 Findings

Building Integrated Photovoltaics (BIPV) was proven to produce reliable energy.

1.6.2 Conclusion

When a roof is already in need of replacement, BIPV is a viable option. Weather conditions, other than cloudy days or snow, had no significant effect on the performance of the PV. The availability of sunlight was the major factor in the performance of the PV.

1.6.3 Recommendations

For new construction or when replacing existing flat roof systems where few vertical items such as vent stacks, little or no rooftop mechanical equipment, and there is no shading of the roof an hour after sunrise to an hour before sunset, BIPV is an option.

1.7 Does This Report Support Findings of Previous Studies?

Techval is not aware of any other independent study of BIPV roofing systems.

1.8 Are More Studies or Demonstrations Needed?

Studies in more diverse environments may reveal features and obstacles that were not found in this demonstration.

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2 Objective

The overall objective of this project was to demonstrate and validate the BIPV roof concept by verifying that an energy efficient roof and renewable energy can be acquired with a roof that performs its expected function.

3 Technical Discussion of Photovoltaic Systems

3.1 Conventional PV Systems

Conventional PV systems consist of rigid glass panels of photovoltaic material mounted in metallic frames and installed on facility roofs or in open fields. The panels are angled toward the sun to achieve the highest possible energy production from the available solar radiation. In some cases, the frames are motorized to track the sun, achieving an even higher energy production.

3.2 BIPV Roofing Systems

Building Integrated Photovoltaic (BIPV) roofing systems differ from conventional PV systems on several points. First, the PV material is flexible thin film PV, not rigid. The material can conform, to an extent, to the contour of the mounting surface. Second, the flexible PV material is installed to match the contour of the mounting surface and not angled toward the sun. Third, the flexible material is not as efficient as the rigid panels and thus has a lower efficacy. As with the rigid panels, there are varying technologies and manufacturing techniques for the flexible material. For both products, the cost and efficiency of the final product varies with the technology, manufacturing process, and installation technique.

BIPV roofing systems consist of a conventional fiberglass reinforced polyester membrane roofing material with the flexible PV material layered on top. Typically, solid insulation is installed on an existing roof. The insulation is then grooved to accept the conduit that will house the wiring needed to connect each BIPV segment into the electrical system. Then a conventional membrane roof is installed over the insulation. Finally, a second roofing membrane containing the PV material is installed over the first membrane. The PV is then connected and the electrical junction boxes are covered with roofing material to complete the installation. The electrical connections are then completed to connect the PV to the load (or electrical grid).

For this demonstration, Techval chose the thin film PV from Uni-Solar. The product has a unique triple junction performance that optimizes the capture of a wide spectrum of light. This unique feature helps produce more kilowatt-hours of energy over the complete daylight period. It is effective in cloudy and low light conditions and uses a Teflon-like protective layer (TEFZEL) that is resistant to seismic, wind, hail, and debris conditions. No glass is used in thin-film technology making it very rugged, durable, and flexible. The PV, when integrated into a roofing panel, is an integral part of the overall roof structure.

4 Implementation

4.1 Design Method

Beyond the typical considerations for a new roof (roof loading, uplift requirements, forecast for continued facility use, etc.), designing for a BIPV roof involves selecting the correct location (facility), maximizing the surface area of the PV, and avoiding obstructions on the roof, such as vent pipes and HVAC equipment. In this case, the size of the photovoltaic system was determined by budget. The entire roof was suitable for the PV, but due to budget restraints, the PV was applied to only 5,700 ft^2 of the roof.

4.2 Facility Selection

Selection of candidate facilities to receive a BIPV roofing system is based on several factors including the size of the facility, condition of the roof, obstructions on the roof, and possible shading to the roof area. In this case, NAVFAC ESC selected NAS Patuxent River as the site for this demonstration. The Techval team, along with site personnel, selected Building 515 as the candidate facility.

4.3 Existing Conditions

Building 515 is a single story wood framed building at the NAS Patuxent River with spaces used as office and warehouse. The existing roof was past its life expectancy and in need of replacement. In several areas the existing roof system had failed and the roof deck had rotted. Photos of the as-found conditions are shown below.

Figure 1 Building 515

Figure 2 Building 515 Roof

Figure 3 Building 515 Rotten Section

4.4 Installation of BIPV Roofing System

The installation of the BIPV was performed between December 1 and December 9, 2009. The installation crew did not interfere with the operation of the facility except for a one (1) hour window near the conclusion of the project to terminate the PV electrical wiring to the facility electrical panel.

Figure 4 is a photo of the installed BIPV roofing system on Building 515. The white boxes are the junction boxes for the PV electrical connections.

Figure 4 Installed BIPV

5 Data Collection

5.1 Data Points

A monitoring system was designed and installed to evaluate the performance of the BIPV system with respect to local weather conditions, which includes the solar resource (i.e., insolation). A data logger and instrumentation were set up to collect the following data:

- Ambient Air Temperature
- Air Relative Humidity
- Wind Speed
- Rainfall
- PV Surface Temperature
- Roof Surface Temperature
- Solar Radiation
- Energy Generated by the PV

For each point, the instantaneous reading and average, maximum, and minimum values over the sample period were recorded every fifteen (15) minutes. Monitoring began in February 2009 and concluded in February 2011.

5.2 Monitoring Devices

Techval selected the following instruments to measure the performance of the BIPV system. The installed instruments are shown in Figure 5.

Table 1 - Monitoring Devices

Instrument Name	Manufacturer	Model
Ambient Temperature / Relative Humidity	Kele	GEH5-O-TT2
Wind Speed	Kele	A70-SL

Instrument Name	Manufacturer	Model
Rain	Kele	A70-RL
PV Surface Temperature	Omega	RTD-830
Roof Surface Temperature	Omega	RTD-830
Pyranometer*	Apogee	SP-215
Energy Meter**	Veris	H-8163-0200-1-3

* A pyranometer is a device used to measure solar irradiance, also known as solar insolation.

** The Energy meter is connected to the AC side of the energy inverter.

Figure 5 Monitoring Equipment

5.3 Analysis Methods

Techval evaluated the complete set of collected data. In doing so, the analysts recognized trends related to the environmental conditions present at the time the data was collected. The data set was segregated into categories based on the weather as (1) sunny/clear, (2) partly cloudy, and (3) mostly cloudy. The factors for distinguishing solar insolation for sunny/clear, partly cloudy, and mostly cloudy days were determined by the reported weather condition. The weather condition was obtained from the local weather station report. Using the weather condition report from the weather station, gives an accurate account of the weather. Using a solar insolation range to determine the weather condition will be conflicting since the solar insolation changes throughout the year and the day, which would give false energy production for certain days and times. Each category was then evaluated.

The BIPV system was monitored over a two (2) year period with data recorded every quarter hour. The collection produced a total of 68,788 lines of data, which was refined to hourly averages. An algorithm was used to remove the night hours from the remaining lines of hourly data. The remaining lines of data were used to produce the charts and analysis in Section 6 of this report.

5.4 Data Gaps

Data was harvested from the data logger through a telephone line provided by the site. There were gaps in the data due to telephone line connection and sensor failures. At times, the phone line would not connect to the data logger and some data was lost. After several attempts to correct the problems with the phone line, local site personnel collected data directly from the data logger and forwarded the data to the analysts. In particular, data from June and July 2009, February 2010, and August 2010 were lost. Missing data appears as gaps in the data seen in the forthcoming charts.

The original outside air temperature and humidity sensor was a GE model. After it failed, it was replaced with a Veris model. It is believed that these failed because high humidity associated with the site being located so close to Patuxent River. The roof and PV surface temperature sensors and transmitters were replaced after they began to produce temperature reading well above and below the expected ranges. These surface temperature sensors may have failed due to the hot roof environment. Data from the Patuxent River weather station (KNHK) located 1.2 mile east of building 515 were used for reference in determining if sensors were operating within expected range. The PV power meter stopped working. To correct this, the voltage leads were reconnected.

6 Data Analysis Results

6.1 Overall Energy Production

Energy generated by the PV was monitored to evaluate activity as well as energy production. The energy readings are used to evaluate the efficiency of the system based on average output and potential maximum output. A pyranometer was used to quantify the amount of solar insolation at this location to determine the relationship between solar insolation and energy. On the shortest day of the year, December 21, the peak energy was 9.89 kilowatts. The peak energy on the longest day of the year, June 21, was 12.77 kilowatts. The weather was mostly cloudy on the shortest and longest day.

Over the course of the two (2) years of monitoring, the BIPV system produced a peak energy of 20.5 kilowatts, with an average of 6.6 kilowatts (See Figure 6). A total of 61,000 kilowatt-hours of energy was produced throughout the monitoring period. The BIPV is able to support an off-grid load of up to 20 kilowatts, but is best suited for a load of 5.31 kilowatts in that application.

The BIPV system was designed for a peak installed capacity of 34.848 kWp DC STC. STC refers to factory standard test conditions. Sun conditions for this facility were developed using the NREL PV Watts version 1.0 program and were estimated at 4.66 peak solar hours per day for Baltimore, MD. Typical system efficiencies provide outputs of approximately 77% of the DC STC rating at the utility meter. Based on the system size and location we estimated typical yearly output at 42,787 kWh. Output calculations were based on US DOE PV Watts version 1.0 program.

Table 2 - Calculator for Overall DC to AC Derate Factors

Calculator for Overall DC to AC De-Rating Factors		
Component De-rated Factors	**Component De-rated Values**	**Range of Acceptable Values**
PV module nameplate DC rating	0.95	0.80 - 1.05
Inverter and Transformer	0.92	0.88 - 0.98
Mismatch	0.98	0.97 - 0.995
Diodes and connections	0.995	0.99 - 0.997
DC wiring	0.98	0.97 - 0.99
AC wiring	0.99	0.98 - 0.993
Soiling	0.95	0.30 - 0.995
System availability	0.98	0.00 - 0.995
Shading	1	0.00 - 1.00
Sun-tracking	1	0.95 - 1.00
Age	1	0.70 - 1.00
Overall DC to AC de-rating factor	0.770	

The estimated system performance was 42,787 kWh and the actual system produced 30,500 kWh annually. Annually, the system underperformed design expectations by 28.72%. BIPV system was designed at 34.848 kWp DC. An actual 24.740kWp AC was recorded on July 19, 2010 at 3:00PM. At peak, the BIPV underperformed expectations by 29%. Based on these findings, the de-rating factor is actually 0.63 instead of 0.77. The de-rating factor is the combination de-rating factors that affect each component of the system. More study would be needed to determine which of these de-rating factors actually varied from design conditions.

There was no noticeable change in the performance between year one and year two. Periodic cleaning of the PV and additional monitoring could help determine actual preventive maintenance practices.

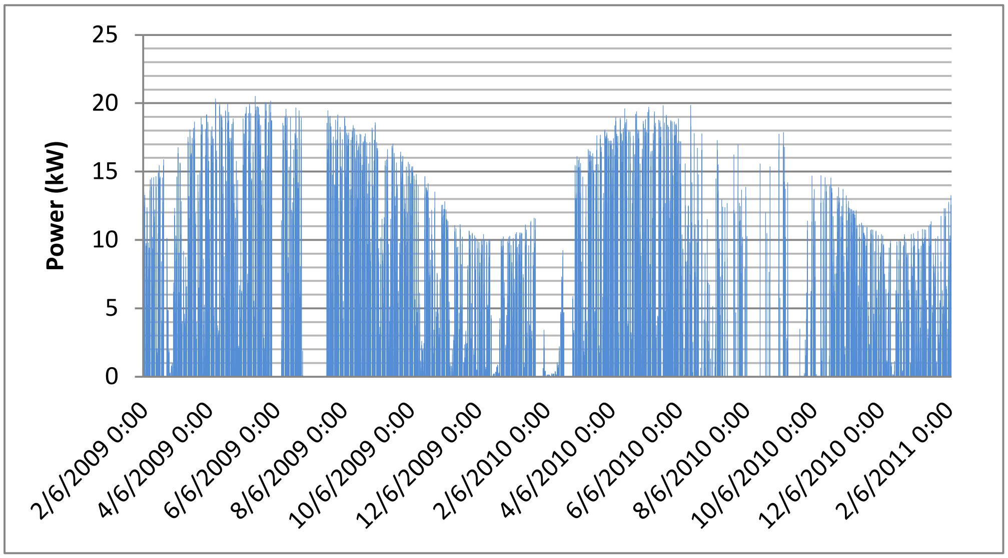


Figure 6 Energy throughout Monitoring

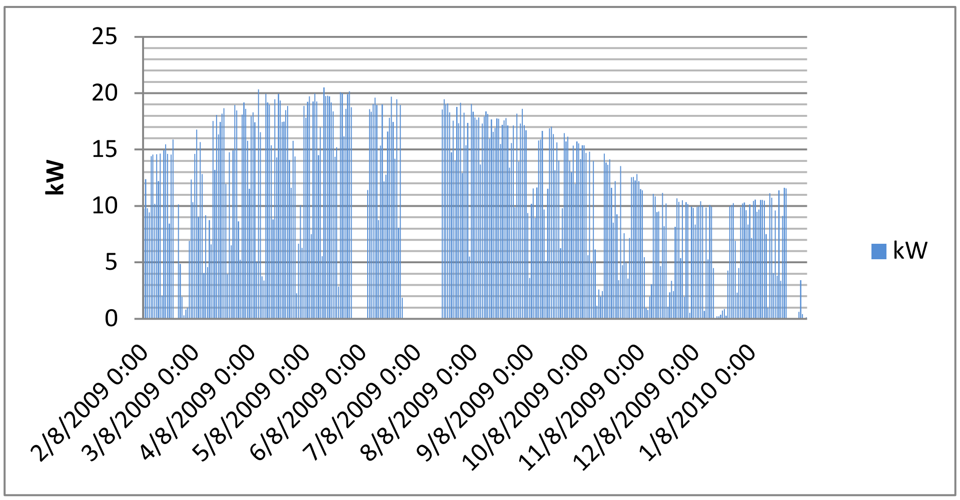


Figure 7 Energy Monitoring for Year 1 (09/10)

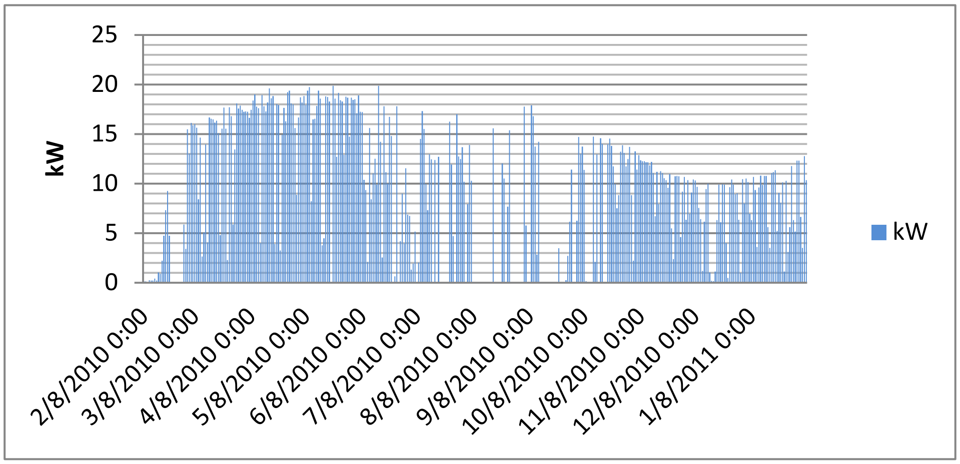


Figure 8 Energy Monitoring for Year 2 (10/11)

Solar angle refers to the inclination of the sun in relationship to the horizon. As the earth revolves around the sun, the tilt of the earth causes the inclination of the sun to be lower during the winter months in the northern hemisphere. As a result, the sun produces less solar insolation during the winter months. This is clearly demonstrated in Figure 6 by the sinusoidal shape of the energy peaks over the course of a year. As expected, there is a direct relationship of energy produced by the PV and the available solar insolation as demonstrated in Figure 9 below. The solar insolation ranged from 6 W/m^2 to 877.5 W/m^2 during the monitoring period. The 6 W/m^2 was the lowest amount of solar insolation recorded, which occurred on January 8, 2011 at 10 am with overcast skies. The 877.5 W/m^2 was the highest amount of solar insolation recorded, which occurred on October 24, 2010 at 2 pm.

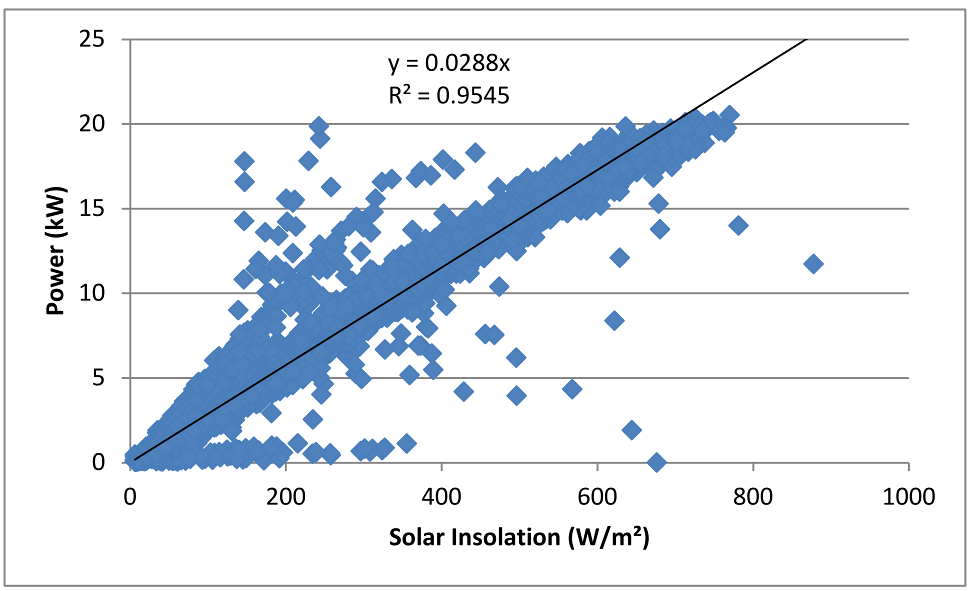


Figure 9 Energy Produced vs. Solar Irradiance

6.2 Energy Produced vs. Atmospheric Conditions

Aside from the facility's positioning on the earth, atmospheric conditions play a major role in determining the amount of energy that is produced by a PV system. The following paragraphs and charts illustrate the impact of atmospheric conditions on energy generation.

6.2.1 Energy Produced in Relation to Solar Insolation

The most powerful factor in the production of electrical energy by any PV system is the availability of solar insolation. The following three (3) charts illustrate the generation of energy for the three (3) cases of available insolation – sunny/clear, partly cloudy, and mostly cloudy days.

The data for the days that were deemed to be sunny/clear, partly cloudy, and mostly cloudy days were split up into the differing types of weather conditions. The data for the different types of weather conditions was used to determine the amount of energy being produced for the given weather condition.

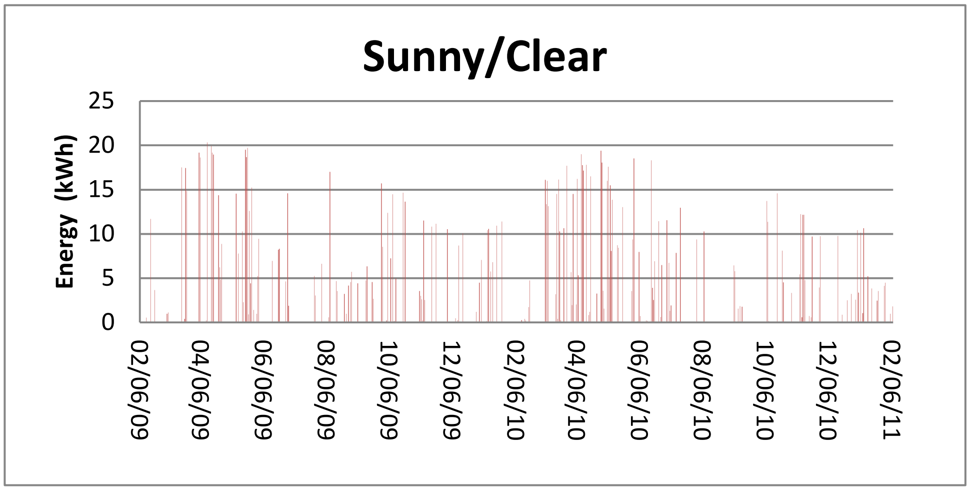


Figure 10 Energy Production on a Sunny Day

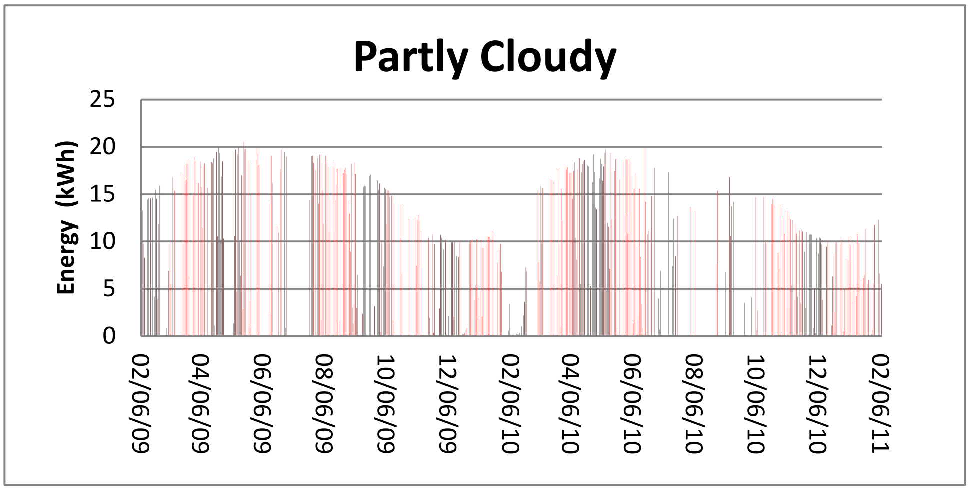


Figure 11 Energy Production on a Partly Cloudy Day

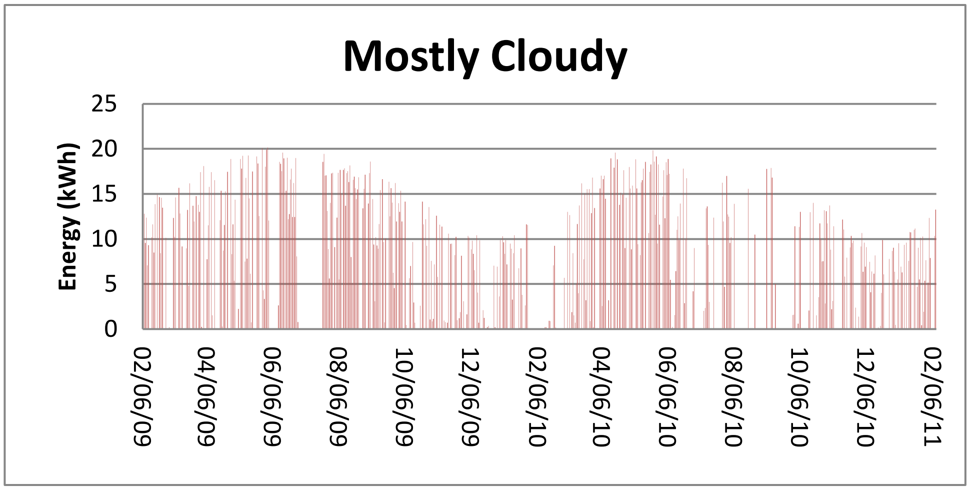


Figure 12 Energy Production on a Mostly Cloudy Day

As shown in the preceding charts, the impact of solar insolation is not directly affected by the type of cloud coverage. Clear/sunny days reached a peak solar insolation of 763.5 W/m^2 with an average hourly energy production of 6.7 kW. Partly cloudy days produced an average energy rate of 8.6 kW/h, with a peak solar insolation of 769.7 W/m^2. Mostly cloudy days produced 7.1 kW/h with a peak solar insolation of 877.5 W/m$^{2.}$

6.2.2 Energy Produced vs. Temperature

A factor in a PV system's ability to produce energy is the temperature of the PV components. Most, if not all, manufacturers claim that as the components heat up, the efficiency of the system decreases. In contrast to the manufacturer's claims, the following charts show that energy production increases with ambient, roof surface, and PV surface temperatures. However, it should be noted that the high ambient and surfaces temperatures are a direct result of more solar irradiation which in itself results in high output from the PV but the efficiency of the PV decreases with temperature as the manufacturers claim. This is demonstrated by the downward curve of the trend lines on the graph below.

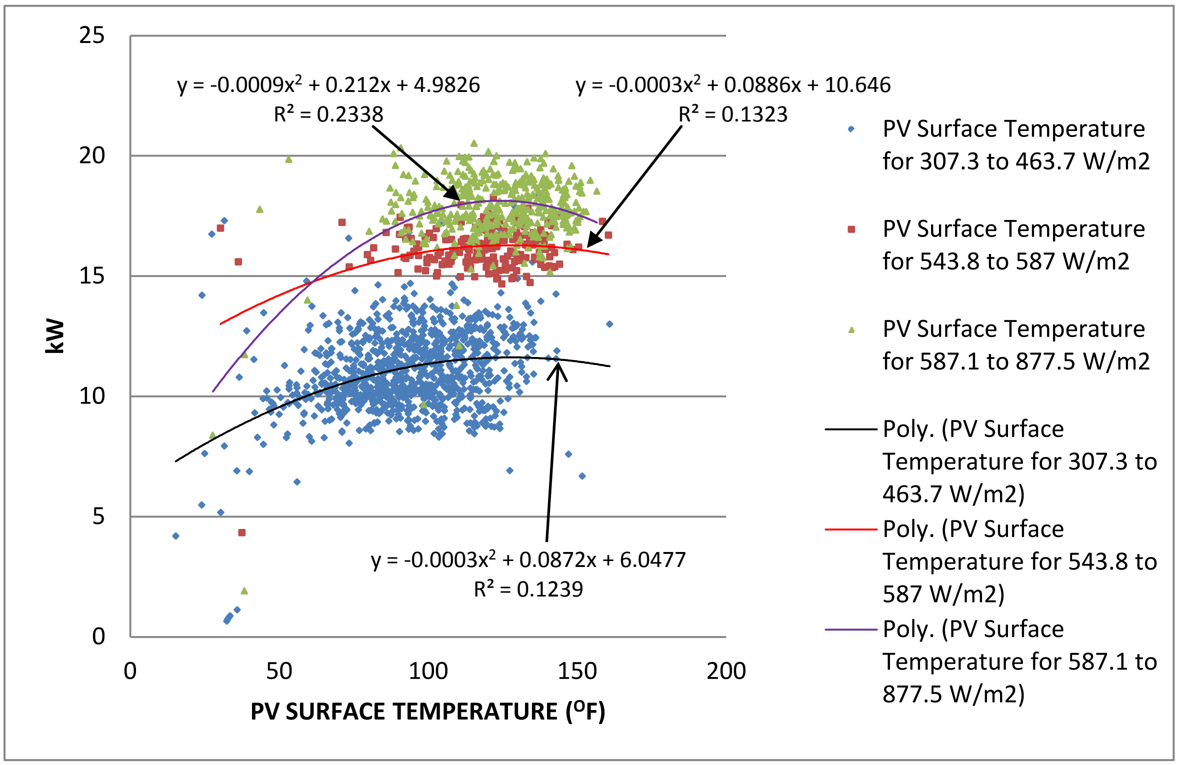


Figure 13 Energy vs. PV Surface Temperature

6.2.3 Energy Produced vs. Rain, Snow, and Wind

It is expected that rainy conditions would adversely affect the production of energy by the PV. Rainfall was collected to compare energy output under dry conditions to the output under rainy conditions.

Rainfall over the course of the monitoring period varied. The chart below shows how output energy is reduced by more rainfall. Rainfall did not completely prevent any output, but severely limited the energy production. Peak energy of 20.52 kilowatts was produced on a day with no rain while the highest energy output on a day with rain was 13.78 kilowatts with 0.23 inches of rainfall. The average energy output for days with rain was 1.95 kilowatts as compared to 6.94 kilowatts on dry days.

The rainfall did not have a noticeable impact on the amount of output power before and after a rainfall. Standing water was expected to cause some problems, but comparing solar insolation to energy output before and after rainfall showed no significant impact. The amount of cloud coverage did, however, affect the amount of output energy.

Snow is another source of concern since it can accumulate on the PV panels and completely block the panel from harvesting any energy. During the course of monitoring, SEI only had a few days where snow was present. The majority of the data collected during these times was erratic and suspect. It was not included in the final data set. The remaining points of data were too few to make an assessment as to the effects snow had on the system.

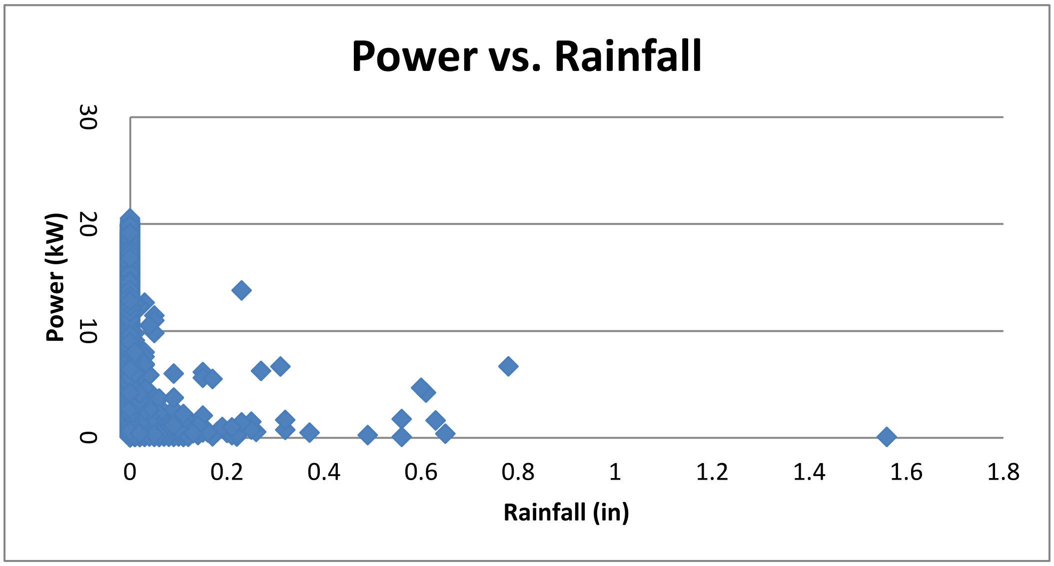


Figure 14 Energy Produced vs. Rainfall

Wind on the other hand did not demonstrate any direct effect on the production of energy by the PV, but could help to cool the PV panels by removing warm air from the PV surface. The following charts show that the wind helped cool the surface temperature of the PV Panel. As shown previously, higher PV surface temperatures cause energy production outputs to start to degrade.

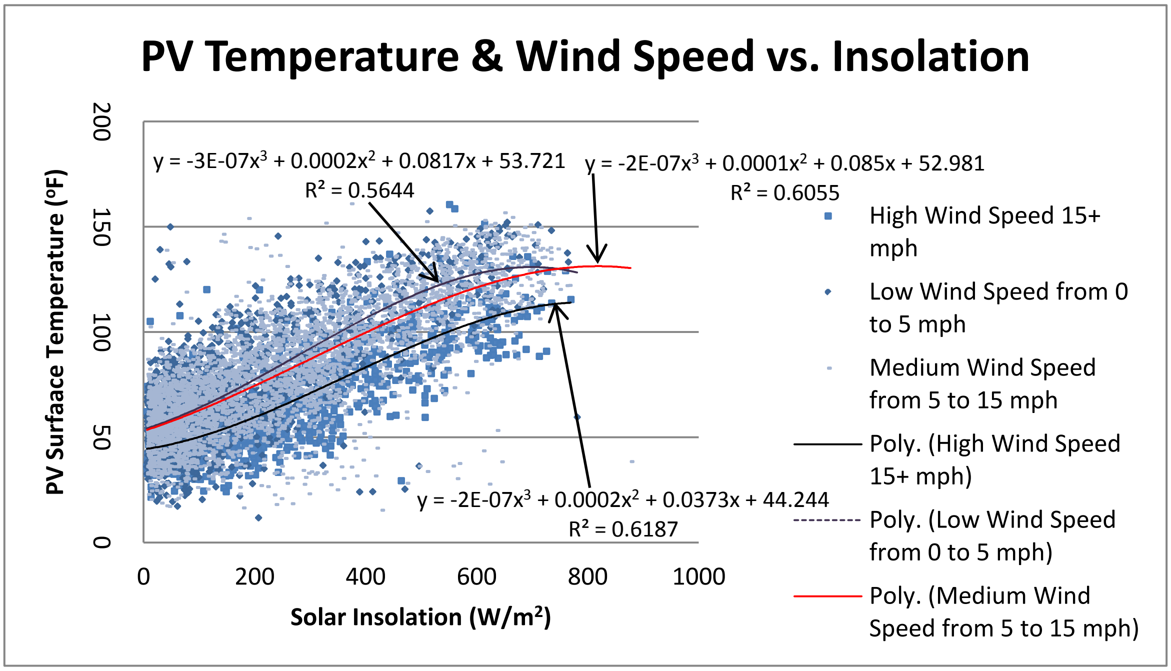


Figure 15 Energy vs. Solar Insolation for Multiple Wind Speeds

6.3 Conclusions

The full and precise energy analysis for the energy production of the installed BIPV roof is much more complex than just sun to power. There were many conditions and factors that played a pivotal role in the accuracy of this analysis. At times equipment used for monitoring failed, which resulted in inaccurate data reading and recording. This data was deemed inaccurate and unusable; therefore, it was removed during the data refinement process. During the data refinement process, other information that did not affect the system monitoring was removed (i.e. night time data).

During the data refinement process, snow data was filtered out. This data was lost due to such low power output and points of time in which snow was falling. There were no images/videos or personnel with a physical presence to report on how long the snow was present, so it is deemed from this report that effects of snow are still undetermined both immediately falling and while standing on the roof.

The weather conditions were assumed to be the biggest factor into energy production amounts, but as shown in the preceding charts the energy production for the multiple weather conditions varied little. There was only a separation of 1.9 kW between the hourly energy production between the associated weather conditions (sunny/clear, partly cloudy, and mostly cloudy). Partly cloudy days produced the highest amount of energy on average at 8.6 kWh with Sunny/Clear days having the weakest average for energy production of only 6.7 kWh.

Rainfall, as expected, had an impact on energy production. As the rainfall amounts got higher, energy production became lower. The most rainfall throughout the monitoring period was 1.56 inches and only produced 0.8 kW.

Wind did not directly affect solar insolation amounts, which is the available amount of sunlight for production. Wind did, however, help to cool the PV surface temperature which lowered the overall operating temperature of the PV modules. At higher PV surface temperatures the amount of energy production starts to degrade. The average amount of energy was directly affected by solar insolation. As the amount of solar insolation increased, so did the amount of energy being produced.

The overall comparison of sustainability from year one to year two shows that the energy production for both years follow the same trend. The longer days of the warmer months (summer) produced more energy than the shorter days of the colder months (winter). February had the lowest amounts of energy production, while June produced the highest amounts of energy.

7 Life Cycle Cost Analysis

This project was installed under a firm fixed price contract of $349,772 which included $305,781 for the BIPV installation, $13,991 for the design of the roof and PV systems and $30,000 for repairs.

With a utility rate of $0.11/kWh, the simple payback is calculated to be 91.6 years. This equates to a (30,354kWhr/yr * $0.11/kWh) $3,339 annual energy revenue. This equates to a ($305,781/$3,339/yr) 91.6 year simple payback.

It is estimated that the replacement costs of a traditional roofing system would be about $112,757 for this building. The total additional cost to replacing the roof and adding BIPV is ($305,781 - $112,757) $193,024. Based on this estimate, the simple payback is reduced to ($193,024/$3,339/yr) 57.8 years.

It is estimated that to obtain a payback period of 25 years, a few things must first happen. At the extremes, the utility rate would have to be at least $0.25/kWh (more than double the current rate ($0.11/kWh) at NAS Patuxent River). It is also possible to obtain a 25 year payback with the current system and $0.11/kWh utility rate if the energy output of the system were 70,190 kWh/yr. A 25 year payback is also possible with a utility rate of $0.15/kWh and an annual energy production of 51,473 kWh/yr from the PV.

8 Assessment Tool

Use the following assessment tool to evaluate specific locations and facilities to determine if this technology is appropriate for the situation. This tool is intended to be a guide and should not be considered an absolute measure of the potential for energy savings. For each variable, select the appropriate range for the candidate facility and determine the score for that range. Sum the scores for all variables. Use the following map to determine the average solar resource for a candidate location.

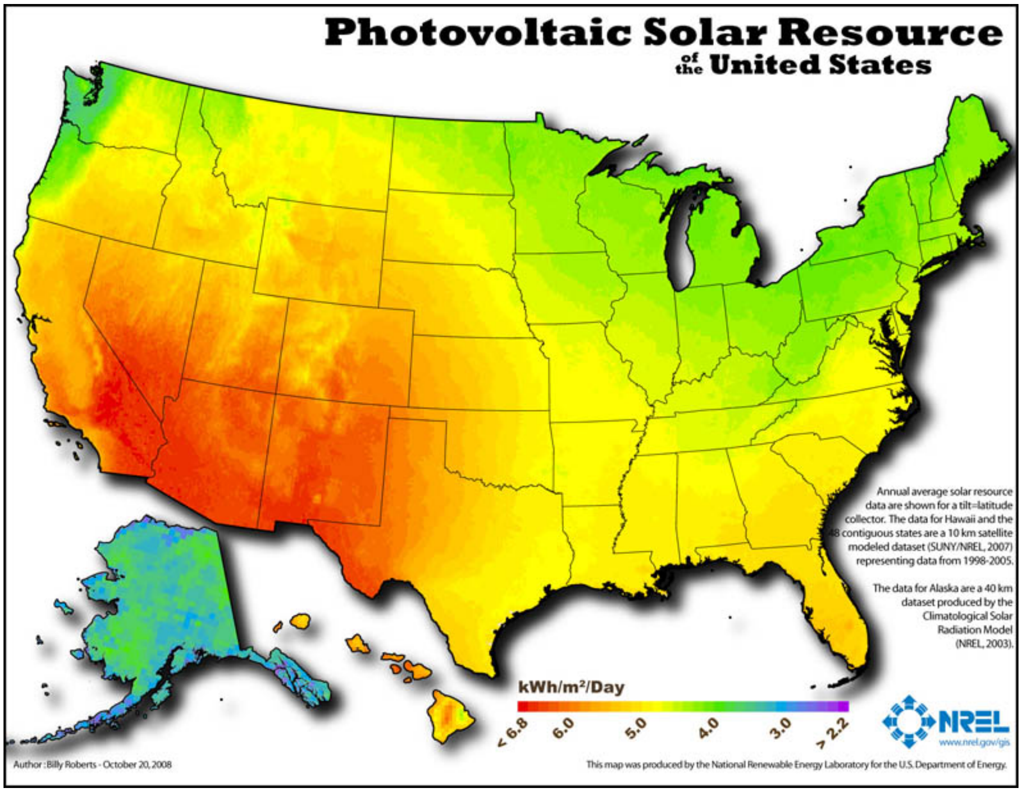


Figure 16 US PV Solar Resource

Table 3 - Decision Calculator

BIPV Technology Decision Calculator			
	Score		
Variable	**1**	**2**	**3**
Plans to reroof soon	Roof needs replacement in 10 years	Roof needs replacement in 5 years	Roof needs replacement now
Unobstructed area of roof	<20,000 ft^2	20,000 to 40,000 ft^2	>40,000 ft^2
Shading	Little shading	Very little shading	No shading
Cost of Electricity ($/kWh)	<10¢	10¢ - 20¢	>20¢
Solar Resource (kWh/m²/day)	<5.0	5.0 -6.0	>6.0

If the total score is <8, the candidate facility is **not a good candidate** for this technology.

If the total score is 8 – 13, it is **worth further investigation**.

If the total score is >13, it is a strong indicator of a **good candidate** for this technology.

For the demonstration at NAS Patuxent River, the scores are:

Table 4 - Facility Score

Variable	**Value**	**Score**
Plans to reroof soon	Yes	3
Unobstructed area	16,000 ft^2	1
Shading	No shading	3
Cost of Electricity (kWhr)	11¢	2
Solar Resource ($kWhr/m^2/day$)	4.0 -5.0	1
Total	**-**	**10**

9 Lessons Learned

The roof performed as expected with no reported leaks. The PV produced energy within expected ranges.

10 Customer Documented Problem

The roof had a number of significant problems. The PVC carrier sheet that holds the solar panels is experiencing strong black mold growth. The mold is not growing on the portion of the roof that does not have solar panels. This leads to the belief that the carrier sheet is not the same material as the rest of the roofing membrane. Mold is known to break down the plasticizers in PVC reducing the membrane life. This may only be a problem on this generation of BIPV roof, as the new version of this roof has migrated from PVC to TPO membranes.

The roof has insufficient slope that, when combined with sloppy workmanship, causes a great deal of ponding. Ponding encourages microbial and vegetative growth as well as adding to the dead load of the roof. It is not cost effective to repair this after the fact. It is recommended that during a reroof tapered insulation be installed to achieve a slope of at least ½:12.

The underlayment is cupping. Cupping of the underlayment indicates that water is infiltrating the roofing materials. As there are no complaints of leakage inside the buildings and there are no penetrations in the portion of the roof experiencing the cupping it is strongly suspected that there is condensation between the roofing layers. Building 515 is a mid-century building with wood board roof decking located on the banks of a large body of water. It is suspected that moist air is migrating into the roof through the porous deck. The high emissivity of the membrane allows the membrane's temperature to stay below the dew point causing water to condense on the bottom of the roofing membrane. This can be prevented in the future by adding a vapor barrier to cool roofs in areas that do not ordinarily require one. Non porous roof decks do not necessarily require a vapor barrier.

Appendix H
Site II (NAS Patuxent River) ROOFER Assessments

2009 ROOFER Assessment

Maintenance, Repair & Replacement Analysis

Building:	515 - BIPV Test Building	Area Cost Index:	$2.00
Section:	A	Roof Replacement Cost:	$15.00 per SF
Section Area:	16000	Insulation Replacement Cost:	$10.00 per SF
Roofing Type:	SINGLE-PLY: PVC		

Originally Constructed/Last Replaced:	2009	Visual Inspection Date:	6/17/2009
Current Age:	0 Year(s)	Insulation Inspection Date:	--------

Predicted Year of Replacement (w/o repairs):		2022					
Additional Service Life (w/repairs):		0	Year(s)			Current	Improved
Predicted Year of Replacement (w/repairs):		2022			RCI	91	92
					FCI	90	90
Cost for Repairs:	$	13898.00	------	$/year	MCI	90	93
Cost for Replacement:	$	240000.00	12000.00	$/year	100	100	

Adjusted Repair/Replace Ratio = --- Recommendation: Replace

Corrective Action Requirement Sheet

Major Repair

(Note: Attach a copy of this form, along with a copy of the Roof Inspection Worksheet to DA Form 4283

Agency/Inst.:	515 - NAS Patuxent River, Md	Facility No:	515
Bldg No./Sec:	515 A	Bldg Name:	BIPV Test Building
Bldg Use:	Admin	Inspection Date:	Jun/2009
Membrane:	SINGLE-PLY: PVC	Area (SF):	16000
Surfacing:	None	Age (Yrs):	0
Vapor Ret:	NONE	Deck Type:	WOOD BOARDS
Insulation:	POLYISOCYANURATE	Est. Repair Cost:	$ 13898.00

CORRECTIVE ACTION RECOMMENDED: Maintenance, Repair and/or Partial Replacement

JUSTIFICATION: An economic analysis of the roof condition, including age, indicates that it is more cost effective to accomplish the necessary maintenance, repairs and/or partial replacement of the roofing components rather than replace the roofing system. Therefore, accomplish the following actions for the above roof section.

[Note: numbers refer to identification numbers of distresses corresponding with the Roof Inspection Worksheet]

4. PD-M-1 200 SF — Remove wrinkled membrane blocking drainage, clean and prepare surface and install membrane patch. [5]

5. PD-M-2 100 SF — Cut membrane over underlying bowed insulation, remove insulation and replace. Clean and prepare surface and patch repair with new membrane. [6]

Corrective Action Requirement Sheet

Roof Replacement

(Note: Attach a copy of this form, along with a copy of the Roof Inspection Worksheet to DA Form 4283)

Agency/Inst.:	515 - NAS Patuxent River, Md	Facility No:	515
Bldg No./Sec:	515 A	Bldg Name:	BIPV Test Building
Bldg Use:	Admin	Inspection Date:	Jun/2009
Membrane:	SINGLE-PLY: PVC	Area (SF):	16000
Surfacing:	None	Age (Yrs):	0
Vapor Ret:	NONE	Deck Type:	WOOD BOARDS
Insulation:	POLYISOCYANURATE	Est Replace Cost:	$ 240000.00

CORRECTIVE ACTION RECOMMENDED: Total replacement of roof in 2022

JUSTIFICATION: An economic analysis of the roof condition, including age, indicates that it is more cost effective to totally replace the roofing system, rather than perform the necessary maintenance, repair, and/or partial replacement of the roofing system.

DESIGN CONSIDERATIONS: The following considerations should be addressed during the design and construction phases of the replacement system:

a. Type replacement systems could include
   1) bituminous built-up membrane
   2) single-ply membrane, such as EPDM, PVC etc.. If a ballasted system is selected, determine if the structural components can sustain the added weight (approx. 10 lbs/SF).

b. Ensure that the roof has positive drainage slope of at least 1/4 inches per foot. Correct all areas that now contain ponded water.

c. Remove all unnecessary roof mounted equipment.

d. Inspect and repair or replace, as necessary, all remaining roof mounted equipment.

e. Ensure that all roof mounted equipment and penetrations are properly installed on the roof.

f. Live load and dead load impacts shall be taken into account in the design.

g. Until the replacement roof is installed, accomplish temporary repairs to ensure that the roof remains leak free.

Economic Evaluation Worksheet for a Single-Ply Roofing System

Agency/Inst: 515 - NAS Patuxent River, Md | Building/Section: 515 A | Area: 16000 SF | Age: 0

Total Repair Costs Additional Service Life	$ 13898 0 Yrs		Replacement Cost @ $15.00/SF	$	240000
Total Repair Cost/ Additional Service Life	$ ------ $/Yr		Replacement Cost/20 Years	$	12000 $/Yr

Cost Analysis — Generated: Jun/29/2009

Ratio = Repair Cost/Year / Replace Cost/Year = ---

Adjusted Ratio = Ratio + (0.01 * Age) = ---

Adjusted Ratio	Recommended Action
0 - 0.8	Repair
0.8 - 1.2	Marginal
> 1.2	Replace

Membrane

DIS-SL-DF	Unit Cost	Qty	Total Cost	DIS-SL-DF	Unit Cost	Qty	Total Cost
DS-H-1	29.18			MS-M-1	33.60		
DS-H-2	35.42			MS-M-2	39.42		
DS-M-1	24.74			MS-M-3	26.18		
DS-M-2	35.42			PA-H-1	33.98		
DV-H-1	42.66			PA-M-1	33.98		
DV-H-2	42.66			PD-M-1	32.22	200	$ 6444.00
DV-M-1	5.86			PD-M-2	59.54	100	$ 5954.00
DV-M-2	42.66			RG-H-1	24.10		
DV-M-3	5.86			SC-M-1	19.88		
EQ-H-1	89.92			SP-H-1	24.10		
EQ-H-2	81.94			SS-H-1	35.96		
EQ-M-1	41.90			SS-H-2	27.58		
EQ-M-2	81.94			SS-H-3	27.72		
HL-H-1	66.54			SS-H-4	5.68		
HL-H-2	29.52			SS-M-1	35.96		
HL-M-1	14.30			SS-M-2	27.58		
MD-H-1	25.04			SS-M-3	27.72		
MD-M-1	14.46			SS-M-4	5.68		

Economic Evaluation Worksheet for a Single-Ply Roofing System

Agency/Inst: 515 - NAS Patuxent River, Md | Building/Section: 515 A | Area: 16000 SF | Age: 0

Flashing

DIS-SL-DF	Unit Cost	Qty	Total Cost	DIS-SL-DF	Unit Cost	Qty	Total Cost
BC-H-1	51.76			EM-H-1	19.24		
BC-H-2	47.78			EM-H-2	70.76		
BC-H-3	20.84			EM-H-3	36.18		
BC-H-4	152.08			EM-H-4	31.10		
BC-M-1	47.78			EM-H-5	39.50		
BC-M-2	29.90			EM-H-6	21.44		
BC-M-3	20.84			EM-M-1	21.44		
BC-M-4	47.78			EM-M-2	30.00		
BC-M-5	44.36			EM-M-3	10.76		
BF-H-1	36.54			EM-M-4	17.34		
BF-H-2	36.54			EM-M-5	32.06		
BF-H-3	19.16			EM-M-6	32.82		
BF-H-4	34.32			EM-M-7	39.50		
BF-H-5	62.26			EM-M-8	20.20		
BF-M-1	11.10			FP-H-1	28.70		
BF-M-2	24.88			FP-H-2	17.34		
BF-M-3	62.26			FP-H-3	118.22		
BF-M-4	39.80			FP-H-4	105.32		
BF-M-5	35.62			FP-H-5	118.22		
BF-M-6	19.16			FP-M-1	10.76		
BF-M-7	43.94			FP-M-2	17.34		
DR-H-1	58.66			FP-M-3	5.74		
DR-H-2	76.62			FP-M-4	16.24		
DR-H-3	88.44			FP-M-5	49.16		
DR-H-4	86.08			FP-M-6	43.40		
DR-H-5	187.54			MC-H-1	15.20		
DR-H-6	190.94			MC-H-2	15.20		
DR-M-1	10.76			MC-H-3	18.84		
DR-M-2	17.34			MC-H-4	13.24		
DR-M-3	64.14			MC-H-5	18.92		
DR-M-4	39.10			MC-H-6	9.78		
DR-M-5	174.08			MC-M-1	15.52		

Economic Evaluation Worksheet for a Single-Ply Roofing System

Agency/Inst: 515 - NAS Patuxent River, Md | Building/Section: 515 A | Area: 16000 SF | Age: 0

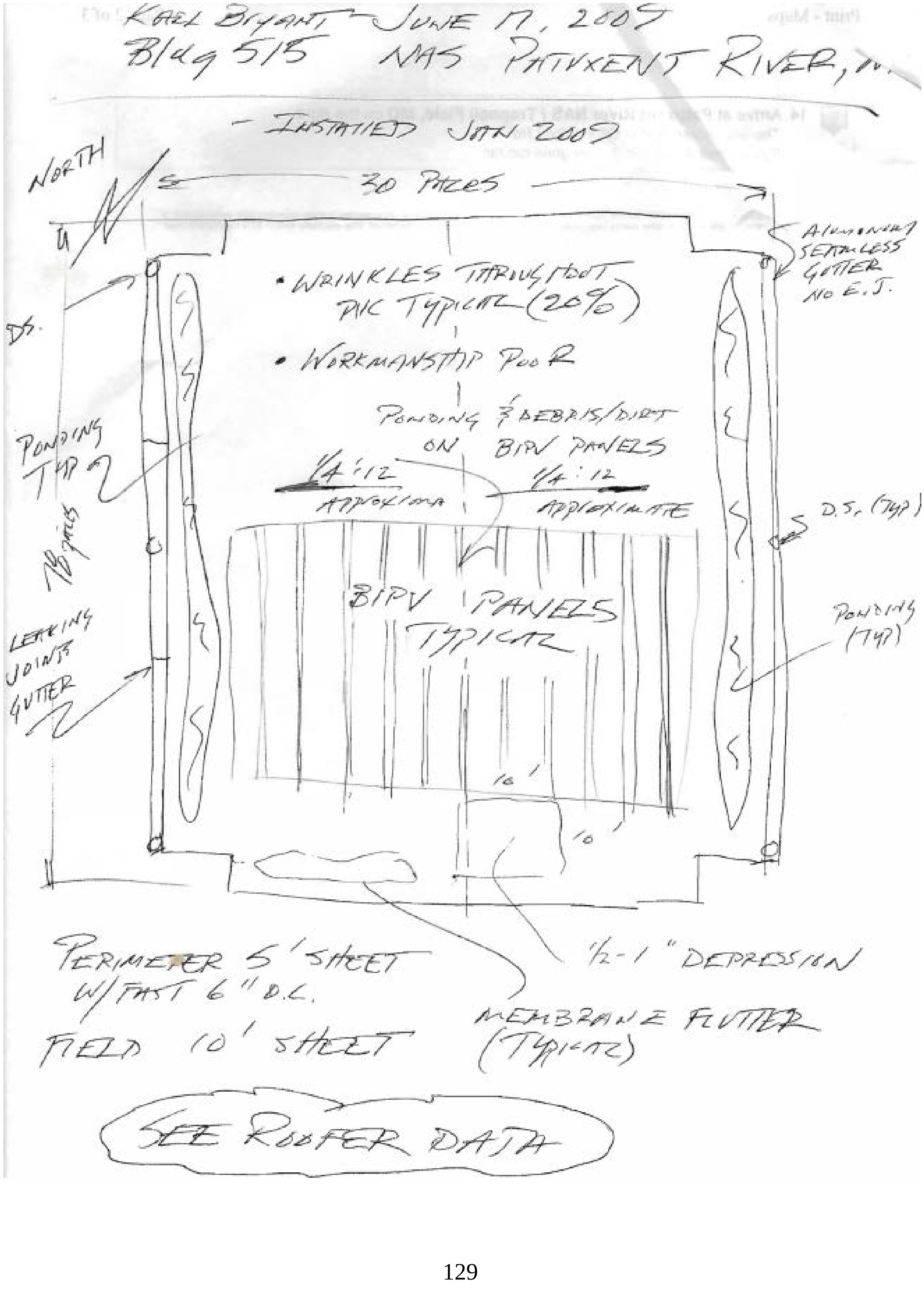
Flashing

DIS-SL-DF	Unit Cost	Qty	Total Cost	DIS-SL-DF	Unit Cost	Qty	Total Cost
MC-M-2	7.10						
MC-M-3	9.98						
PP-H-1	58.66						
PP-H-2	76.62						
PP-H-3	73.42						
PP-H-4	107.86						
PP-H-5	264.70						
PP-M-1	10.76						
PP-M-2	17.34						
PP-M-3	43.40						
PP-M-4	264.70						

Insulation: 0.00 NONE

Repair SetUp Charge = $ 1500

2009 ROOFER Field Notes



2010 ROOFER Assessment

- Source files were lost due to computer failure.

2011 ROOFER Assessment

Date: AUG/16/2011	Visual Inspection Summary	Page 1

Installation: 0000 - NAS Patuxent River

Date Inspected:	07/27/2011
Building:	515 - BIPV Test Building
Section:	515A - 515 A
Roof Type:	Membrane
Category Code:	90000 Real Estate

Roof Section Area: 16000 SqFt

Flashing Length: 580 Ft Perimeter: 580 Ft Curb: 0 Ft

FCI of Section:	91	Rating: Excellent
MCI of Section:	74	Rating: Very Good
ICI of Section:	None	Rating: None
RCI of Section:	80	Rating: MINOR REPAIRS NEEDED

Flashing Distresses

Distress Type		Severity	Quantity	Density	Deduct
FP	FLASHED PEN	M	4	0.69	6.3
MC	METAL CAP	L	75	12.93	8.8

Membrane Distresses

Distress Type		Severity	Quantity	Density	Deduct
DV	DEBRIS & VEG	M	2000	12.50	10.8
MS	MEMBRANE SUPPORT	L	2800	17.50	26.4
PA	PATCHING	L	5	0.03	2.2
PD	PONDING	M	225	1.41	4.9
SS	SYS. SECUREMENT	H	8	0.05	2.2
SS	SYS. SECUREMENT	M	23	0.14	3.7

Maintenance, Repair & Replacement Analysis

Building:	515 - BIPV Test Building	Area Cost Index:	$2.00
Section:	515A	Roof Replacement Cost:	$8.00 per SF
Section Area:	16000	Insulation Replacement Cost:	$12.00 per SF
Roofing Type:	SINGLE-PLY: PVC		

Originally Constructed/Last Replaced:	2009	Visual Inspection Date:	7/27/2011
Current Age:	2 Year(s)	Insulation Inspection Date:	--------

Predicted Year of Replacement (w/o repairs):			2013				
Additional Service Life (w/repairs):			7	Year(s)		Current	Improved
Predicted Year of Replacement (w/repairs):			2020		RCI	80	80
					FCI	91	91
Cost for Repairs:	$	20933.00	2990.43	$/year	MCI	74	74
Cost for Replacement:	$	128000.00	6400.00	$/year	100	100	

Adjusted Repair/Replace Ratio = 0.49 Recommendation: Repair

Corrective Action Requirement Sheet

Roof Replacement

(Note: Attach a copy of this form, along with a copy of the Roof Inspection Worksheet to DA Form 4283)

Agency/Inst.:	0000 - NAS Patuxent River	Facility No:	515
Bldg No./Sec:	515 515A	Bldg Name:	BIPV Test Building
Bldg Use:	Admin	Inspection Date:	Jul/2011
Membrane:	SINGLE-PLY: PVC	Area (SF):	16000
Surfacing:	NONE	Age (Yrs):	2
Vapor Ret:	NONE	Deck Type:	WOOD BOARDS
Insulation:	POLYISOCYANURATE	Est Replace Cost:	$ 128000.00

CORRECTIVE ACTION RECOMMENDED: Total replacement of roof in 2013

JUSTIFICATION: An economic analysis of the roof condition, including age, indicates that it is more cost effective to totally replace the roofing system, rather than perform the necessary maintenance, repair, and/or partial replacement of the roofing system.

DESIGN CONSIDERATIONS: The following considerations should be addressed during the design and construction phases of the replacement system:

a. Type replacement systems could include
    1) bituminous built-up membrane
    2) single-ply membrane, such as EPDM, PVC etc.. If a ballasted system is selected, determine if the structural components can sustain the added weight (approx. 10 lbs/SF).

b. Ensure that the roof has positive drainage slope of at least 1/4 inches per foot. Correct all areas that now contain ponded water.

c. Remove all unnecessary roof mounted equipment.

d. Inspect and repair or replace, as necessary, all remaining roof mounted equipment.

e. Ensure that all roof mounted equipment and penetrations are properly installed on the roof.

f. Live load and dead load impacts shall be taken into account in the design.

g. Until the replacement roof is installed, accomplish temporary repairs to ensure that the roof remains leak free.

Corrective Action Requirement Sheet

Major Repair

(Note: Attach a copy of this form, along with a copy of the Roof Inspection Worksheet to DA Form 4283

Agency/Inst.:	0000 - NAS Patuxent River	Facility No:	515
Bldg No./Sec:	515 515A	Bldg Name:	BIPV Test Building
Bldg Use:	Admin	Inspection Date:	Jul/2011
Membrane:	SINGLE-PLY: PVC	Area (SF):	16000
Surfacing:	NONE	Age (Yrs):	2
Vapor Ret:	NONE	Deck Type:	WOOD BOARDS
Insulation:	POLYISOCYANURATE	Est. Repair Cost:	$ 20933.00

CORRECTIVE ACTION RECOMMENDED: Maintenance, Repair and/or Partial Replacement

JUSTIFICATION: An economic analysis of the roof condition, including age, indicates that it is more cost effective to accomplish the necessary maintenance, repairs and/or partial replacement of the roofing components rather than replace the roofing system. Therefore, accomplish the following actions for the above roof section.

[Note: numbers refer to identification numbers of distresses corresponding with the Roof Inspection Worksheet]

1.	PD-M-1 45 SF	Remove wrinkled membrane blocking drainage, clean and prepare surface and install membrane patch. [1]
2.	PD-M-1 30 SF	Remove wrinkled membrane blocking drainage, clean and prepare surface and install membrane patch. [2]
3.	PD-M-1 30 SF	Remove wrinkled membrane blocking drainage, clean and prepare surface and install membrane patch. [3]
4.	PD-M-1 30 SF	Remove wrinkled membrane blocking drainage, clean and prepare surface and install membrane patch. [4]
5.	PD-M-1 10 SF	Remove wrinkled membrane blocking drainage, clean and prepare surface and install membrane patch. [5]
6.	PD-M-1 10 SF	Remove wrinkled membrane blocking drainage, clean and prepare surface and install membrane patch. [6]
7.	PD-M-1 50 SF	Remove wrinkled membrane blocking drainage, clean and prepare surface and install membrane patch. [7]
8.	PD-M-1 20 SF	Remove wrinkled membrane blocking drainage, clean and prepare surface and install membrane patch. [8]
9.	SS-M-2 23 SF	Remove loose fastener, install new fastener and install membrane patch over repair area. [9]
10.	SS-H-2 8 SF	Remove loose fasteners, install new fasteners and install membrane patch over repair area. [10]
12.	DV-M-1 2000 SF	Clean membrane surface of dirt and vegetation. [12]
15.	FP-M-3 2 LF	Seal top of flashing sleeve around flashed penetration. [15]
16.	FP-M-5 2 LF	Install umbrella or weather hood on flashed penetration. [16]

Economic Evaluation Worksheet for a Single-Ply Roofing System

Agency/Inst: 0000 - NAS Patuxent River | Building/Section: 515 515A | Area: 16000 SF | Age: 2

Total Repair Costs	$	20933		Replacement Cost @ $8.00/SF	$	128000
Additional Service Life		7	Yrs			
Total Repair Cost/ Additional Service Life	$	2990.43	$/Yr	Replacement Cost/20 Years	$	6400 $/Yr

Cost Analysis

Generated: Aug/16/2011

$$\text{Ratio} = \frac{\text{Repair Cost/Year}}{\text{Replace Cost/Year}} = 0.47$$

Adjusted Ratio = Ratio + (0.01 * Age) = 0.49

Adjusted Ratio	Recommended Action
0 - 0.8	Repair
0.8 - 1.2	Marginal
> 1.2	Replace

Membrane

DIS-SL-DF	Unit Cost	Qty	Total Cost	DIS-SL-DF	Unit Cost	Qty	Total Cost
DS-H-1	29.18			MS-M-2	39.42		
DS-H-2	35.42			MS-M-3	26.18		
DS-M-1	24.74			PA-H-1	33.98		
DS-M-2	35.42			PA-M-1	33.98		
DV-H-1	42.66			PD-M-1	32.22	225	$ 7249.50
DV-H-2	42.66			PD-M-2	59.54		
DV-M-1	5.86	2000	$ 11720.00	RG-H-1	24.10		
DV-M-2	42.66			SC-M-1	19.88		
DV-M-3	5.86			SP-H-1	24.10		
EQ-H-1	89.92			SS-H-1	35.96		
EQ-H-2	81.94			SS-H-2	27.58	8	$ 220.64
EQ-M-1	41.90			SS-H-3	27.72		
EQ-M-2	81.94			SS-H-4	5.68		
HL-H-1	66.54			SS-M-1	35.96		
HL-H-2	29.52			SS-M-2	27.58	23	$ 634.34
HL-M-1	14.30			SS-M-3	27.72		
MD-H-1	25.04			SS-M-4	5.68		
MD-M-1	14.46						
MS-M-1	33.60						

Economic Evaluation Worksheet for a Single-Ply Roofing System

Agency/Inst: 0000 - NAS Patuxent River | Building/Section: 515 515A | Area: 16000 SF | Age: 2

Flashing

DIS-SL-DF	Unit Cost	Qty	Total Cost	DIS-SL-DF	Unit Cost	Qty	Total Cost
BC-H-1	51.76			EM-H-1	19.24		
BC-H-2	47.78			EM-H-2	70.76		
BC-H-3	20.84			EM-H-3	36.18		
BC-H-4	152.08			EM-H-4	31.10		
BC-M-1	47.78			EM-H-5	39.50		
BC-M-2	29.90			EM-H-6	21.44		
BC-M-3	20.84			EM-M-1	21.44		
BC-M-4	47.78			EM-M-2	30.00		
BC-M-5	44.36			EM-M-3	10.76		
BF-H-1	36.54			EM-M-4	17.34		
BF-H-2	36.54			EM-M-5	32.06		
BF-H-3	19.16			EM-M-6	32.82		
BF-H-4	34.32			EM-M-7	39.50		
BF-H-5	62.26			EM-M-8	20.20		
BF-M-1	11.10			FP-H-1	28.70		
BF-M-2	24.88			FP-H-2	17.34		
BF-M-3	62.26			FP-H-3	118.22		
BF-M-4	39.80			FP-H-4	105.32		
BF-M-5	35.62			FP-H-5	118.22		
BF-M-6	19.16			FP-M-1	10.76		
BF-M-7	43.94			FP-M-2	17.34		
DR-H-1	58.66			FP-M-3	5.74	2	$ 11.48
DR-H-2	76.62			FP-M-4	16.24		
DR-H-3	88.44			FP-M-5	49.16	2	$ 98.32
DR-H-4	86.08			FP-M-6	43.40		
DR-H-5	187.54			MC-H-1	15.20		
DR-H-6	190.94			MC-H-2	15.20		
DR-M-1	10.76			MC-H-3	18.84		
DR-M-2	17.34			MC-H-4	13.24		
DR-M-3	64.14			MC-H-5	18.92		
DR-M-4	39.10			MC-H-6	9.78		
DR-M-5	174.08			MC-M-1	15.52		

Economic Evaluation Worksheet for a Single-Ply Roofing System

Agency/Inst: 0000 - NAS Patuxent River | Building/Section: 515 515A | Area: 16000 SF | Age: 2

Flashing

DIS-SL-DF	Unit Cost	Qty	Total Cost	DIS-SL-DF	Unit Cost	Qty	Total Cost
MC-M-2	7.10						
MC-M-3	9.98						
PP-H-1	58.66						
PP-H-2	76.62						
PP-H-3	73.42						
PP-H-4	107.86						
PP-H-5	264.70						
PP-M-1	10.76						
PP-M-2	17.34						
PP-M-3	43.40						
PP-M-4	264.70						

Insulation: 0.00 NONE

Repair SetUp Charge = $ 1000

2011 ROOFER Field Notes

ROOF INSPECTION WORKSHEET

AGENCY/ INST. PAX RIVER

BUILDING 515
SECTION

PER. FLASHING 580 LF
CURB FLASHING 0 LF

AREA SF
NAME/DATE 27 Jul 2011

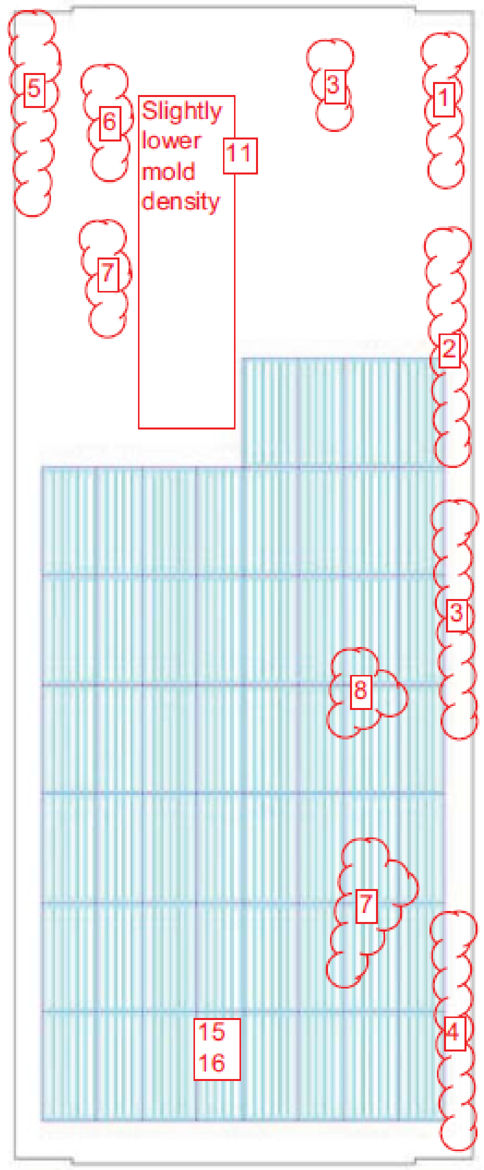
BUILT–UP ROOF	BUILT–UP AND SINGLE PLY			SINGLE PLY
BL–BLISTER SR–SURF DET SL–SLIPPAGE	BF–BASE FLASH MC–METAL CAP EM–EMBEDDED MET FP–FLASHED PEN PP–PITCH PAN	HL–HOLES PA–PATCHING DV–DEB & VEG EQ–EQ SUPPORT PD–PONDING	DR–DRAIN & SCUP RG–RIDGES SP–SPLITS	BC–BASE FL–METAL DS–DEF SEAM SC–SURF COAR MD–MEM DET SS–SYSTEM SEC MS–MEM SUPPORT

ID #	DIS	SEV	DEF	QTY
1	PD	M	1	45
2	PD	M	1	30
3	PD	M	1	30
4	PD	M	1	30
5	PD	M	1	10
6	PD	M	1	10
7	PD	M	1	50
8	PD	M	1	20
9	SS	M	2	23
10	SS	H	2	8
11	PA	L	1	5
12	DV	M	1	2000
13	MS	L	1	2800
14	MC	L	2	75
15	FP	M	3	2
16	FP	M	5	2

12: 5% mold on all exposed PVC

13: All Underlayment warped

9,10 Along attachment lines 23 non consecutive fasteners popped and 8 examples of 2 or more consecutive fasteners



515

SYMBOLS KEY
- □ ROOF CURB
- ○ VENT STACK
- ● HEAT STACK
- → SLOPE DIRECTION
- ● ROOF DRAIN
- ◐ FLASHED PENETRATION
- ① DEFECT LOCATION

Appendix I
Site II (NAS Patuxent River) Albedo Assessments

Sample Number	**1**	**2**	**3**
Sample Description	PVC near Met Station	PV near met tower	large area PVC
Comments	moldy & slight soiled	looked clean	moldy
E1918/E1918A Trial 1			
Clock Time (hh:mm AM/PM)	10:30 AM	11:05 AM	11:35 AM
Local Standard Time (decimal)	9.5	10.1	10.6
Solar Altitude (degrees above horizon)	53	59	64
Solar Altitude at least 45 degrees?	TRUE	TRUE	TRUE
Expected Incident Solar Radiation (W m^{-2})	827	906	958
Incident Solar Radiation, Initial (W m^{-2})	792	842	878
Solar Radiation Reflected from Sample + White Mask over Black Mask (W m^{-2})	572	335	587
Solar Radiation Reflected from Sample + Black Mask (W m^{-2})	301	109	346
Solar Radiation Reflected from Sample (W m^{-2})	470	168	560
Incident Solar Radiation, Final (W m^{-2})	796	846	882
Absolute Difference in Incident Solar Radiation (W m^{-2})	4	4	4
E1918 Solar Reflectance (0-1) **(valid only if surface area ? 10 m^2)**	0.593	0.200	0.638
E1918A Solar Reflectance (0-1) **(describes surface covered by masks)**	0.462	0.222	0.636
E1918/E1918A Trial 2			
Clock Time (hh:mm AM/PM)	10:35 AM	11:10 AM	11:40 AM
Local Standard Time (decimal)	9.6	10.2	10.7
Solar Altitude (degrees above horizon)	54	60	65
Solar Altitude at least 45 degrees?	TRUE	TRUE	TRUE
Expected Incident Solar Radiation (W m^{-2})	840	915	965
Incident Solar Radiation, Initial (W m^{-2})	803	847	888
Solar Radiation Reflected from Sample + White Mask over Black Mask (W m^{-2})	530	348	595
Solar Radiation Reflected from Sample + Black Mask (W m^{-2})	302	106	352
Solar Radiation Reflected from Sample (W m^{-2})	508	168	568
Incident Solar Radiation, Final (W m^{-2})	809	848	893
Absolute Difference in Incident Solar Radiation (W m^{-2})	6	1	5
E1918 Solar Reflectance (0-1) **(valid only if surface area ? 10 m^2)**	0.633	0.198	0.640
E1918A Solar Reflectance (0-1) **(describes surface covered by masks)**	0.646	0.219	0.637
E1918/E1918A Trial 3			
Clock Time (hh:mm AM/PM)	10:45 AM	11:15 AM	11:45 AM
Local Standard Time (decimal)	9.8	10.3	10.8
Solar Altitude (degrees above horizon)	56	61	65
Solar Altitude at least 45 degrees?	TRUE	TRUE	TRUE
Expected Incident Solar Radiation (W m^{-2})	863	925	972
Incident Solar Radiation, Initial (W m^{-2})	814	852	894
Solar Radiation Reflected from Sample + White Mask over Black Mask (W m^{-2})	540	341	602
Solar Radiation Reflected from Sample + Black Mask (W m^{-2})	310	111	364
Solar Radiation Reflected from Sample (W m^{-2})	519	169	573
Incident Solar Radiation, Final (W m^{-2})	822	856	898
Absolute Difference in Incident Solar Radiation (W m^{-2})	8	4	4
E1918 Solar Reflectance (0-1) **(valid only if surface area ? 10 m^2)**	0.638	0.198	0.641
E1918A Solar Reflectance (0-1) **(describes surface covered by masks)**	0.650	0.216	0.630
E1918 Summary			
Trial 1	0.593	0.200	0.638
Trial 2	0.633	0.198	0.640
Trial 3	0.638	0.198	0.641
Mean	0.621	0.199	0.639
Standard Deviation	0.024	0.001	0.002

Appendix J
Site III (MCAS Yuma) ROOFER Assessments

2010 ROOFER Assessment

Date: DEC/18/2009	Visual Inspection Summary	Page 1

Installation: MCAS - Yuma MCAS

Date Inspected: 12/17/2009
Building: 288 - Building 288 Enviromental
Section: 1 - Main
Roof Type: Membrane

Category Code: 90000 Real Estate

Roof Section Area: 9043 SqFt

Flashing Length: 472 Ft Perimeter: 460 Ft Curb: 12 Ft

FCI of Section:	94	Rating:	Excellent
MCI of Section:	98	Rating:	Excellent
ICI of Section:	None	Rating:	None
RCI of Section:	95	Rating:	ROUTINE MAINTENANCE ONLY

Flashing Distresses

Distress Type		Severity	Quantity	Density	Deduct
BF	BASE FLASHING	L	12	2.54	5.7
FP	FLASHED PEN	L	1	0.21	2.5

Membrane Distresses

Distress Type		Severity	Quantity	Density	Deduct
DS	DEFECTIVE SEAMS	L	6	0.07	2.2
PA	PATCHING	L	1	0.01	0.3

Maintenance, Repair & Replacement Analysis

Building:	288 - Building 288 Enviromental	Area Cost Index:	$2.00
Section:	1	Roof Replacement Cost:	$8.00 per SF
Section Area:	9043	Insulation Replacement Cost:	$12.00 per SF
Roofing Type:	SINGLE-PLY: PVC		

Originally Constructed/Last Replaced: 2009 Visual Inspection Date: 12/17/2009
Current Age: 0 Year(s) Insulation Inspection Date: --------

Predicted Year of Replacement (w/o repairs): 2024
Additional Service Life (w/repairs): 0 Year(s)
Predicted Year of Replacement (w/repairs): 2024

	Current	Improved
RCI	95	95
FCI	94	94
MCI	98	98
100	100	

Cost for Repairs:	$	0.00	------	$/year
Cost for Replacement:	$	72344.00	3617.00	$/year

Adjusted Repair/Replace Ratio = --- Recommendation: Replace

2011 ROOFER Assessment – Without Patch from Testing

Without Patch

Maintenance, Repair & Replacement Analysis

Building:	288 - Building 288 Enviromental	Area Cost Index:	$2.00
Section:	1	Roof Replacement Cost:	$8.00 per SF
Section Area:	9043	Insulation Replacement Cost:	$12.00 per SF
Roofing Type:	SINGLE-PLY: PVC		

Originally Constructed/Last Replaced:	2009	Visual Inspection Date:	10/14/2011
Current Age:	3 Year(s)	Insulation Inspection Date:	--------

Predicted Year of Replacement (w/o repairs):		2016				
Additional Service Life (w/repairs):		11 Year(s)			Current	Improved
Predicted Year of Replacement (w/repairs):		2027		RCI	95	95
				FCI	94	94
Cost for Repairs:	$ 1072.00	97.45	$/year	MCI	98	98
Cost for Replacement:	$ 72344.00	3617.00	$/year	100	100	

Adjusted Repair/Replace Ratio = 0.06 Recommendation: Repair

Corrective Action Requirement Sheet

Major Repair

(Note: Attach a copy of this form, along with a copy of the Roof Inspection Worksheet to DA Form 4283

Agency/Inst.:	MCAS - Yuma MCAS	Facility No:	288
Bldg No./Sec:	288 1	Bldg Name:	Building 288 Enviromental
Bldg Use:	Ofice	Inspection Date:	Oct/2011
Membrane:	SINGLE-PLY: PVC	Area (SF):	9043
Surfacing:	NONE	Age (Yrs):	3
Vapor Ret:	NONE	Deck Type:	PLYWOOD
Insulation:	POLYISOCYANURATE	Est. Repair Cost:	$ 1072.00

CORRECTIVE ACTION RECOMMENDED: Maintenance, Repair and/or Partial Replacement

JUSTIFICATION: An economic analysis of the roof condition, including age, indicates that it is more cost effective to accomplish the necessary maintenance, repairs and/or partial replacement of the roofing components rather than replace the roofing system. Therefore, accomplish the following actions for the above roof section.

[Note: numbers refer to identification numbers of distresses corresponding with the Roof Inspection Worksheet]

3. SS-M-1 1 SF — Cut unadhered membrane, clean and prepare surface, readhere and install membrane patch over repair area. [3]

5. SS-M-1 1 SF — Cut unadhered membrane, clean and prepare surface, readhere and install membrane patch over repair area. [5]

Economic Evaluation Worksheet for a Single-Ply Roofing System

Agency/Inst: MCAS - Yuma MCAS | Building/Section: 288 1 | Area: 9043 SF | Age: 3

Total Repair Costs	$	1072		Replacement Cost @ $8.00/SF	$	72344
Additional Service Life		11	Yrs			
Total Repair Cost/ Additional Service Life	$	97.45	$/Yr	Replacement Cost/20 Years	$	3617 $/Yr

Cost Analysis — Generated: Oct/17/2012

Ratio = Repair Cost/Year / Replace Cost/Year = 0.03

Adjusted Ratio = Ratio + (0.01 * Age) = 0.06

Adjusted Ratio	Recommended Action
0 - 0.8	Repair
0.8 - 1.2	Marginal
> 1.2	Replace

Membrane

DIS-SL-DF	Unit Cost	Qty	Total Cost
DS-H-1	29.18		
DS-H-2	35.42		
DS-M-1	24.74		
DS-M-2	35.42		
DV-H-1	42.66		
DV-H-2	42.66		
DV-M-1	5.86		
DV-M-2	42.66		
DV-M-3	5.86		
EQ-H-1	89.92		
EQ-H-2	81.94		
EQ-M-1	41.90		
EQ-M-2	81.94		
HL-H-1	66.54		
HL-H-2	29.52		
HL-M-1	14.30		
MD-H-1	25.04		
MD-M-1	14.46		
MS-M-1	33.60		
MS-M-2	39.42		
MS-M-3	26.18		
PA-H-1	33.98		
PA-M-1	33.98		
PD-M-1	32.22		
PD-M-2	59.54		
RG-H-1	24.10		
SC-M-1	19.88		
SP-H-1	24.10		
SS-H-1	35.96		
SS-H-2	27.58		
SS-H-3	27.72		
SS-H-4	5.68		
SS-M-1	35.96	2	$ 71.92
SS-M-2	27.58		
SS-M-3	27.72		
SS-M-4	5.68		

Economic Evaluation Worksheet for a Single-Ply Roofing System

Agency/Inst: MCAS - Yuma MCAS | Building/Section: 288 1 | Area: 9043 SF | Age: 3

Flashing

DIS-SL-DF	Unit Cost	Qty	Total Cost
BC-H-1	51.76		
BC-H-2	47.78		
BC-H-3	20.84		
BC-H-4	152.08		
BC-M-1	47.78		
BC-M-2	29.90		
BC-M-3	20.84		
BC-M-4	47.78		
BC-M-5	44.36		
BF-H-1	36.54		
BF-H-2	36.54		
BF-H-3	19.16		
BF-H-4	34.32		
BF-H-5	62.26		
BF-M-1	11.10		
BF-M-2	24.88		
BF-M-3	62.26		
BF-M-4	39.80		
BF-M-5	35.62		
BF-M-6	19.16		
BF-M-7	43.94		
DR-H-1	58.66		
DR-H-2	76.62		
DR-H-3	88.44		
DR-H-4	86.08		
DR-H-5	187.54		
DR-H-6	190.94		
DR-M-1	10.76		
DR-M-2	17.34		
DR-M-3	64.14		
DR-M-4	39.10		
DR-M-5	174.08		
EM-H-1	19.24		
EM-H-2	70.76		
EM-H-3	36.18		
EM-H-4	31.10		
EM-H-5	39.50		
EM-H-6	21.44		
EM-M-1	21.44		
EM-M-2	30.00		
EM-M-3	10.76		
EM-M-4	17.34		
EM-M-5	32.06		
EM-M-6	32.82		
EM-M-7	39.50		
EM-M-8	20.20		
FP-H-1	28.70		
FP-H-2	17.34		
FP-H-3	118.22		
FP-H-4	105.32		
FP-H-5	118.22		
FP-M-1	10.76		
FP-M-2	17.34		
FP-M-3	5.74		
FP-M-4	16.24		
FP-M-5	49.16		
FP-M-6	43.40		
MC-H-1	15.20		
MC-H-2	15.20		
MC-H-3	18.84		
MC-H-4	13.24		
MC-H-5	18.92		
MC-H-6	9.78		
MC-M-1	15.52		

Economic Evaluation Worksheet for a Single-Ply Roofing System

Agency/Inst: MCAS - Yuma MCAS | Building/Section: 288 1 | Area: 9043 SF | Age: 3

Flashing

DIS-SL-DF	Unit Cost	Qty	Total Cost
MC-M-2	7.10		
MC-M-3	9.98		
PP-H-1	58.66		
PP-H-2	76.62		
PP-H-3	73.42		
PP-H-4	107.86		
PP-H-5	264.70		
PP-M-1	10.76		
PP-M-2	17.34		
PP-M-3	43.40		
PP-M-4	264.70		

Insulation: 0.00 NONE

Repair SetUp Charge = $ 1000

Without Patch

Date: OCT/17/2012	Visual Inspection Summary	Page 1

Installation: MCAS - Yuma MCAS

Date Inspected:	10/14/2011
Building:	288 - Building 288 Enviromental
Section:	1 - Main
Roof Type:	Membrane
Category Code:	90000 Real Estate
Roof Section Area:	9043 SqFt

Flashing Length: 472 Ft   Perimeter: 460 Ft   Curb: 12 Ft

FCI of Section:	94	Rating:	Excellent
MCI of Section:	98	Rating:	Excellent
ICI of Section:	None	Rating:	None
RCI of Section:	95	Rating:	ROUTINE MAINTENANCE ONLY

Flashing Distresses

Distress Type		Severity	Quantity	Density	Deduct
BF	BASE FLASHING	L	6	1.27	3.7
FP	FLASHED PEN	L	9	1.91	5.4

Membrane Distresses

Distress Type		Severity	Quantity	Density	Deduct
DS	DEFECTIVE SEAMS	L	6	0.07	2.2
SS	SYS. SECUREMENT	M	2	0.02	0.2

Remarks

simulated without patching. to account for roofcondition if testing had not been done

2011 ROOFER Assessment – With Patch from Testing

Maintenance, Repair & Replacement Analysis

Building:	288 - Building 288 Enviromental	Area Cost Index:	$2.00
Section:	1	Roof Replacement Cost:	$8.00 per SF
Section Area:	9043	Insulation Replacement Cost:	$12.00 per SF
Roofing Type:	SINGLE-PLY: PVC		

Originally Constructed/Last Replaced:	2009	Visual Inspection Date:	10/12/2011
Current Age:	2 Year(s)	Insulation Inspection Date:	--------

Predicted Year of Replacement (w/o repairs):		2014				
Additional Service Life (w/repairs):		9 Year(s)			Current	Improved
Predicted Year of Replacement (w/repairs):		2023		RCI	89	89
				FCI	94	94
Cost for Repairs:	$ 1072.00	119.11	$/year	MCI	85	85
Cost for Replacement:	$ 72344.00	3617.00	$/year	100	100	

Adjusted Repair/Replace Ratio = 0.05   Recommendation: Repair

Corrective Action Requirement Sheet

Roof Replacement

(Note: Attach a copy of this form, along with a copy of the Roof Inspection Worksheet to DA Form 4283)

Agency/Inst.:	MCAS - Yuma MCAS	Facility No:	288
Bldg No./Sec:	288 1	Bldg Name:	Building 288 Enviromental
Bldg Use:	Ofice	Inspection Date:	Oct/2011
Membrane:	SINGLE-PLY: PVC	Area (SF):	9043
Surfacing:	NONE	Age (Yrs):	2
Vapor Ret:	NONE	Deck Type:	PLYWOOD
Insulation:	POLYISOCYANURATE	Est Replace Cost:	$ 72344.00

CORRECTIVE ACTION RECOMMENDED: Total replacement of roof in 2014

JUSTIFICATION: An economic analysis of the roof condition, including age, indicates that it is more cost effective to totally replace the roofing system, rather than perform the necessary maintenance, repair, and/or partial replacement of the roofing system.

DESIGN CONSIDERATIONS: The following considerations should be addressed during the design and construction phases of the replacement system:

a. Type replacement systems could include
   1) bituminous built-up membrane
   2) single-ply membrane, such as EPDM, PVC etc.. If a ballasted system is selected, determine if the structural components can sustain the added weight (approx. 10 lbs/SF).

b. Ensure that the roof has positive drainage slope of at least 1/4 inches per foot. Correct all areas that now contain ponded water.

c. Remove all unnecessary roof mounted equipment.

d. Inspect and repair or replace, as necessary, all remaining roof mounted equipment.

e. Ensure that all roof mounted equipment and penetrations are properly installed on the roof.

f. Live load and dead load impacts shall be taken into account in the design.

g. Until the replacement roof is installed, accomplish temporary repairs to ensure that the roof remains leak free.

Corrective Action Requirement Sheet

Major Repair

(Note: Attach a copy of this form, along with a copy of the Roof Inspection Worksheet to DA Form 4283

Agency/Inst.:	MCAS - Yuma MCAS	Facility No:	288
Bldg No./Sec:	288 1	Bldg Name:	Building 288 Enviromental
Bldg Use:	Ofice	Inspection Date:	Oct/2011
Membrane:	SINGLE-PLY: PVC	Area (SF):	9043
Surfacing:	NONE	Age (Yrs):	2
Vapor Ret:	NONE	Deck Type:	PLYWOOD
Insulation:	POLYISOCYANURATE	Est. Repair Cost:	$ 1072.00

CORRECTIVE ACTION RECOMMENDED: Maintenance, Repair and/or Partial Replacement

JUSTIFICATION: An economic analysis of the roof condition, including age, indicates that it is more cost effective to accomplish the necessary maintenance, repairs and/or partial replacement of the roofing components rather than replace the roofing system. Therefore, accomplish the following actions for the above roof section.

[Note: numbers refer to identification numbers of distresses corresponding with the Roof Inspection Worksheet]

3.	SS-M-1 1 SF	Cut unadhered membrane, clean and prepare surface, readhere and install membrane patch over repair area. [3]
9.	SS-M-1 1 SF	Cut unadhered membrane, clean and prepare surface, readhere and install membrane patch over repair area. [9]

Economic Evaluation Worksheet for a Single-Ply Roofing System

Agency/Inst: MCAS - Yuma MCAS | Building/Section: 288 1 | Area: 9043 SF | Age: 2

Total Repair Costs	$	1072		Replacement Cost @ $8.00/SF	$	72344
Additional Service Life		9	Yrs			
Total Repair Cost/ Additional Service Life	$	119.11	$/Yr	Replacement Cost/20 Years	$	3617 $/Yr

Cost Analysis — Generated: Oct/18/2011

Ratio = Repair Cost/Year / Replace Cost/Year = 0.03

Adjusted Ratio = Ratio + (0.01 * Age) = 0.05

Adjusted Ratio	Recommended Action
0 - 0.8	Repair
0.8 - 1.2	Marginal
> 1.2	Replace

Membrane

DIS-SL-DF	Unit Cost	Qty	Total Cost	DIS-SL-DF	Unit Cost	Qty	Total Cost
DS-H-1	29.18			MS-M-2	39.42		
DS-H-2	35.42			MS-M-3	26.18		
DS-M-1	24.74			PA-H-1	33.98		
DS-M-2	35.42			PA-M-1	33.98		
DV-H-1	42.66			PD-M-1	32.22		
DV-H-2	42.66			PD-M-2	59.54		
DV-M-1	5.86			RG-H-1	24.10		
DV-M-2	42.66			SC-M-1	19.88		
DV-M-3	5.86			SP-H-1	24.10		
EQ-H-1	89.92			SS-H-1	35.96		
EQ-H-2	81.94			SS-H-2	27.58		
EQ-M-1	41.90			SS-H-3	27.72		
EQ-M-2	81.94			SS-H-4	5.68		
HL-H-1	66.54			SS-M-1	35.96	2	$ 71.92
HL-H-2	29.52			SS-M-2	27.58		
HL-M-1	14.30			SS-M-3	27.72		
MD-H-1	25.04			SS-M-4	5.68		
MD-M-1	14.46						
MS-M-1	33.60						

Economic Evaluation Worksheet for a Single-Ply Roofing System

Agency/Inst: MCAS - Yuma MCAS | Building/Section: 288 1 | Area: 9043 SF | Age: 2

Flashing

DIS-SL-DF	Unit Cost	Qty	Total Cost	DIS-SL-DF	Unit Cost	Qty	Total Cost
BC-H-1	51.76			EM-H-1	19.24		
BC-H-2	47.78			EM-H-2	70.76		
BC-H-3	20.84			EM-H-3	36.18		
BC-H-4	152.08			EM-H-4	31.10		
BC-M-1	47.78			EM-H-5	39.50		
BC-M-2	29.90			EM-H-6	21.44		
BC-M-3	20.84			EM-M-1	21.44		
BC-M-4	47.78			EM-M-2	30.00		
BC-M-5	44.36			EM-M-3	10.76		
BF-H-1	36.54			EM-M-4	17.34		
BF-H-2	36.54			EM-M-5	32.06		
BF-H-3	19.16			EM-M-6	32.82		
BF-H-4	34.32			EM-M-7	39.50		
BF-H-5	62.26			EM-M-8	20.20		
BF-M-1	11.10			FP-H-1	28.70		
BF-M-2	24.88			FP-H-2	17.34		
BF-M-3	62.26			FP-H-3	118.22		
BF-M-4	39.80			FP-H-4	105.32		
BF-M-5	35.62			FP-H-5	118.22		
BF-M-6	19.16			FP-M-1	10.76		
BF-M-7	43.94			FP-M-2	17.34		
DR-H-1	58.66			FP-M-3	5.74		
DR-H-2	76.62			FP-M-4	16.24		
DR-H-3	88.44			FP-M-5	49.16		
DR-H-4	86.08			FP-M-6	43.40		
DR-H-5	187.54			MC-H-1	15.20		
DR-H-6	190.94			MC-H-2	15.20		
DR-M-1	10.76			MC-H-3	18.84		
DR-M-2	17.34			MC-H-4	13.24		
DR-M-3	64.14			MC-H-5	18.92		
DR-M-4	39.10			MC-H-6	9.78		
DR-M-5	174.08			MC-M-1	15.52		

Economic Evaluation Worksheet for a Single-Ply Roofing System

Agency/Inst: MCAS - Yuma MCAS | Building/Section: 288 1 | Area: 9043 SF | Age: 2

Flashing

DIS-SL-DF	Unit Cost	Qty	Total Cost	DIS-SL-DF	Unit Cost	Qty	Total Cost
MC-M-2	7.10						
MC-M-3	9.98						
PP-H-1	58.66						
PP-H-2	76.62						
PP-H-3	73.42						
PP-H-4	107.86						
PP-H-5	264.70						
PP-M-1	10.76						
PP-M-2	17.34						
PP-M-3	43.40						
PP-M-4	264.70						

Insulation: 0.00 NONE

Repair SetUp Charge = $ 1000

Installation: MCAS - Yuma MCAS

Date Inspected:	10/12/2011
Building:	288 - Building 288 Enviromental
Section:	1 - Main
Roof Type:	Membrane
Category Code:	90000 Real Estate

Roof Section Area: 9043 SqFt

Flashing Length: 472 Ft | Perimeter: 460 Ft | Curb: 12 Ft

FCI of Section:	94	Rating:	Excellent
MCI of Section:	85	Rating:	Very Good
ICI of Section:	None	Rating:	None
RCI of Section:	89	Rating:	ROUTINE MAINTENANCE ONLY

Flashing Distresses

Distress Type		Severity	Quantity	Density	Deduct
BF	BASE FLASHING	L	6	1.27	3.7
FP	FLASHED PEN	L	9	1.91	5.4

Membrane Distresses

Distress Type		Severity	Quantity	Density	Deduct
DS	DEFECTIVE SEAMS	L	6	0.07	2.2
PA	PATCHING	L	321	3.55	14.7
SS	SYS. SECUREMENT	M	2	0.02	0.2

Appendix K
Site III (MCAS Yuma) Albedo Assessments

Sample Number	1	2	3
Sample Description	PVC near ladder	PVC near junction box	PV near fence in front
Comments	soiled	soiled	soiled
E1918/E1918A Trial 1			
Clock Time (hh:mm AM/PM)	2:15 PM	2:40 PM	3:00 PM
Local Standard Time (decimal)	13.3	13.7	14.0
Solar Altitude (degrees above horizon)	62	57	53
Solar Altitude at least 45 degrees?	TRUE	TRUE	TRUE
Expected Incident Solar Radiation (W m^{-2})	939	882	829
Incident Solar Radiation, Initial (W m^{-2})	902	889	777
Solar Radiation Reflected from Sample + White Mask over Black Mask (W m^{-2})	635	603	381
Solar Radiation Reflected from Sample + Black Mask (W m^{-2})	307	327	114
Solar Radiation Reflected from Sample (W m^{-2})	652	622	163
Incident Solar Radiation, Final (W m^{-2})	893	846	773
Absolute Difference in Incident Solar Radiation (W m^{-2})	9	43	4
E1918 Solar Reflectance (0-1) **(valid only if surface area ? 10 m^2)**	0.723	0.700	0.210
E1918A Solar Reflectance (0-1) **(describes surface covered by masks)**	0.744	0.755	0.171
E1918/E1918A Trial 2			
Clock Time (hh:mm AM/PM)	2:20 PM	2:45 PM	3:05 PM
Local Standard Time (decimal)	13.3	13.8	14.1
Solar Altitude (degrees above horizon)	61	56	52
Solar Altitude at least 45 degrees?	TRUE	TRUE	TRUE
Expected Incident Solar Radiation (W m^{-2})	929	869	815
Incident Solar Radiation, Initial (W m^{-2})	887	841	753
Solar Radiation Reflected from Sample + White Mask over Black Mask (W m^{-2})	628	577	378
Solar Radiation Reflected from Sample + Black Mask (W m^{-2})	302	299	110
Solar Radiation Reflected from Sample (W m^{-2})	652	614	165
Incident Solar Radiation, Final (W m^{-2})	882	841	765
Absolute Difference in Incident Solar Radiation (W m^{-2})	5	0	12
E1918 Solar Reflectance (0-1) **(valid only if surface area ? 10 m^2)**	0.735	0.730	0.219
E1918A Solar Reflectance (0-1) **(describes surface covered by masks)**	0.759	0.798	0.185
E1918/E1918A Trial 3			
Clock Time (hh:mm AM/PM)	2:25 PM	2:50 PM	3:10 PM
Local Standard Time (decimal)	13.4	13.8	14.2
Solar Altitude (degrees above horizon)	60	55	51
Solar Altitude at least 45 degrees?	TRUE	TRUE	TRUE
Expected Incident Solar Radiation (W m^{-2})	918	856	801
Incident Solar Radiation, Initial (W m^{-2})	877	811	765
Solar Radiation Reflected from Sample + White Mask over Black Mask (W m^{-2})	616	571	374
Solar Radiation Reflected from Sample + Black Mask (W m^{-2})	304	295	113
Solar Radiation Reflected from Sample (W m^{-2})	641	599	159
Incident Solar Radiation, Final (W m^{-2})	866	755	744
Absolute Difference in Incident Solar Radiation (W m^{-2})	11	56	21
E1918 Solar Reflectance (0-1) **(valid only if surface area ? 10 m^2)**	0.731	0.739	0.208
E1918A Solar Reflectance (0-1) **(describes surface covered by masks)**	0.763	0.777	0.166
E1918 Summary			
Trial 1	0.723	0.700	0.210
Trial 2	0.735	0.730	0.219
Trial 3	0.731	0.739	0.208
Mean	0.730	0.723	0.212
Standard Deviation	0.006	0.020	0.006

Appendix L
Site III (MCAS Yuma) ASTM D 4434 Test Results

Momentum Technologies, inc.
1507 Boettler Rd. Uniontown, OH 44685
Ph: 330-896-5900
Fax: 330-896-9943

Technical Service Report

Project #:	NX10L0A
Quote #:	2010-372-1
Date:	1/7/2011
PO#:	

SEI Group, Inc.
Mark Kelley
303 Williams Ave SW Suite 135
Huntsville AL 35801
Ph: 256-533-0500 **Fax:** 256-533-5516

Abstract: Analysis of one field Aged PVC membrane per customer selected tests contained within ASTM D4434.

MTI#	Description of Material	Receiving Date
MTI-100948	Field Aged PVC Membrane labeled Yuma Roof Open Roof	11/4/2010

Test	ASTM	Requirement	Result	Conclusion
Breaking Strength per ASTM D751, A - Grab Method - MD	D 4434 Type III	min. 35 kN/m (200 lbf/in)	303 lbf/in.	Pass
Breaking Strength per ASTM D751, A - Grab Method - XMD	D 4434 Type III	min. 35 kN/m (200 lbf/in)	299 lbf/in	Pass
Change in Weight after Immersion in Water per ASTM D570 (168 hrs @ 70°C)	D 4434 Type III	max. ± 3.0	0.68%	Pass
Dynamic Puncture Resistance per ASTM D5635	D 4434 Type III	Pass at min. 20 J (7.3 ft-lb)	22.6 joules	Pass
Elongation at Break per ASTM D751, A - Grab Method - MD		min. 15%	115.6%	Pass
Elongation at Break per ASTM D751, A - Grab Method - XMD	D 4434 Type III	min. 15%	82.4%	Pass
Heat Aging (56 days @ 80°C) per ASTM D3045	D 4434 Type III		Completed Jan 6, 2011	
Linear Dimensional Change per ASTM D1204 (6 hrs @ 80°C) Cross Machine Direction	D 4434 Type III	max. 0.5%	0.0%	Pass
Linear Dimensional Change per ASTM D1204 (6 hrs @ 80°C) Machine Direction	D 4434 Type III	max. 0.5%	-0.25%	Pass
Low Temperature Bend per ASTM D2136 @ -40°C	D 4434 Type III	Pass	No Cracking	Pass

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Project #: NX10L0A Company: SEI Group, Inc. Page 1 of 2

Test	ASTM	Requirement	Result	Conclusion
Overall Thickness per ASTM D751	D 4434 Type III	min. 1.14 mm (0.045 in.)	.0483 in	Pass
Overall Thickness per ASTM D751 MD	D 4434 Type III	min. 1.14 mm (0.045 in.)	.0479 in	Pass
Post Heat Aged Breaking Strength per ASTM D751, A - Grab Method - MD	D 4434 Type III	min. 90% of original	367 lbf	Pass
Post Heat Aged Breaking Strength per ASTM D751, A - Grab Method - XMD	D 4434 Type III	min. 90% of original	344 lbf	Pass
Post Heat Aged Elongation per ASTM D751, A - Grab Method - MD	D 4434 Type III	min. 90% of original	128 %	Pass
Post Heat Aged Elongation per ASTM D751, A - Grab Method - XMD	D 4434 Type III	min. 90% of original	90%	Pass
Seam Strength per ASTM D751, A - Grab Method	D 4434 Type III	min. 75% of breaking strength(150 lbf/in)	156.5 lbf/in	Pass
Static Puncture Resistance per ASTM D5602	D 4434 Type III	Pass at min. 15 kg (33 lbf)	No puncture @ 75 lb	Pass
Tearing Strength per ASTM D751, B - Tongue Tear Method (8x8) - MD	D 4434 Type III	min. 200 N (45.0 lbf)	35 lbf	Fail
Tearing Strength per ASTM D751, B - Tongue Tear Method (8x8) - XMD	D 4434 Type III	min. 200 N (45.0 lbf)	54 lbf	Pass

Conclusion: Yuma Roof Open Roof does not meet the requirements for Tearing Strength (in Machine Direction) per ASTM D4434 Type III.

Tested By:

Jim Nespo

Laboratory Technician

Reviewed By

Cindy Campbell

Laboratory Manager

ISO 17025

Cert. 2711.01

Technical Service Report

Momentum Technologies, inc.
1507 Boettler Rd. Uniontown, OH 44685 Ph: 330-896-5900 Fax: 330-896-9943

SEI Group, Inc.
Mark Kelley
303 Williams Ave SW Suite 135
Huntsville AL 35801
Ph: 256-533-0500 **Fax:** 256-533-5516

Project #: **NX10L0B**
Quote #: **2010-372-2**
Date: **1/7/2011**
PO#:

Abstract: Analysis of one field Aged PVC membrane per customer selected tests contained within ASTM D4434.

MTI#	Description of Material	Receiving Date
MTI-100968	Field Aged PVC Membrane labeled Yuma Roof Under PV	11/10/2010

Test	ASTM	Requirement	Result	Conclusion
Breaking Strength per ASTM D751, A - Grab Method - MD	D 4434 Type III	min. 35 kN/m (200 lbf/in)	363 lbf/in	Pass
Breaking Strength per ASTM D751, A - Grab Method - XMD	D 4434 Type III	min. 35 kN/m (200 lbf/in)	299 lbf/in	Pass
Change in Weight after Immersion in Water per ASTM D570 (168 hrs @ 70°C)	D 4434 Type III	max. ± 3.0	0.63%	Pass
Dynamic Puncture Resistance per ASTM D5635	D 4434 Type III	Pass at min. 20 J (7.3 ft-lb)	22.6 Joules	Pass
Elongation at Break per ASTM D751, A - Grab Method - MD	D 4434 Type III	min. 15%	119.6%	Pass
Elongation at Break per ASTM D751, A - Grab Method - XMD	D 4434 Type III	min. 15%	79.8%	Pass
Heat Aging (56 days @ 80°C) per ASTM D3045	D 4434 Type III		Completed Jan 6 ,2011	
Linear Dimensional Change per ASTM D1204 (6 hrs @ 80°C) Cross Machine Direction	D 4434 Type III	max. 0.5%	-.05%	Pass
Linear Dimensional Change per ASTM D1204 (6 hrs @ 80°C) Machine Direction	D 4434 Type III	max. 0.5%	-.015%	Pass
Low Temperature Bend per ASTM D2136 @ -40°C	D 4434 Type III	Pass	No Cracking	Pass

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Test	ASTM	Requirement	Result	Conclusion
Overall Thickness per ASTM D751	D 4434 Type III	min. 1.14 mm (0.045 in.)	.046 in	Pass
Overall Thickness per ASTM D751 MD	D 4434 Type III	min. 1.14 mm (0.045 in.)	.0463 in	Pass
Post Heat Aged Breaking Strength per ASTM D751, A - Grab Method - MD	D 4434 Type III	min. 90% of original	378 lbf	Pass
Post Heat Aged Breaking Strength per ASTM D751, A - Grab Method - XMD	D 4434 Type III	min. 90% of original	348 lbf	Pass
Post Heat Aged Elongation per ASTM D751, A - Grab Method - MD	D 4434 Type III	min. 90% of original	131%	Pass
Post Heat Aged Elongation per ASTM D751, A - Grab Method - XMD	D 4434 Type III	min. 90% of original	92%	Pass
Seam Strength per ASTM D751, A - Grab Method	D 4434 Type III	min. 75% of breaking strength (150 lbf/in)	180.2 lbf/in	Pass
Static Puncture Resistance per ASTM D5602	D 4434 Type III	Pass at min. 15 kg (33 lbf)	No puncture 80 lbs	Pass
Tearing Strength per ASTM D751, B - Tongue Tear Method (8x8) - MD	D 4434 Type III	min. 200 N (45.0 lbf)	37 lbf	Fail
Tearing Strength per ASTM D751, B - Tongue Tear Method (8x8) - XMD	D 4434 Type III	min. 200 N (45.0 lbf)	52 lbf	Pass

Conclusion: Yuma Roof Under PV does not meet the requirements for Tearing Strength (in Machine Direction) per ASTM D4434 Type III.

Tested By:

Jim Nespo

Laboratory Technician

Reviewed By

Cindy Campbell

Laboratory Manager

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Cert. 2711.01

Appendix M
Site III (MCAS Yuma) ASTM G 21 Microbial Test Results

Antimicrobial Test Laboratories

Fast, Reliable Antimicrobial Efficacy Testing

Microbiology Study Report NG2320

Client Information

Company Name:	SEI Group, Inc.	Sponsor:	Mark Kelly
Sponsor's Phone:	(256) 533-0500 x329	E-mail:	mark.kelly@seigroupinc.com

Test Information

Test(s) Performed:	ASTM G 21 (Resistance of Synthetic Polymeric Materials to Fungi) Study ID NG2320
Performed by:	J. Williams

Sample Information

Test Substance ID(s):	Under Panel	Sample(s) Received:	10/26/2010
	Field Membrane		10/26/2010

Parameters

Microorganisms:	*P. funiculosum* ATCC 11797	*A. brasiliensis* ATCC 9642	*C. globosum* ATCC 6205
	T. virens ATCC 9645	*A. pullulans* ATCC 15233	

Growth Medium:	PDA (Potato Dextrose Agar)	Exposure Temp.	30.0 ± 1°C
Exposure Medium:	Nutrient Salts Agar	Suspenion Medium:	Nutrient Salts Solution
Targeted CFU/ml:	1×10^6, For Each Fungal Isolate	Exposure Time(s):	28 Days

Controls

Positive Control:	Passed, Confluent Growth	Inoc. Media Control:	No Growth Observed

Test Results

Test(s) Valid?:	Yes	Confirmation:	Visual Observation

Notes: None

Tests Completed:	11/29/2010	**Report Sent:**	12/2/2009

3000 Joe DiMaggio Blvd
Suite 32
Round Rock, Texas 78665

Phone: (512) 310-TEST
E-Mail: info@AntimicrobialTestLabs.com
Web site: http://www.AntimicrobialTestLabs.com

Test Summary

1. Individual spore suspensions were prepared according to ASTM G 21 guidelines.
2. Each spore suspension was normalized to between 8 x 10^5 - 1.2 x 10^6 CFU/ml.
3. An equal volume of each spore suspension was pooled and added to a sterile atomizer.
4. Test coupons (2 x 2 in.) were cut from each sample (in triplicate) and placed on sterile nutrient salts agar.
5. Postive controls (1 x 1 inch filter paper) were placed on sterile nutrient salts agar.
6. All samples and controls were sprayed for ~1 second to moisten the sample and agar surface.
7. Sterile media was also sprayed and served as the inoculum only control.
8. Samples and controls were sealed and incubated for 28 days at 30±1°C.

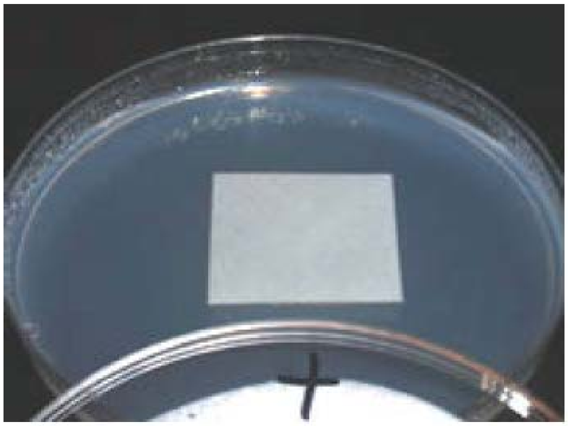
Scoring

Score	Description
0	No Growth Detected on Surface of Sample
1	Traces of Growth Detected on Sample (<10%)
2	Light Growth Detected on Sample (10%-30%)
3	Medium Growth Detected on Sample (30%-60%)
4	Heavy Growth Detected on Sample (60%-Complete)

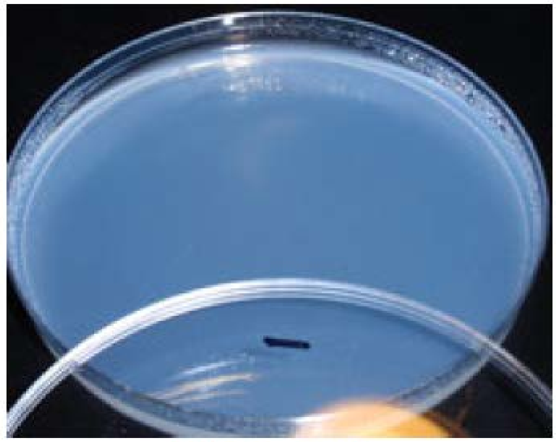
Results

	Incubation Time and Score			
Sample	**Day 7**	**Day 14**	**Day 21**	**Day28**
Under Panel	1	1	1	2
Field Membrane	1	1	1	2
Negative Control	0	0	0	0
Positive Control	4	4	4	4

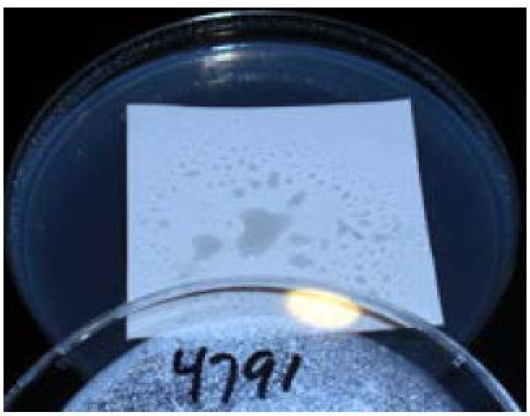
Day Zero Inoculation



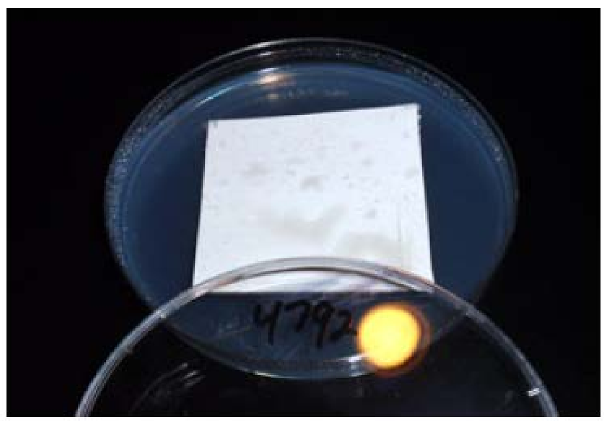
Positive Control



Negative Control

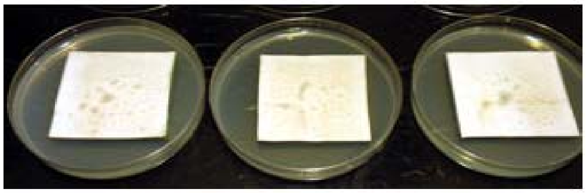


Under Panel



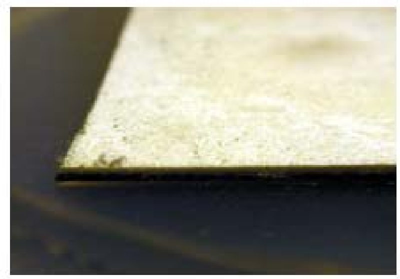
Field Membrane

Results Day = 7



Under Panel

Field Membrane

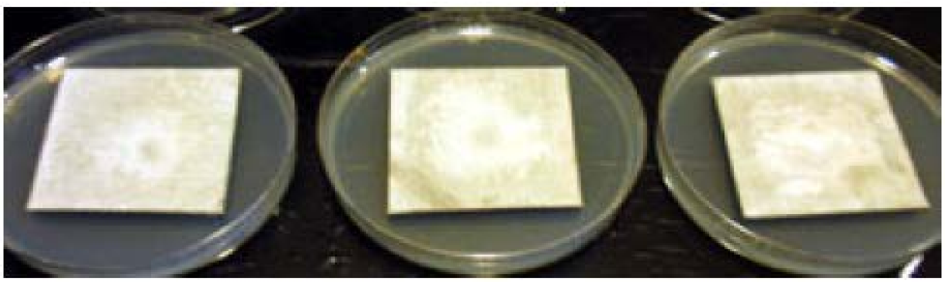


Neg. Control

Pos. Control

Results Day = 14

Under Panel

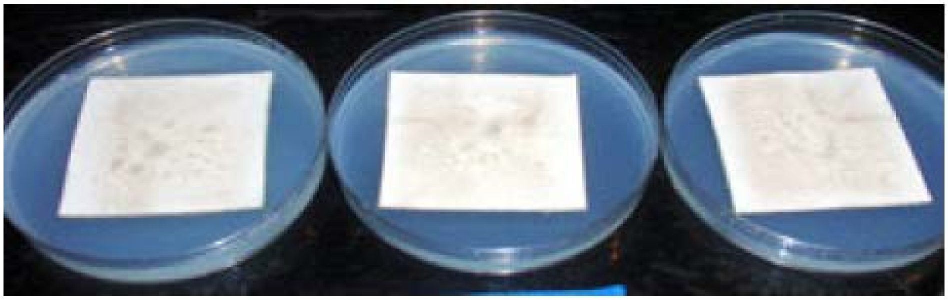


Field Membrane

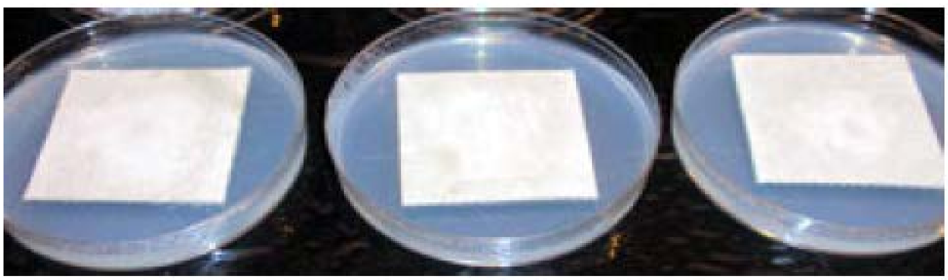
Neg. Control

Pos. Control

Results Day = 21

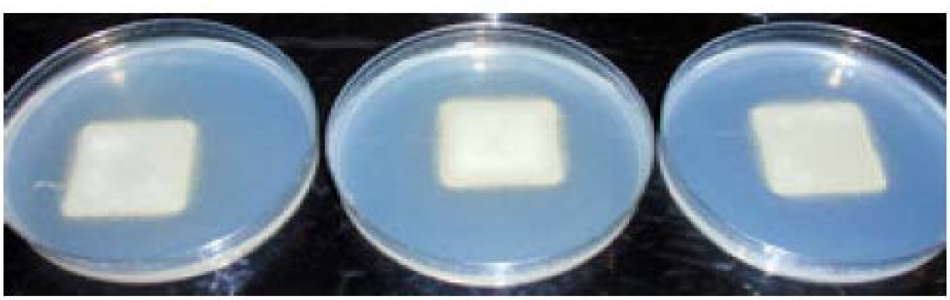


Under Panel



Field Membrane

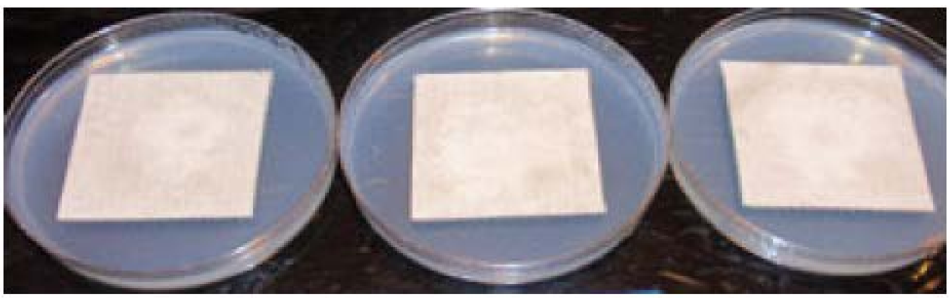
Neg. Control



Pos. Control

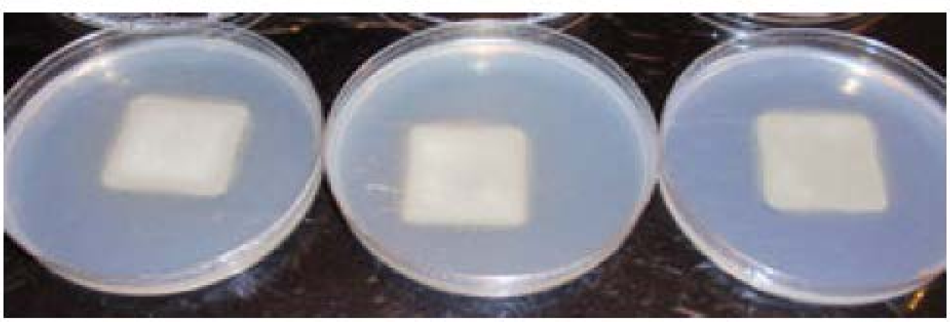
Results Day = 28

Under Panel



Field Membrane

Neg. Control



Pos. Control