ERDC/CERL TR-14-1

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DoD Corrosion Prevention and Control Program

Corrosion-Resistant Roof with Integrated Photovoltaic Power System

Final Report on Project F09-AR04

David M. Bailey, Tarek Abdallah, Karl Palutke, Larry Clark, Rick Miles, and Mike Merrick

February 2014

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Final report

Approved for public release; distribution is unlimited.

Prepared for US Army Corps of Engineers
Washington, DC 20314-1000

Under Project F09-AR04, "Corrosion Resistant Roofs with Integrated Sustainable Photovoltaic Power Systems"

Abstract

This report documents the demonstration of a self-adhering, thin-film photovoltaic (PV) technology applied to a new aluminum-zinc coated standing-seam metal roof (SSMR) with a high-performance coating. The demonstration took place at Kilauea Military Camp (KMC), HI, which has a uniquely corrosive environment due to the periodic presence of volcanic gases. It also has high electric utility costs and limited grid capacity.

The corrosion performance of the roof and PV solar array was evaluated by periodic visual examination, onsite atmospheric coupon testing, and accelerated weathering laboratory tests of material coupons. Sensors were also installed at the interface between the PV membrane and roofing material, mounted in outdoor exposure at the site, to record any developing signs of corrosion. After a year in service, the PV appliqué modules were found to have no deleterious effect on the new SSMR, and the PV system performed as expected. However, due to the high first-costs related to procuring the thin-film PV components, the 30 year return on investment (ROI) ratio was only 0.19. Although the system is not economical enough to warrant Army-wide implementation, it may be specified in individual cases where energy sustainability is a higher priority than ROI.

Contents

Figures and Tables

Figures

Tables

Preface

This demonstration was performed for the Office of the Secretary of Defense (OSD) under Department of Defense (DoD) Corrosion Control and Prevention Project F09AR04, "Corrosion Resistant Roofs with Integrated Photovoltaic Power Systems." The proponent was the US Army Office of the Assistant Chief of Staff for Installation Management (ACSIM), and the stakeholder was the US Army Installation Management Command (IMCOM). The technical monitors were Daniel J. Dunmire (OUSD(AT&L)), Bernie Rodriguez (IMPW-FM), and Valerie D. Hines (DAIM-ODF).

The work was performed by the Materials and Structures Branch (CEERD-CF-M), Facilities Division (CF), US Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL), Champaign, IL. The ERDC-CERL project manager was David M. Bailey. Portions of the work were performed by Mandaree Enterprise Corporation (MEC), Warner Robins, GA; Penta Engineering Group, Inc.; and Ultimate Roofing and Hawaii Solar Roofing, LLC. At the time this report was prepared, the Chief of the ERDC-CERL Materials and Structures Branch was Vicki L. Van Blaricum (CEERD-CF-M), the Chief of the Facilities Division was L. Michael Golish, (CEERD-CF), and the Technical Director for Installations was Martin J. Savoie (CEERD-CV-ZT). The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti and the Director was Dr. Ilker Adiguzel.

The following personnel are gratefully acknowledged for their support and assistance in this project:

- Mr. Alan Goo– deputy director, Directorate of Public Works (DPW), Hawaii
- Mr. Roger Panzer – Maintenance Mechanic Supervisor, Kilauea Military Camp, Hawaii.

The Commander of ERDC was COL Jeffrey R. Eckstein and the Director was Dr. Jeffery P. Holland.

Executive Summary

This DoD Corrosion Prevention and Control project demonstrated the use of a flexible-membrane photovoltaic (PV) solar array in conjunction with a corrosion-resistant aluminum-zinc standing-seam metal roof (SSMR) with a high-performance coating. The system was installed on a building at Kilauea Military Camp (KMC), Hawaii. The KMC environment is unique, characterized by moderate temperatures, high humidity, and periodic exposure to corrosive volcanic gases. The corrosion performance of the roofing system and thin-film PV system components were evaluated by

- periodic visual examination of the completed roof
- examination of atmospheric exposure coupons mounted at the site
- accelerated weathering tests of material coupons in the laboratory
- sensors installed at the interface of a roof panel and PV module on a specimen that was mounted in outdoor exposure.

This report documents installation of the SSMR and PV system, onsite observations, and data collection taken during the first year. To date, no corrosion or water intrusion has been observed on the roof. For the exposure and laboratory testing, some coupons were cut from metal panels with the high-performance coating and some without the coating. Both sets of coupons included some with thin-film PV appliqués applied and others without.

Through 1 year of exposure testing, only the scribed, uncoated coupons without the PV appliqué show signs of degradation, with corrosion evident in the area of the scribe and several pinpoints elsewhere. In laboratory testing, the coupons with PV appliqué generally performed better than uncoated coupons without the appliqué. Scribed PV coupons showed evidence that upon moisture penetration, corrosion within the PV cell occurs more rapidly than corrosion of the metal panel beneath the appliqué. The findings indicate that the PV system does not compromise corrosion-resistance of the roofing system. However as was seen in the scribed laboratory coupons, if a breaks occur in the surface of the PV appliqué, the internal corrosion vulnerability within the cell is high, and the break should be sealed immediately even if it reduces the operational efficiency of that cell.

The calculated 30 year return on investment ratio for this system was 0.19, which does not offer attractive economics for Army-wide adoption. The dominating economic factor was current system procurement costs. It is possible that with significantly lower PV system first costs, this flexible-membrane PV technology could become an economical option for supplying electricity to facilities in areas with high electrical costs or grid-capacity constraints.

A lesson learned during this project was the need to allow for plenty of time to obtain the proper permits when intending to connect a PV system to the electric utility grid. Permitting is a critical-path item, and is more likely to be a cause of delay than technical or construction issues.

Unit Conversion Factors

Multiply	By	To Obtain
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
gallons (US liquid)	3.785412 E-03	cubic meters
in.	0.0254	meters
mils	0.0254	millimeters
square feet	0.09290304	square meters
pounds (force) per square inch	6.894757	kilopascals

1 Introduction

1.1 Problem statement

Kilauea Military Camp (KMC) is a Department of Defense (DoD) facility located in Hawaii Volcanoes National Park, where it is subject to a harsh marine environment and highly corrosive gases venting from the nearby Kilauea Caldera. The metal roofing used on several buildings at the camp has become severely corroded from atmospheric exposure and a microclimate of alternating rain and sunlight. These structures protect mission-essential equipment, spare parts, and maintenance equipment from the tropical outdoor environment. Most new DoD roofing systems are based on metal-panel designs. Current metal roofing systems with coatings such as polyvinyl fluoride (PVF) and polyvinylidene fluoride (PVDF) can provide excellent corrosion protection in corrosive environments such as KMC.

Sustainable, building-integrated photovoltaic systems are a technology of growing interest to US military installations and other building owners in Hawaii. US military installation electric power costs continually rise, and show no sign of leveling in the near future. Because metal roofs comprise a large portion of an installation's building-surface area that is directly exposed to sunlight for most of the day, they can be exploited to help capture solar energy. For example, thin-film photovoltaic (PV) appliqué systems can be integrated with metal roofing systems, potentially offer a large source of sustainable energy. However, to be considered a viable sustainable energy solution, integration of such products must not compromise the corrosion resistance or performance of a roofing system at any point during its design service life.

Currently, the effects of thin-film PV appliqué systems on the corrosion resistance of coated metal roofing systems is not known. Potential corrosion mechanisms include moisture trapped between the appliqué and metal roofing panel interface, and potential initiation sites where connections are made between roofing components and PV appliqué sheets.

1.2 Objective

The objective of this project was to demonstrate the efficacy of a flexible-membrane (thin-film) PV power system as attached to a metal-panel roof that is protected with a high-performance, corrosion-resistant coating.

1.3 Approach

A severely corroded corrugated metal roof on Building 84 at KMC was selected for the demonstration. The old roof was replaced with an aluminum-zinc coated standing seam metal roof (SSMR) with a PVDF coating. A thin-film appliqué PV system was selected and adhered to the roofing panels, installed on the roof, and connected to a power inverter to convert direct current (DC) to alternating current (AC).

The effects of the thin-film PV solar array on the corrosion performance of the new roof were monitored through periodic onsite visual inspections, examination of exposure coupons mounted onsite, and laboratory testing of roofing material coupons. The monitoring continues in order to assess the longer-term performance of the systems and materials.

2 Technical Investigation

2.1 Project overview

Building 84, which is located in a service-utility section at KMC, was selected for the demonstration. The building (Figure 1) was constructed in 1946. It is used primarily as a warehouse and for vehicle storage, with some office and storage space on the east and west ends. It has one level with approximately 5,500 sq ft of flooring. The main section of the building has a gable roof and open bays along the north wall for vehicle access and parking. Figure 2 shows a layout of the building sections. There are two additions on the south side of the building's main section that have monoslope ("shed") roofs (Figure 3). The roofs on all three sections of the building were made of corrugated metal panels, and were severely corroded as a consequence of time in service.

Figure 1. Building 84.

Figure 2. Layout of roof - Building 84.

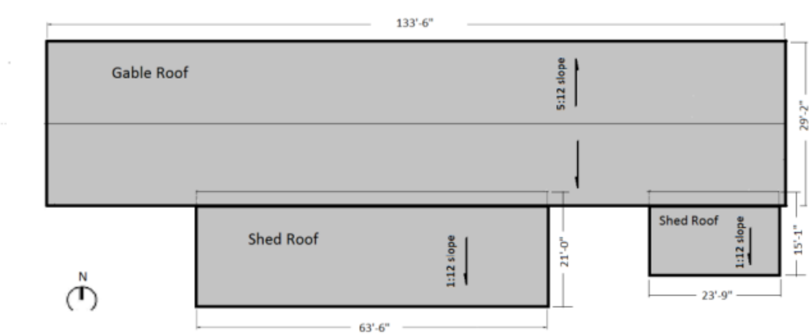
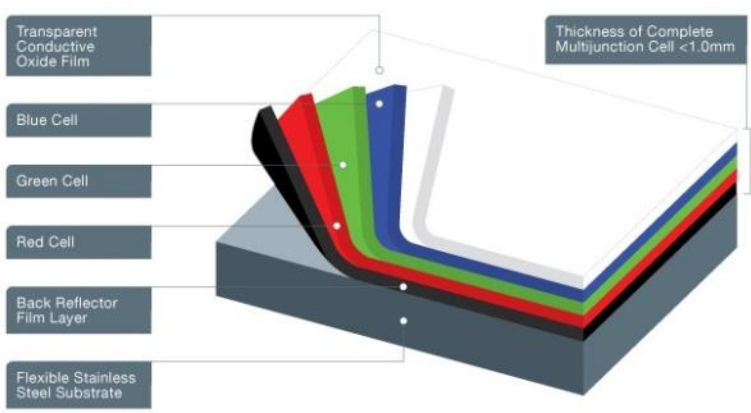


Figure 3. South side of building showing two shed roofs.

2.1.1 Description of the thin-film modules

The demonstrated PV modules are manufactured by depositing a thin film of amorphous silicon onto a metal substrate. The film material includes three layers of semiconducting material (Figure 4). The bottom, middle, and top semiconducting layers absorb red, green, and blue light, respectively, for maximum capture of energy from the solar spectrum. A reflective film is adhered below the PV layers and bonded to a flexible stainless steel substrate. The top, exposed layer of the appliqué is a transparent, electrically conductive oxide film. The PV modules are backed with an ethylene propylene copolymer adhesive material that includes a microbial inhibitor.

Figure 4. Thin-film photovoltaic cell (www.Unisolar.com).



The efficiency of amorphous silicon used in the PV modules is between 5 to 8 percent. This is much lower than the 15 percent efficiency of standard framed, rigid crystalline silicon PV panels that are mounted on metal racks and attached to the roof surface. However, because the thin-film PV modules can be adhered directly to metal roof panels, they do not add significant weight to the roof structure or create any wind resistance loads. Therefore, engineered strengthening of the structure is typically not required.

Application of the PV modules to metal roof panels is straightforward. The release sheet is peeled away from the back of the appliqué, exposing a layer of the adhesive. The appliqué is then rolled onto the roof panel using a technique to avoid trapping air between the two surfaces. A rubber roller is applied to the top of the appliqué in order to create optimum contact between the adhesive and the roof panel.

To provide adequate power for greater electric loads, the PV appliqués can be joined together to form larger units. The modules can be connected in series to produce higher voltage, or in parallel to produce more current.

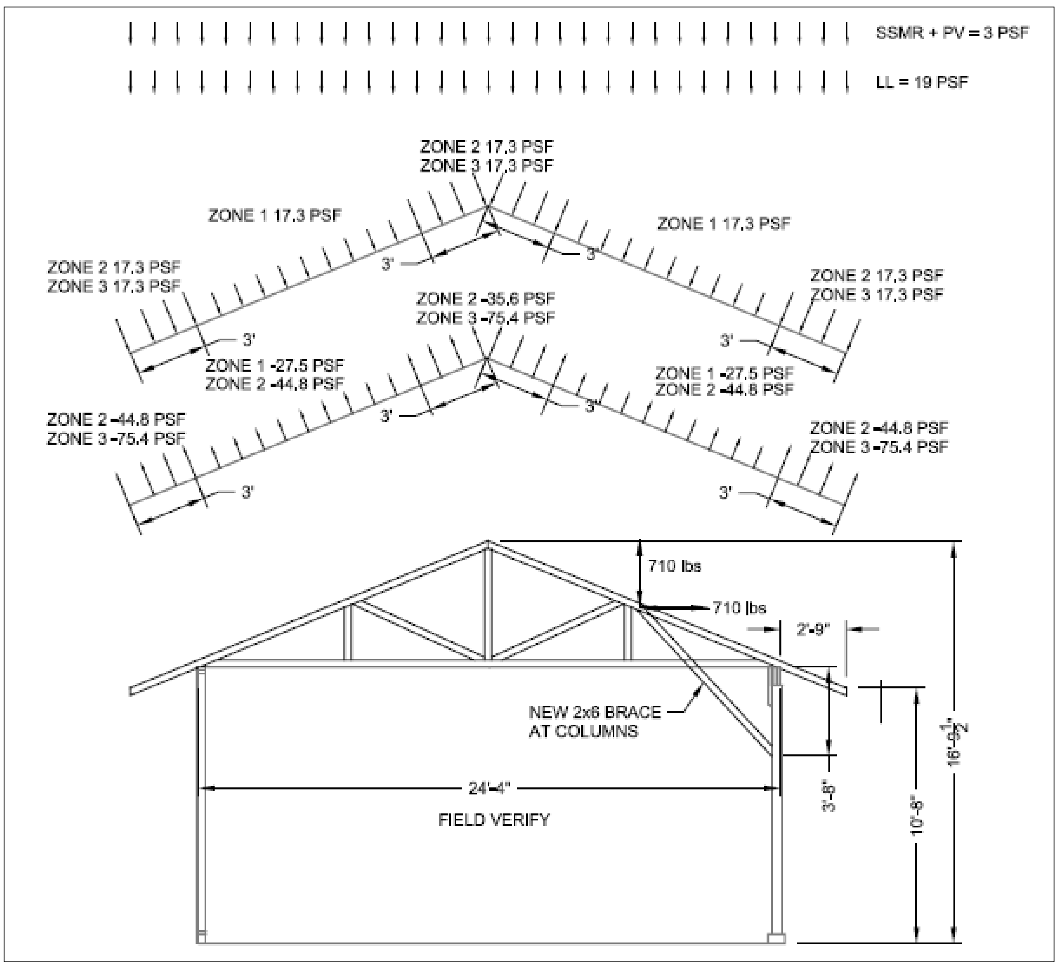
2.1.2 Roof system design

An engineering study was performed to establish the design wind forces for the new standing seam metal roofing (SSMR) system using American Society of Civil Engineers (ASCE) Standard 7, *Minimum Design Loads for Buildings and Other Structures*. The design wind load was a 3 second, 105 mph gust at a 50 year mean recurrence interval. The subsequent wind uplift resistance of the system was designed to meet International Building Code (IBC) requirements for the KMC location.

Based on a site survey, documentation of the existing construction, and a structural analysis, the existing wooden roof framing system for Building 84 was determined to be inadequate for supporting the new roofing system and its design live load (Figure 5). Therefore, it was decided to replace the roof framing. Truss configuration and design loads are shown in Figure 6. The engineering drawings for the new framing system and roof are provided in Appendix A. A roof live load of 19 pounds per square foot was required for a replacement gable roof having a slope of 5:12.

Figure 5. Original gable truss structure.

Figure 6. Truss configuration and roof design loads.



2.1.2.1 Gable roof framing system

For the gable roof section of the building, a fabricated metal plate-connected gable truss system (Figure 7 and Figure 8) was designed with trusses installed at 2 ft on-center. The replacement trusses were constructed of treated lumber to resist insect damage. Permanent longitudinal bracing of the roof trusses was achieved by using nominal 2 x 4 in. members connected to the top and bottom ends of the truss king posts.

Figure 7. Replacement gable end truss.

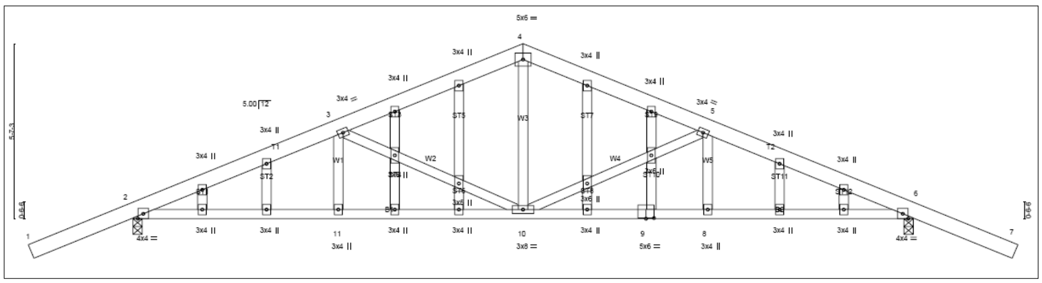
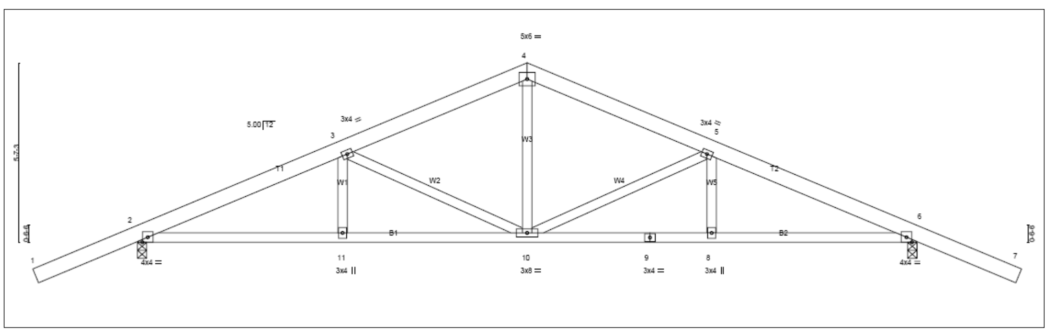


Figure 8. Replacement common truss.



The original ribbed metal panel roof system, mounted to the truss structure, provided diaphragm resistance for the structure. The replacement SSMR provides no diaphragm resistance because it is designed to allow thermal expansion and contraction of the roofing panels. Therefore, to provide necessary structural reinforcement for the new roof, the design required that horizontal x-bracing be added to the bottom side of the bottom truss chords. Purlin spacing was dictated by the gravity and wind uplift resistance requirements of the roofing system.

2.1.2.2 Shed roof framing systems

The in-place shed roofs of the two building additions were supported by rafters located below the eaves of the main roof's gable trusses. These rafters were nominal 2 x 8 in. wood members spaced at 4 ft on-center. This rafter spacing, for the larger building addition, created a loading condition that did not meet code requirements. Therefore, for both additions, supplementary rafters were added between the joists at a spacing of 16 in. on center. For the larger addition, the rafters were supplemented with sistered nominal 2 x 4 in. members in high wind zones near the rake to increase their flexural strength. For both additions, new purlins of 2 x 4 in. dimensioned lumber were attached to the rafters at a spacing of 2 ft on-center to accommodate the span capacity of the new SSMR panels.

2.1.2.3 Metal roofing system

The selected SSMR utilizes 16 in. wide, 24 gauge, 50 ksi aluminum-zinc coated roof panels. The standing seam is 1.5 in. high and has a snap-lock configuration. The profile of the roofing panels can be seen in Figure 9. The panels are coated with a PVDF organic coating on the external facing surface and polyester enamel on the interior-facing surface. The high-performance coating provides greater scratch and mar resistance than previous generation PVDF coatings. Polytetrafluoroethylene (PTFE) is included in the coating to resist stains and improve cleanability. The coating complies with Cool Roof Energy Council, Energy Star, and LEED 2009 standards.

Figure 9. Eave end of new standing seam metal roof.

Anchoring of the metal panels at the eave is provided by fixed metal clips. With the line of fixity being provided at the eave, accumulated panel contraction and expansion is designed to occur at the ridge, which is concealed beneath a ridge cap.

2.1.2.4 Gutters

The original roof gutters were constructed of stainless steel (Figure 10), having a rectangular cross section measuring 6 in. wide by 4 in. high. The primary downspouts were painted 4 in. diameter polyvinyl chloride (PVC) piping with a 45 degree elbows at the discharge end. With the gutters and downspouts being in very good condition, they were salvaged and reinstalled after the new roof system was installed. Due to the slight increase in the eave length of the new roof, the original downspout leader had to be changed. The existing downspout hardware was modified with 4 in. PVC pipe as shown in Figure 11.

Figure 10.Original gutter and downspout leader.

Figure 11. Updated connection between gutter and downspout.

2.1.3 PV system design

The PV system design utilized two different sizes of PV laminate modules: the Uni-Solar PVL-144, which is 216 in. in length; and the PVL-68, which is 112 in. in length. Both modules are 15.5 in. in width, which is a suitable width for placing between the standing seams in the roofing system. The bank of PV modules for the large shed roof incorporates four strings of ten Uni-Solar PVL-144s. For the gable roof, the metal panels were not long enough to accommodate the PVL-144s. Therefore, for both the north and south exposure of this roof, the shorter PVL-68s were selected. For each exposure, a bank of four strings of twenty modules was specified. For the overall design, there are 160 PVL-68 modules having a total rating of 10.88 kW, and 40 PVL-144 modules having a total rating of 7.20 kW. The PVL-68 module has a rated power capacity of 68 W, and the PVL-144 module has a rated capacity of 144 W. Physical and electrical specifications for the two module types are summarized in Table 1.

Table 1. Physical and electrical specifications for PV laminate modules.

Physical Specification:	Laminate Length	Laminate Width	Laminate Thickness	Weight
PVL-68	9 ft. 4⅛ in.	15½ in.	0.16 in.	9 lb.
PVL-144	18 ft.	15½ in.	0.16 in.	17 lb.

Electrical Specification:	PVL-68	PVL-144	Units
Rated Power P_{max}	68	144	Watts
Nominal Operating Voltage	12	24	Volts
Operating Voltage (Volts) V_{mp}	16.5	33.0	Volts
Operating Current (Amps) I_{mp}	4.13	4.36	Amps
Open-Circuit Voltage (Volts) V_{oc}	23.1	46.2	Volts
Short-Circuit Current (Amps) I_{sc}	5.1	5.3	Amps
Series Fuse Rating (Amps)	10	10	Amps
Min. Blocking Diode	10	10	Amps

The PV modules are electrically connected to an inverter capable of supplying power directly to the building or providing power to the local power grid. When the PV power output is greater than that needed for building usage, the excess is transferred to the grid for use by other buildings at

KMC. There is no means of energy storage provided with the system. Technical data for the PV system are provided in Appendix B.

The inverter and associated hardware, which include a combiner box, two disconnects, and a system-monitoring module, are shown as installed in Figure 12. The Solectria PVI 15 kW inverter is housed in a weatherproof National Electrical Manufacturers Association (NEMA) 3R steel enclosure. The inverter converts DC produced by the solar array into AC that suitable for powering the building or supplying the electrical grid. Internally, the current generated by the inverter is run through a filter, a delta/wye transformer, and electromagnetic interference (EMI) filters. The inverter's specifications are provided in Table 2.

Figure 12. Inverter and associated hardware.

Table 2. Solectria PVI 15 kW inverter specifications.

Output	
Maximum continuous power	15 kW AC
Power factor	Unity
Voltage (L-L), -12%, +10%	240 VAC, 3-phase
Maximum continuous current	42/18 A (AC)
Current distortion	< 5% THD, Nominal power
Frequency, ±1%	60 Hz
Inverter peak efficiency (1)	94.5%
Input	
Array configuration: monopole, negative grounded (positive ground optional)	
Max Voc (2)	475 VDC
Maximum DC current	68 A
MPT voltage range	225-380 VDC
CEC full power voltage range	235-380 VDC

Protection (3)	
AC grid-connection	Over/under voltage Over current Over/under frequency
AC disconnect (internal)	NEMA 3R, w/fuses
DC combiner-fuse enclosure (optional (4))	10A/15A fuses available, 6-7 pole NEMA 3R TVSS
DC disconnect integral	Break load rated, NEMA 3R
Environmental	
Ambient temperature	-25 to 50 deg C
Cooling	Forced convection
Enclosure	NEMA 3R
Enclosure-electronics	Sealed, IP-64
General	
Weight	398 lb / 181 kg (1)
Dimensions (4) in. (mm)	34.5 [876] 26 [660] 13.6 [345]
Warranty	5 years (10& 15 extended available)
Communications, optional data acquisition	RS232, RS485, PVIDAQ PC software Fat spaniel inverter-direct option

1. Fully Integrated Package: Includes transformer, filters, fan, AC & DC disconnects, and combiner-fuse box.
2. Max Open circuit voltage (Voc) of PV array = 1.25 x Voc-rated (per National Electrical Code [NEC] 690-7).
3. Complies with grid connection and safety standards ("Safety Features").
4. Integrated into inverter package if selected.
5. Forward-facing disconnect option width is 47" 1194 mm.

The combiner box houses the collection of electrical leads from the PV modules and their connections to the inverter (Figure 13). The DC disconnect switch disconnects the inverter from the PV array. With the inverter being powered by DC from the PV array, this switch also cuts power to the inverter's internal electronics. The AC disconnect switch allows for electrical disconnection of the inverter from both Building 84 and the local grid. The electrical connection between the inverter and the building's electrical system is housed in the breaker box.

The monitoring module, manufactured by Fat Spaniel Technologies, allows remote monitoring and recording of its performance. The interior of the monitoring module enclosure is shown in Figure 14. Above the module is a wireless bridge that provides communication between the monitoring system and the KMC guest wireless computer network.

Figure 13. Interior of DC combiner box.

Figure 14. Interior of monitoring module enclosure.

2.2 System installation

2.2.1 Replacement roofing system

The existing gutters and downspouts were removed and stored for reuse. Next, the old metal roofing was removed from the frame on both the main building section and the two additions. The gable trusses were removed from the main building and the purlins were removed from the roof framing systems of the additions. Some salvaged material was used to temporarily brace the gable end walls until the permanent trusses were installed.

The roof trusses and associated bracing were assembled on the ground before being lifted and placed onto the building. The installation of the new trusses is shown in Figure 15. This construction method helped prevent damage to the trusses, which are weak in the out-of-plane direction, and improved work safety by minimizing rooftop assembly work. Once the trusses were in place, the purlins were attached. Before installing the horizontal x-bracing, the SSMR system was installed.

Figure 15. Truss installation.

Roof panels were formed and cut to proper length. Panels were installed perpendicular to the roof ridge. Roofing clips, which secure the metal panels to the structure, were installed at the side laps of the roof panels and at each purlin location. Panel clips were attached to purlins using #10 x 0.5 in. wood screws (detail shown in Figure 16). Before adjacent roof panels were seamed together, a construction-grade flexible silicon joint sealant was field-applied within the seam. Eave flashing and gutters were installed as shown in the eave detail provided in Figure 17. For the gable roof, the roof cap flashing at the ridge was design and installed to allow for unrestricted panel movement at the ridge (Figure 18). For the two shed roofs, the flashings at the headwall-to-roof intersection were installed as shown in Figure 19 to also allow for thermal movement.

Figure 16. Clip detail.

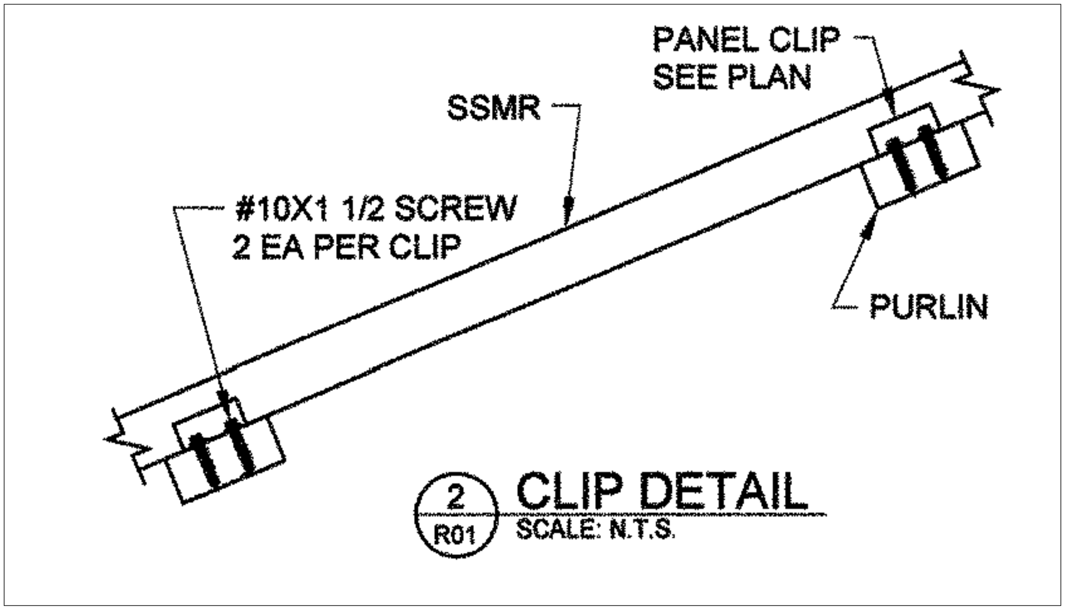


Figure 17. Eave detail.

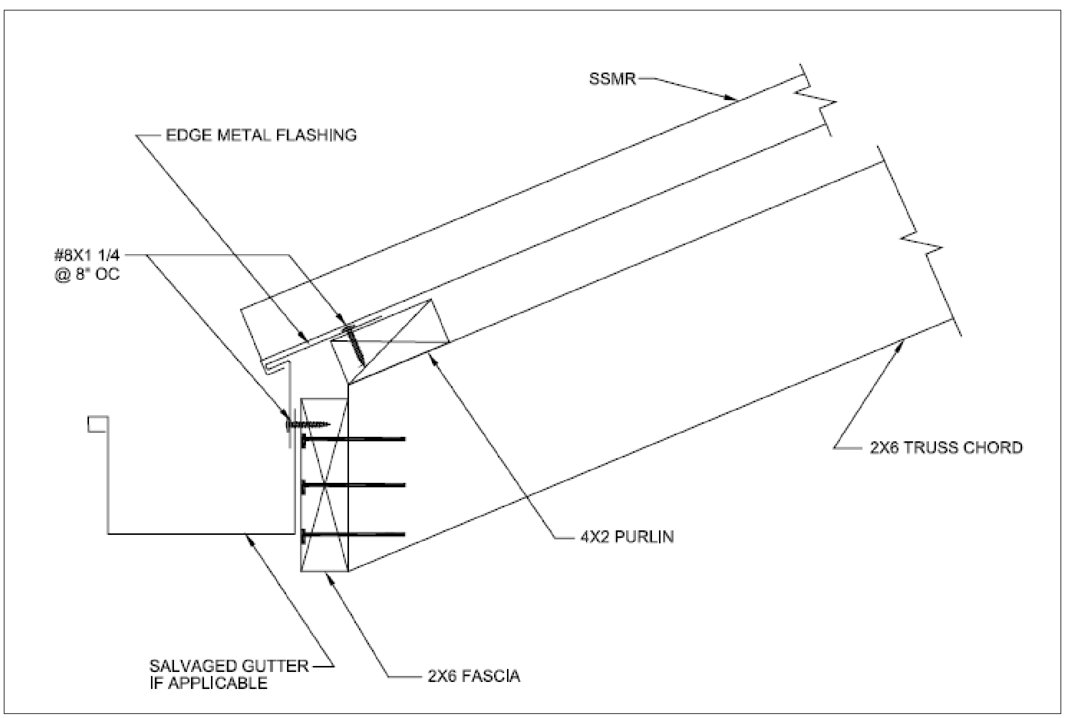


Figure 18. Ridge detail.

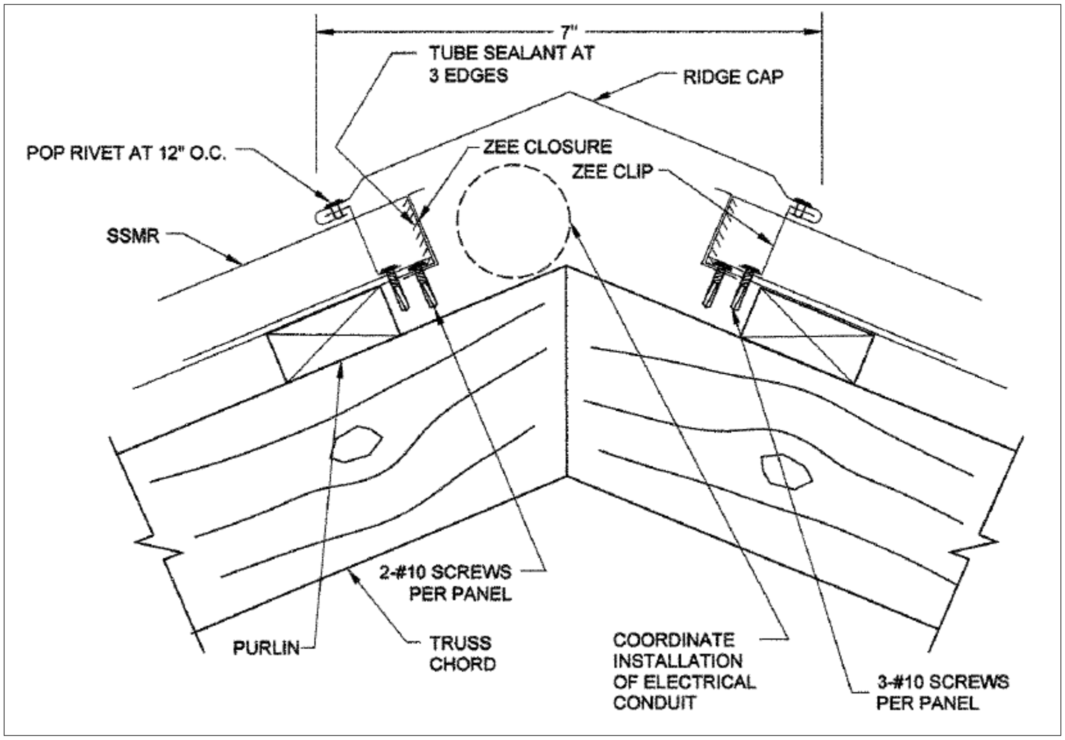
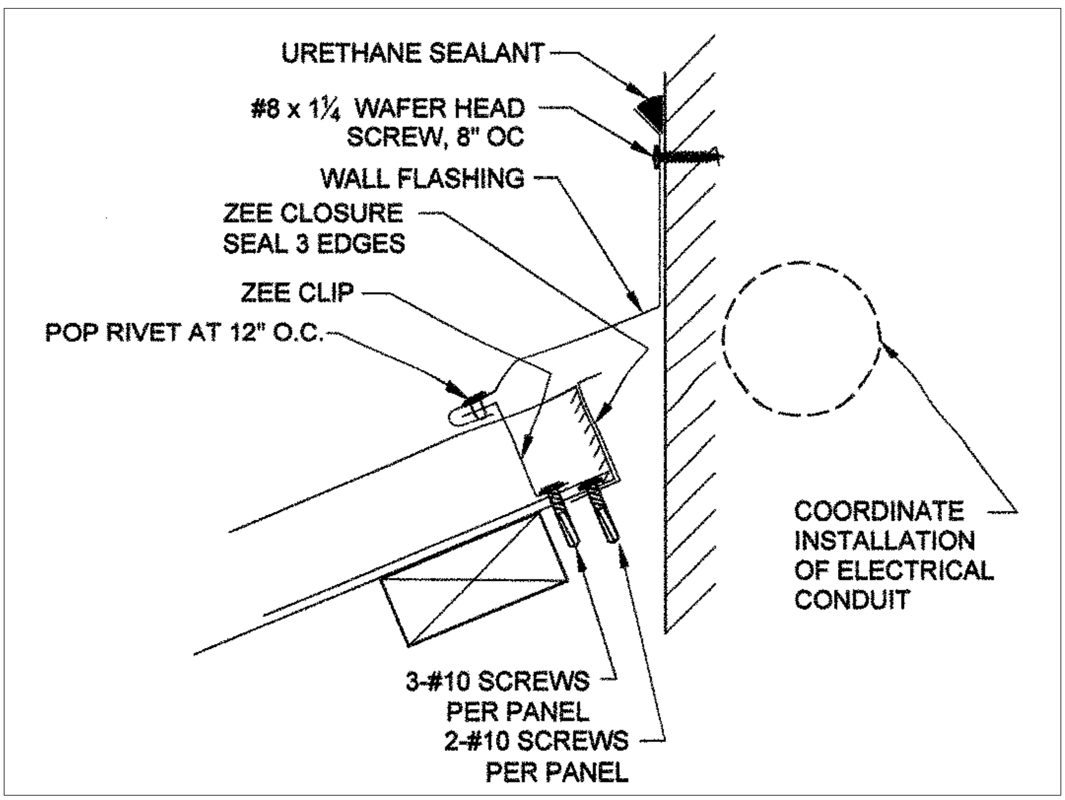


Figure 19. Metal roof-to-wall flashing.



The horizontal x-bracing beneath the trusses were connected next. Field modifications to the strapping size and quantity were accomplished under the direction of the engineer while in the field. The x-bracing changes were made because of local availability of specified materials and sizes. Multiple layers of narrower sheet metal strapping were used to provide an equivalent capacity where unavailable wider sheet metal strapping had been specified. In these cases, coated strapping was used instead of galvanized strapping in order to mitigate accelerated corrosion associated with stacked galvanized metal.

2.2.2 PV System

For the gable roof, the modules were applied to the roof panels before the roof sections were installed, as recommended by the manufacturer. The panel surfaces were first wiped with a solvent (Figure 20). Next, the release paper was removed from the back side of the PV appliqués (Figure 21) and each module was pressed in place against the panel using a rubber roller to avoid the formation of air bubbles at the interface (Figure 22). The metal panels were then raised to the rooftop, with the ends having electrical connectors placed upslope (Figure 23). Figure 24 shows the PV modules installed on the gable roof section.

Figure 20. Roof panel surface wiped with solvent before applying PV module.

Figure 21. Removal of release paper from back of PV module.

Figure 22. Pressing PV module in place against metal roof panel using rollers.

Figure 23. Electrical connectors located at upslope end of PV modules.

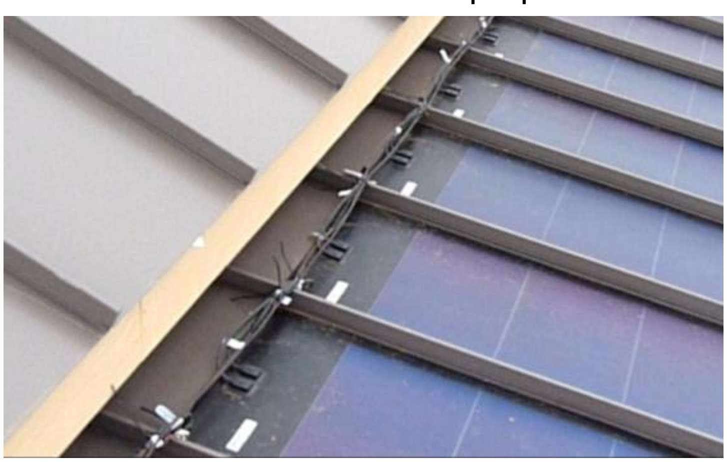


Figure 24. PV modules installed on gable roof section of Building 84.

For the two shed roofs, the PV modules were placed on the metal panels after the panels were installed on the roof (Figure 25). This order of work was decided upon so the replacement shed roofs could first be used as working surfaces while placing the SSMR system on the gable roof. Once the gable roof was completed, the PV modules were installed on the metal shed roof panels. Application of the solar modules to the already installed shed-roof panels required the same steps as previously described for the gable roof panels, but with the additional safety considerations given for working at roof level.

Figure 25. Application of PV modules on shed roof section.

Each array of PV modules had an 8 A fused circuit installed. The arrays were connected to the inverter using #2 thermoplastic high water-resistant nylon-coated (THWN-2) wire for the positive and negative lines, and #6

AWG[*] copper wire for the ground. The connection to the inverter is rated for a current of 105 A (maximum rated output of the array is 67.3 A). All wiring was enclosed in 1.5 in. PVC conduit. Three #2 THWN-2 wires and one bare copper #6 AWG wire for ground run through 1 in. PVC conduit were used to connect the inverter to the building's breaker box. The connection to the building's energy system and power grid was performed in accordance with National Electrical Code (NEC) Article 690.

2.3 Technology operation and monitoring

Due to permitting and technical issues, the activation of the inverter was delayed for several months after completion of the SSMR and PV systems. The PV system was commissioned in December 2010, and performance monitoring began shortly thereafter. The inverter reports energy and power production information to the monitoring system. However, the power production data does not indicate whether the electricity is consumed by Building 84 or is distributed to the other buildings at KMC. The data are automatically uploaded to an external server. Users with an authorized account can access the data from a secure website in the form of tabulated data and graphs describing the system's performance. The user can download the data to a spreadsheet application for analysis and processing.

Two identical sets of coupons of the coated metal panels and PV laminate were constructed—one set to be placed on an exposure rack at the KMC site (Figure 26) and the other set to be subjected to accelerated corrosion testing in the laboratory. (In this discussion the term *PV laminate* refers to a small sample of the PV material cut from a module.) Four different configurations of test coupons were made. These included coated metal panel (as supplied by the SSMR manufacturer) both with and without the PV laminate applied; and metal panel with only zinc-aluminum coating and no PVDF, both with and without the laminate applied. For each configuration, three coupons were scribed and one was unscribed. Scribing of the bare metal coupons was performed according to instructions in ASTM D1654, *Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments*. However, the method had to be altered for the coupons covered with PV laminate material. A rotary disc with a fin cutoff disc was used to cut through the PV laminate and into the metal material to achieve a scribe as close as possible to the ASTM requirement.

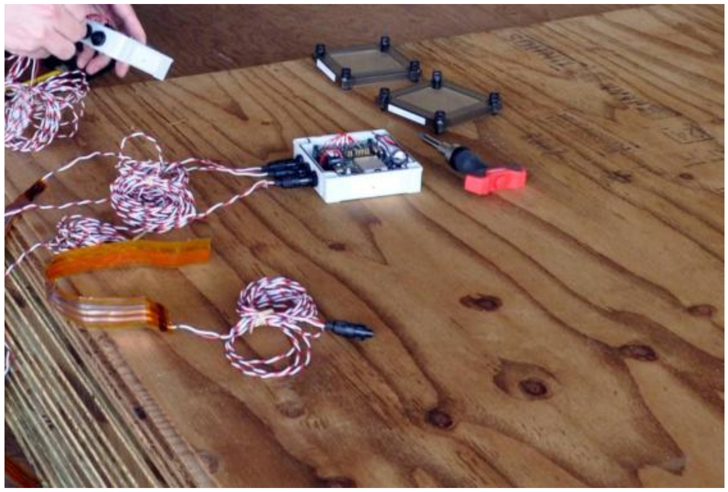
* AWG: American Wire Gauge.

Figure 26. Exposure rack.

The set of coupons that underwent accelerated aging were subjected to laboratory conditions as prescribed in ASTM G85, Annex A5, *Standard Practice for Modified Salt Spray Testing*. These coupons were exposed to 500 cycles of 1 hour of salt spray at room temperature (24 ± 3 °C), with each cycle followed by 1 hour of drying at 35 ± 2 °C (1,000 hours total). After completion of the accelerated aging, the coupons were evaluated using standard tests as described in Chapter 3. These same tests were used to evaluate the coupons placed on the exposure rack after they were exposed to the KMC climate for 1 year.

Corrosion conditions at the interface between the PV appliqué and metal roof panel are being monitored using a non-operational mockup of a PV module and roofing panel installed on the exposure rack. Four experimental corrosion sensors manufactured by Aginova, Inc., have been placed at different points along the interface. A sensor and its data-logger box are shown in Figure 27. An additional sensor is mounted on a coupon of roofing material with an inert section of PV attached to act as a control. The sensors record wetness and corrosivity data hourly.

Figure 27. Ribbon sensor (near left center) with recording box.



3 Discussion

3.1 Metrics

The corrosion performance of the SSMR with the integrated PV power system was assessed by (1) visual observation and evaluation of the completed roof, (2) evaluation of coupons that have been subjected to natural exposure and accelerated corrosion testing, and (3) evaluation of recorded environmental conditions at the interface between the PV module and roof panel. The energy and power output of the inverter are also being monitored to assess the energy performance of the PV modules.

The discussions below cite the industry or technical standards applied to the assessments.

3.2 Results

3.2.1 Visual inspection

Technicians visited the project site both 6 and 12 months after installation and inspected the SSMR and PV systems. Both systems were determined to be performing exceptionally well in the KMC environment. There were no visual indications of corrosion in components of the roof or PV systems, and no roof leaks were reported. The metal panel coating and PV modules showed no visible sign of deterioration, and the wiring and connections showed no signs of corrosion.

3.2.2 Coupon evaluation

The observations of the accelerated-aging coupons are summarized in Table 3. The coupons with PV laminate and no scribe performed well. This may be attributable the gummy nature of the appliqué adhesive, which behaves like a sealant to inhibit moisture penetration. However, the coupons with the scribed PV laminate did show some corrosion effects (Figure 28), which were advancing beneath the top surface of the laminate material. This result was not replicated on the same scribed coupon configurations that were mounted on the exposure rack; the outdoor coupons were not exposed to the same levels of chlorides and surface wetness that occur in accelerated testing, and the conditions for the oxygen concentration cell corrosion were not present. Therefore, it seems possible that a damaged

PV module properly mounted on a roof would not experience the same level corrosion that was seen in the ASTM G85 testing.

Table 3. Evaluation of coupons after accelerated aging.

Configuration	Sample	Observations
Uncoated with no PV laminate	#1 no scribe	No evidence of blistering, cracking, peeling or delaminating
	#2 scribe	No evidence of blistering, cracking, peeling or delaminating
	#3 scribe	No evidence of blistering, cracking, peeling or delaminating
	#4 scribe	No evidence of blistering, cracking, peeling or delaminating
Coated with no PV laminate	#1 no scribe	Evidence of blistering, cracking and peeling
	#2 scribe	Evidence of blistering, cracking and peeling
	#3 scribe	Evidence of blistering, cracking and peeling
	#4 scribe	Evidence of blistering, cracking and peeling
Uncoated with PV laminate	#1 no scribe	No evidence of blistering, cracking, peeling or delaminating
	#2 scribe	No evidence of blistering, cracking, peeling or delaminating
	#3 scribe	Evidence of peeling
	#4 scribe	Evidence of peeling
Coated with PV laminate	#1 no scribe	No evidence of blistering, cracking, peeling or delaminating
	#2 scribe	Evidence of peeling
	#3 scribe	Evidence of peeling
	#4 scribe	Evidence of peeling

Figure 28. Corrosion occurring at the cut edges and along the scribe of the PV laminate material (accelerated-weathering coupon).

The set of coupons placed on the exposure rack at KMC were visually inspected after 6 months. Examination showed that the coupons displayed no evidence of corrosion, with the exception of the uncoated metal panel coupons, which began to show corrosion in the scribes and also spots of corrosion elsewhere. An example is shown in Figure 29.

Figure 29. Corrosion on scribe on uncoated coupon from exposure rack.

After 12 months in place, the coupons were removed from the exposure rack and evaluated using test methods ASTM D1654, ASTM D610 *Standard Practice for Evaluating Degree of Rusting on Painted Steel Surfaces*, and ASTM D714, *Standard Test Method for Evaluating Degree of Blistering of Paints*.

Using ASTM D1654, the amount of rust creepage that occurs at the scribe area is measured. A rating of 0–10 is used, with 10 being no creepage and 0 being creepage of 0.625 in. or more. The inspection metric for ASTM D610 is a rating of 0–10 of visible rust, with 10 being less than or equal to 0.01% of the surface area of visible rust. Results from these two test methods are summarized in Table 4.

Table 4. Evaluation of coupons after 12 months on exposure rack at KMC.

Configuration	Sample	ASTM Method	Observations
Uncoated with no PV laminate	#1 no scribe	D-1654	No visible corrosion, small chip in AL-ZN coating, appears to be mechanical damage. rating: 10
		D-610	Rust distribution – 0, grade 10
	#2 scribe	D-1654	Corrosion in scribe, not extending (< 1mm) into coating. rating 9.5
		D-610	Rust distribution – n/a, percent of area rusted - 0.5%, grade 6, type H
	#3 scribe	D-1654	No visible corrosion. rating: 10
		D-610	Rust distribution – pinpoint; percent of area rusted - < 0.3%, grade 9, type P
	#4 scribe	D-1654	No visible corrosion. rating: 10
		D-610	Rust distribution – 0, grade 10

Configuration	Sample	ASTM Method	Observations
Coated with no PV laminate	#1 no scribe	D-1654	No visible corrosion, slight mechanical damage to coating
		D-610	Rust distribution – 0, grade 10
	#2 scribe	D-1654	No corrosion in scribe, rating 10
		D-610	Rust distribution – 0, grade 10
	#3 scribe	D-1654	Very light corrosion in scribe, not extending into coating. rating 10
		D-610	Rust distribution – in scribe only; percent of area rusted - <0.3%, grade 9, type H (hybrid)
	#4 scribe	D-1654	No corrosion in scribe, rating 10
		D-610	Rust distribution – 0, grade 10
Uncoated with PV laminate	#1 no scribe	D-1654	No corrosion visible, rating 10
		D-610	Rust distribution – 0, grade 10
	#2 scribe	D-1654	No corrosion in scribe, rating 10
		D-610	Rust distribution – 0, grade 10
	#3 scribe	D-1654	No corrosion in scribe, rating 10
		D-610	Rust distribution – 0, grade 10
	#4 scribe	D-1654	No corrosion in scribe, rating 10
		D-610	Rust distribution – 0, grade 10
Coated with PV laminate	#1 no scribe	D-1654	No corrosion in scribe, rating 10
		D-610	Rust distribution – 0, grade 10
	#2 scribe	D-1654	No corrosion in scribe, rating 10
		D-610	Rust distribution – 0, grade 10
	#3 scribe	D-1654	No corrosion in scribe, rating 10
		D-610	Rust distribution – 0, grade 10
	#4 scribe	D-1654	No corrosion in scribe, rating 10
		D-610	Rust distribution – 0, grade 10

The inspection standard for ASTM D714 is a rating system describing blisters in the paint. The results of this test did not provide discernible difference between the coupon configurations; none of the coupons experienced blistering.

As can be seen from examining the data produced by the other two tests, the coupons are generally performing very well, and the coupons with coating and the PV laminate show no signs of corrosion.

3.2.3 PV module-metal panel interface conditions

Examination of 1 year's data downloaded from the corrosion sensors placed between the metal panel and PV module on the system mockup indicated no wetness or any corrosive activity at the metal/appliqué interface.

3.2.4 PV energy performance

Monitoring of the PV system began on 20 January 2011. However, after 3 months the remote monitoring system failed and was offline for 4 months before it could be repaired. The monitoring was continued beyond the original 12 months to collect a full year's worth of data for the energy savings assessment.

A 1 week plot of power output data can be seen in Figure 30. Each point in the graph represents the average power output over a 15-minute period. The energy output from the solar panel system was measured by the data logger on an hourly basis. The weekly outputs ranged from 224 kWh to a maximum of 530 kWh. The wide range of energy output levels is attributed primarily to variable weather affecting the solar exposure of the PV modules. Based on the first 12 months of data (Figure 31), the monthly average energy output from the solar panels was approximately 1,594 kWh.

Figure 30. PV System power output over one week.

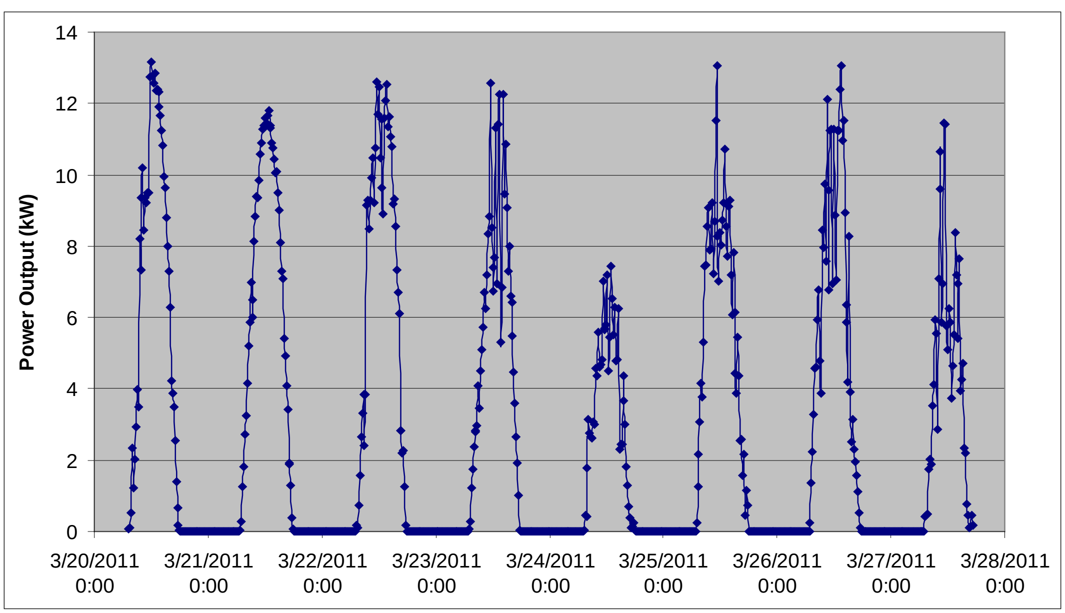
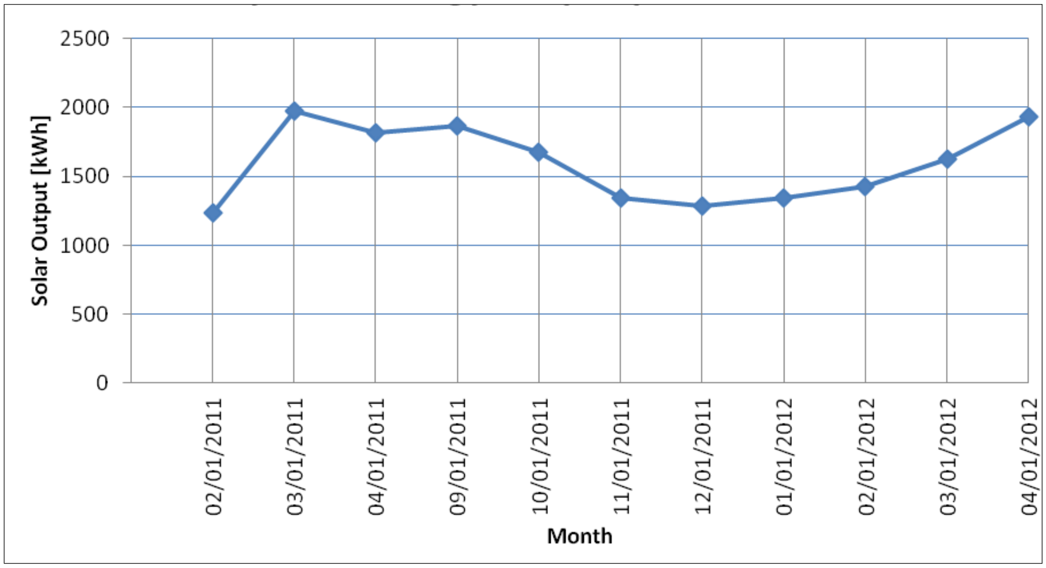


Figure 31. System energy output.



Records submitted to the State of Hawaii Public Utilities Commission by the local electric utility company, Hawaiian Electric Light Company (HELCO), state that the cost per kWh for general service during that time was approximately $0.3518. Based on this figure, the total energy cost saving attributable to the PV system during a 12 month period of service would be approximately $6,729.

3.3 Lessons learned

In completing the demonstration, it became apparent that the permitting process involved with connecting a PV system to a local electric utility company grid is a critical-path item, and more likely to be a cause of delay than technical or construction issues. This is especially true in situations similar to KMC, where there are multiple parties responsible for taking necessary actions or providing necessary information, some of whom have no direct interest in the project.

The PV material provides an effective barrier to moisture intrusion and corrosion initiation, but if breaks occur in the thin-film surface, the cells are highly vulnerable to corrosion. This vulnerability dictates that any breaks should be sealed at once, even if the repair reduces the operational efficiency of the affected cell.

4 Economic Summary

The projected return on investment (ROI) for the demonstrated technologies has been developed based on the actual project costs. Along with the costs of installing and commissioning the demonstrated system, costs for performance monitoring and CPC project management are also accounted for. The costs for local companies to install the roofing and PV systems on similar buildings would not include those demonstration-related costs.

4.1 Costs and assumptions

Conventional Baseline Case. KMC maintenance personnel report that original corrugated steel roofs at KMC need to be replaced after 10–15 years. For the baseline scenario (i.e., continue using corrugated steel roofs), a service life of 10 years is assumed for a replacement roof of galvanized corrugated metal panels. It is also assumed that a new framing system would have been needed, as in the demonstration project, because the original was deteriorated and damaged. The Year 1 estimated total cost for roof replacement in kind and a new framing system is $34,159. For this analysis, the corrugated metal roofing is expected to be replaced at Year 11 and Year 21. The estimated cost for roof removal and replacement is $19,159. Annual maintenance for the corrugated panel roof is estimated to be $0.08/SF.

SSMR with PV Appliqué. The total cost of installing the new SSMR on Building 84 was $42,662, with an additional cost for framing improvements estimated to be $7K. There was an additional $8K design effort for the roof framing system and the SSMR, which was performed as part of the overall project design subcontract. The SSMR with PV appliqués is expected to last more than 30 years, with annual maintenance for the SSMR estimated to be $0.02 per square foot (SF). The cost of installing the PV system was $195,674.

Finally, the value of the estimated annual power generated by the PV system, at current electrical rates, is included as savings (approximately $6,729) provided by the new system.

4.2 Projected return on investment (ROI)

A 7% discount rate is used for the ROI calculation, consistent with CPC program guidance (OMB Circular A-94). The projected ROI is 0.19 over 30 years. The calculation is based on a required CPC project investment of $688,000. A summary of the analysis is shown in Table 5.

Table 5. ROI analysis.

Investment Required			688,000
Return on Investment Ratio	0.19	Percent	19%
Net Present Value of Costs and Benefits/Savings	1,463	134,225	132,762

A Future Year	B Baseline Costs	C Baseline Benefits/ Savings	D New System Costs	E New System Benefits/ Savings	F Present Value of Costs	G Present Value of Savings	H Total Present Value
1	34,159		118	6,729	110	38,214	38,104
2	472		118	6,729	103	6,289	6,186
3	472		118	6,729	96	5,878	5,782
4	472		118	6,729	90	5,493	5,403
5	472		118	6,729	84	5,134	5,050
6	472		118	6,729	79	4,798	4,719
7	472		118	6,729	73	4,484	4,410
8	472		118	6,729	69	4,191	4,122
9	472		118	6,729	64	3,916	3,852
10	472		118	6,729	60	3,660	3,600
11	19,159		118	6,729	56	12,299	12,243
12	472		118	6,729	52	3,197	3,145
13	472		118	6,729	49	2,988	2,939
14	472		118	6,729	46	2,792	2,747
15	472		118	6,729	43	2,609	2,567
16	472		118	6,729	40	2,439	2,399
17	472		118	6,729	37	2,280	2,242
18	472		118	6,729	35	2,131	2,096
19	472		118	6,729	33	1,991	1,958
20	472		118	6,729	30	1,861	1,830
21	19,159		118	6,729	28	6,252	6,223
22	472		118	6,729	27	1,625	1,599
23	472		118	6,729	25	1,519	1,494
24	472		118	6,729	23	1,419	1,396
25	472		118	6,729	22	1,326	1,305
26	472		118	6,729	20	1,240	1,220
27	472		118	6,729	19	1,159	1,140
28	472		118	6,729	18	1,083	1,065
29	472		118	6,729	17	1,012	996
30	472		118	6,729	15	946	931

The project cost for this particular implementation of the PV system on the new metal roof is roughly four times the cost of the new roofing and framing system without a PV system. It is clear that this application does not provide an attractive return on investment for Army facilities. However, a few supplementary comments are appropriate for context.

First, it is reasonable to suppose that costs for the current demonstration project were probably higher than cost of a similar SSMR project with this type of PV system undertaken outside the context of a formal demonstration project.

Another aspect of the economic analysis worth noting is that the ROI is highly sensitive to the affordability of thin-film PV technology. After the demonstration project was begun, the cost of conventional crystalline and silicon-cell PV technology fell dramatically, making thin-film PV technology much less cost-beneficial by comparison (Deign 2012). Cost reductions and efficiency gains by overseas manufacturers of conventional rigid-panel PV collectors have forced most US thin-film PV manufacturers out of business.

It also should be noted that it was beyond the scope of this demonstration to evaluate corrosion-resistant rooftop applications of conventional rigid-panel PV technology, so no conclusions may be inferred about the overall life-cycle costs of conventional solar panels versus thin-film PV technology in highly corrosive environments.

Finally, potential future technical or economic developments could make thin-film PV technology more affordable and attractive for Army use. For example, a technical breakthrough in the design or manufacture of thin-film PV modules could make the technology more competitive with conventional solar panels. Similarly, if system-procurement costs could be reduced in comparison with those recorded for the current project, and given other building structural constraints that would favor thin-film modules over heavier rigid solar panels, the demonstrated technology could become an economically viable option in areas with high electrical costs or grid-capacity constraints.

5 Conclusions and Recommendations

5.1 Conclusions

Standing seam metal roofing with high-performance coatings and heat-shedding pigments is already widely used for Army facility renovation and new construction. This roofing technology has been validated and accepted by industry and the marketplace. Based on the results of this demonstration, the application of self-adhering thin-film PV modules and components has not negatively affected the corrosion performance of a typical standing-seam metal roof. Neither the coated metal roofing panels nor the PV modules exhibited corrosion or other visible deterioration. This finding is supported by the evaluation of test coupons in both environmental and accelerated-weathering exposures, and also by sensors installed at the interface of a non-operational PV module/roof panel assembly mounted on the outdoor coupon exposure rack.

The demonstration results indicate that thin-film PV technology is an effective means of generating electrical power in locations where direct solar radiation is available during most of the year. However, system costs at the time of the demonstration were too high for thin-film PV collectors to be considered cost effective, even over 30 years in an area with high electric utility costs. With significantly lower system procurement costs, it is possible that this PV technology could become an economical option for providing electricity to facilities in areas with high electrical costs or grid-capacity constraints.

Excluding cost considerations, thin-film PV systems can provide benefits relative to systems that use traditional crystalline and silicon-cell technology. Thin-film PV modules can be adhered to the metal panel surface, reducing or eliminating penetrations and metal flashings that are often used with conventional rack-mounted PV systems. As a result, the potential for moisture intrusion and subsequent water damage can be greatly reduced.

5.2 Recommendations

At present, the cost/benefit ratio of this technology does not justify immediate Army-wide adoption.

The technology does operate as designed and has not had any negative effects on the corrosion resistance of the metal substrate or the roofing system in general. In places where energy conservation or the use of alternative energy is desired or mandated, or where the capacity of the existing power infrastructure is deficient, this technology may be considered a possible option. However, users must be aware that current system acquisition costs provide little better than break-even economic benefits over 30 years.

If a PV system is specified as part of a roofing a project, first consideration should be any regulatory requirements set by the local utility if the system is to be connected to the grid. In this project, obtaining the necessary approvals and permits for grid-tied operation was unexpectedly time-consuming; the lesson learned was that application for such permits should probably begin several months before the start of construction to avoid schedule delays.

References

ASCE-7, Minimum Design Loads for Buildings and Other Structures, American Society of Civil Engineers, 01-Jan-2006 / 424 pages, ISBN: 0784408092.

ASTM D610, Standard Practice for Evaluating Degree of Rusting on Painted Steel Surfaces, *Book of ASTM Standards*, vol 06.02 (ASTM).

ASTM D714, Standard Test Method for Evaluating Degree of Blistering of Paints, *Book of ASTM Standards*, vol 06.01, (ASTM).

ASTM D1654, Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments, *Book of ASTM Standards*, vol 06.01, (ASTM).

ASTM G85, Standard Practice for Modified Salt Spray (Fog) Testing. *Book of ASTM Standards*, vol 03.02 (ASTM).

Deign, Jason. 3 January 2012. "Make or break time for CIGS." *PV Insider*, http://news.pv-insider.com/thin-film-pv/make-or-break-time-cigs, accessed 4 April 2013.

Office of Management and Budget (OMB). 1994. *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs*. OMB Circular No. A-94. Washington, DC: Office of Management and Budget.

Appendix A: Engineering Drawings

INSTALL CORROSION RESISTANT ROOF
WITH
INTEGRATED PHOTOVOLTAIC POWER SYSTEM
KILAUEA MILITARY CAMP, HAWAII

SUMMARY OF WORK

INSTALL STANDING SEAM METAL ROOF (SSMR) THAT WILL REPLACE THE EXISTING METAL ROOF FOR BUILDING 84. THE EXISTING METAL ROOF, EXISTING PURLINS, AND EXISTING TRUSSES SHALL BE REMOVED. SALVAGE EXISTING GUTTER AND DOWNSPOUT SYSTEM.

INSTALL NEW FABRICATED METAL PLATE CONNECTED GABLE TRUSSES, NEW PURLINS, STANDING SEAM METAL ROOF WITH INTEGRAL PHOTOVOLTAIC POWER SYSTEM.

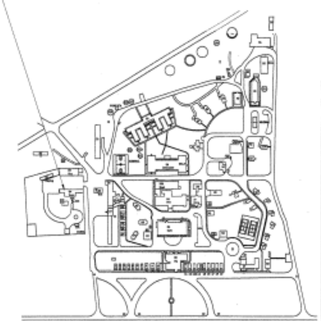
ADD NEW 2 x 8 DIMENSIONED LUMBER ROOF JOISTS AT 16 INCHES ON-CENTER ON THE MONOSLOPED ROOFS AT THE SOUTH ELEVATION OF BLDG 84. INSTALL NEW PURLINS AND STANDING SEAM METAL ROOF.

INSTALL NEW PHOTOVOLTAIC POWER GENERATION SYSTEM TO INCLUDE BUT NOT LIMITED TO PHOTOVOLTAIC LAMINATES, ELECTRICAL INVERTER, ELECTRICAL DISCONNECT, AND ASSOCIATED CABLING AND CONDUIT.

DRAWING INDEX

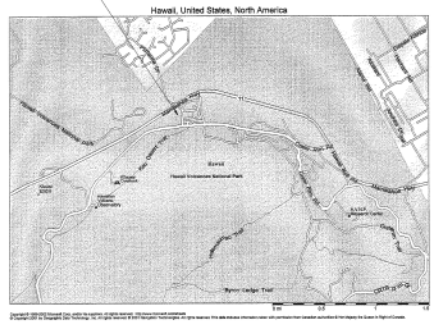
G-01 PROJECT LOCATION AND WORK SUMMARY
G-02 GENERAL NOTES
D-01 DEMOLITION PLAN
S-01 ROOF STRUCTURE
S-02 ROOF STRUCTURE DETAILS
S-03 ROOF STRUCTURE DETAILS
R-01 STANDING SEAM METAL ROOF
E-01 ONE-LINE ENERGY SYSTEM

PROJECT SITE
BUILDING 84
KILAUEA MILITARY CAMP, HAWAII



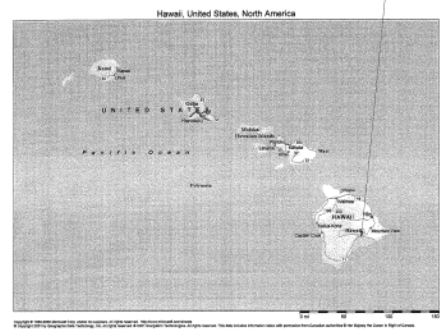
PROJECT SITE
BUILDING 84
KILAUEA MILITARY CAMP, HAWAII

Hawaii, United States, North America



PROJECT SITE
BUILDING 84
KILAUEA MILITARY CAMP, HAWAII

Hawaii, United States, North America



THIS WORK WAS PREPARED BY ME OR UNDER MY SUPERVISION AND CONSTRUCTION OF THIS PROJECT WILL BE UNDER MY OBSERVATION.

Signature 4-30-2010 Expiration Date of the License

DATE	DESCRIPTION
11-2-09	FOR CERL REVIEW

BUILDING 84
KILAUEA MILITARY CAMP
CORROSION RESISTANT ROOF WITH INTEGRATED PHOTOVOLTAIC POWER SYSTEM
KILAUEA MILITARY CAMP, HAWAII

PENTA ENGINEERING GROUP, INC.
6755 Peachtree Industrial Blvd
Suite 150
Atlanta, Georgia 30360
678-282-1999
FAX 678-282-1993

DESCRIPTION
PROJECT LOCATION
SUMMARY OF WORK
DRAWING INDEX

PROJECT 09-4-1193

DATE NOVEMBER 19, 2009

SHEET G-01 OF 8

GENERAL NOTES:

1. BASIS OF DESIGN: ASCE 7-05 MINIMUM DESIGN LOADS FOR BUILDINGS AND OTHER STRUCTURES
TI 809-29 STRUCTURAL CONSIDERATIONS FOR METAL ROOFING
AISI S100-2007 NORTH AMERICAN SPECIFICATION FOR THE DESIGN OF COLD-FORMED STEEL STRUCTURAL MEMBERS
ANSI/AF&PE NDS-2005 NATIONAL DESIGN SPECIFICATION FOR WOOD CONSTRUCTION ASD/LRFD

A. FLOOR LOADS: NO ALTERATION

B. ROOF LIVE LOAD: 19 PSF FOR NEW ROOF PANELS AND REPLACEMENT TRUSSES.

C. GROUND SNOW LOAD: EXISTING ROOF SLOPE 5:12. PLAN DIMENSIONS NOT CHANGED. Pg = 10PSF. BALANCED AND UNBALANCED SNOW LOADS ARE LESS THAN ROOF LIVE LOADS.

D. WIND DESIGN DATA: SPEED: 105 MPH, 3-SECOND GUST.
WIND IMPORTANCE FACTOR: IW = 1.0
PARTIALLY ENCLOSED BUILDING GCPI = +/- 0.55

SEE DIAGRAMS THIS SHEET FOR COMPONENTS AND CLADDING WIND LOADS
MWFRS - NO ALTERATIONS TO STRUCTURAL ELEMENTS. PARAGRAPH 1614.3.

E. SEISMIC DESIGN DATA: NO ALTERATIONS TO STRUCTURAL ELEMENTS, PARAGRAPH 1614.3.

2. SCOPE OF WORK: INSTALL REPLACEMENT GABLE ROOF TRUSSES, PURLINS AND NEW STANDING SEAM ROOF SYSTEM, SALVAGE GUTTERS AND DOWNSPOUTS, AND RELATED FASCIA FINISHES. INSTALL NEW RAFTERS, PURLINS AND NEW STANDING SEAM ROOF SYSTEM AND RELATED FASCIA FINISHES ON MONOSLOPE ROOF.

3. MATERIALS:

A. ROOF PANELS: 24 GAGE, 50 KSI, ALUMINUM-ZINC COATED STANDING SEAM METAL ROOF PANELS AS MANUFACTURED BY CUSTOM METAL ROOFING, KEAAU, HAWAII

SERIES: SHUR-LOCK STANDING SEAM

SEAM HEIGHT: 1½"

PROFILE: SMOOTH PAN

COLOR: TAHITIAN BRONZE

EXTERIOR FINISH: DURAPON 70 WITH TEFLON BY DURACOAT

INTERIOR FINISH: POLYESTER ENAMEL - OFF-WHITE COLOR

PANEL WIDTH: 16"

WARRANTY: MANUFACTURER SHALL WARRANT THE METAL ROOF AGAINST RUPTURE OR PERFORATION OR FROM STRUCTURALLY FAILING DUE TO NORMAL ATMOSPHERIC CONDITIONS FOR A PERIOD OF TWENTY (20) YEARS. IN ADDITION, MANUFACTURER SHALL PROVIDE A 20 YEAR FINISH WARRANTY AGAINST PEELING AND BLISTERING, CHALK, AND FADE (COLOR CHANGE).

INSTALLER SHALL PROVIDE A WRITTEN WARRANTY FOR TWO (2) YEARS FROM THE DATE OF FINAL COMPLETION AND ACCEPTANCE, GUARANTEEING MATERIALS AND WORKMANSHIP FOR WATERTIGHTNESS, WEATHERTIGHTNESS, AND AGAINST ALL LEAKS. DURING THE INITIAL TWO (2) YEAR PERIOD. THE INSTALLER SHALL ASSURE WEATHERTIGHTNESS AND WATERTIGHTNESS OF THE ROOF WITHOUT ANY COST TO THE BUILDING OWNER.

B. FLASHING AND TRIM ACCESSORIES: SHALL BE PROVIDED BY THE PANEL MANUFACTURER AND BE COMPATIBLE WITH AND THE SAME COLOR AS THE PROVIDED ROOF PANELS.

C. WOOD FRAMING:

ALL LUMBER SHALL BE DOUGLAS FIR NO. 2 OR BETTER TREATED WITH ACQ-C, ACQ-D, CA-B, CBA-A WITH NO AMMONIA.

CONSTRUCTION BRACING SHALL BE PROVIDED BY THE CONTRACTOR TO MAINTAIN THE BUILDING PLUMB AND TRUE. THIS BRACING SHALL REMAIN UNTIL THE SPECIFIED PERMANENT BRACING AND STRUCTURAL MEMBERS ARE INSTALLED AND FULLY CONNECTED.

TRUSS DOCUMENTS TO INCLUDE SEALED LAYOUTS, SEALED PROFILES AND CALCULATIONS AND TRUSS BLOCKING REQUIREMENTS.

STAMP AND SIGNATURE OF ENGINEER RESPONSIBLE FOR PREPARATION OF ALL TRUSS DESIGN AND LAYOUT DRAWINGS.
ALLOWABLE LOADS IN LBS/EFFECTIVE NAIL OR LBS/SQ IN FOR LUMBER AND PLATES USED AS ALLOWED BY ICBO AND CURRENT ICBO REPORT
STRESS REDUCTION FACTORS USED FOR PLATES
TOP AND BOTTOM CHORD DESIGN LOADS IN PLF
SIZE, GAUGE, AND EXACT LOCATION BY DIMENSION OF PLATES.
LUMBER SPECIES AND GRADES USED.
CONCENTRATED LOAD REQUIREMENTS HAVE BEEN DESIGNED FOR AND SHOWN ON DOCUMENTS
TRUSS CONNECTION HARDWARE REQUIREMENTS.

ALL TRUSSES MUST BE DESIGNED FOR UPLIFT LOADS. UPLIFT VALUES AT EACH TRUSS BEARING POINT MUST BE SHOWN ON TRUSS ENGINEERING SHEET.

PLATE DESIGN AND MANUFACTURER SHALL BE AS APPROVED BY "THE RESEARCH COMMITTEE FOR THE ICBO". PLATES SHALL BE GALVANIZED OR OTHERWISE PROTECTED FROM CORROSION.

FABRICATION OF TRUSSES SHALL BE AS APPROVED BY THE ICBO EXCEPT THAT THIS SPECIFICATION SHALL GOVERN WHEN IT EXCEEDS ICBO STANDARDS.

FABRICATE TRUSSES FROM APPROVED SHOP DRAWINGS.

FABRICATE TRUSSES IN JIGS WITH MEMBERS ACCURATELY CUT TO PROVIDE FULL CONTACT JOINTS.

EACH CHORD SHALL EXTEND THROUGH TWO PANEL POINTS BEFORE BEING SPLICED.

ALL COMPONENT WEB MEMBERS REQUIRING LATERAL BRACING SHALL HAVE 2-BY T-BRACES UNLESS COMPONENT ENGINEER PROVIDES OTHER BRACING DESIGN AND DETAILS.

MOISTURE CONTENT OF ALL LUMBER SHALL NOT EXCEED 19 %.

D. FASTENERS:

FASTENERS OR CONNECTORS SHALL BE SIMPSON STRONG-TIE PRODUCT, OR EQUIVALENT, UNLESS NOTED OTHERWISE

METAL SCREWS SHALL BE SELF-DRILLING SELF-TAPPING WITH TYPE, SIZE, AND LOCATION AS SHOWN ON THE DRAWINGS.

SCREWS, BOLTS, AND ANCHORS PENETRATING TREATED WOOD SHALL BE HOT-DIPPED GALVANIZED IN ACCORDANCE WITH ASTM A 123/A 123M OR ASTM A 153/A 153M AS APPROPRIATE.

SCREW PENETRATION THROUGH JOINED MATERIALS SHALL NOT BE LESS THAN THREE EXPOSED THREADS.

SCREWS COVERED BY SHEATHING MATERIALS SHALL HAVE LOW PROFILE HEADS.

EXPOSED SCREWS SHALL INCLUDE A COMBINATION STEEL AND NEOPRENE WASHER. SCREW HEAD AND WASHER SHALL BE COLOR MATCHED TO PANEL OR FLASHING.

POP RIVETS SHALL BE STAINLESS STEEL AND COLOR MATCHED TO PANEL OR FLASHING.

E. WELDS: ALL WELDING SHALL BE PERFORMED IN ACCORDANCE WITH AWS C1.1 OR C1.3, AS MODIFIED BY AISI S100-2007.

ALL WELDERS, WELDING OPERATIONS, AND WELDING PROCEDURES SHALL BE QUALIFIED ACCORDING TO AWS C1.1/C1.3.

ALL WELDS SHALL BE CLEANED AND COATED WITH RUST INHIBITIVE GALVANIZING PAINT. DO NOT FIELD WELD MATERIALS LIGHTER THAN 1.2 MM 18 GAGE.

F. CLOSURES AND SEALANTS:GLAS F

JOINT SEALANTS REQUIRED TO BE APPLIED BETWEEN ROOF PANEL SEAMS SHALL BE AS RECOMMENDED BY PANEL MANUFACTURER.

4. INSTALLATION:

A. FRAMING MEMBERS SHALL BE ERECTED WITHIN FOLLOWING LIMITS:

STUDS: 1/4 INCH IN 8 FEET OUT OF PLUMB, NOT CUMULATIVE, AND

FACE OF FRAMING MEMBERS: 1/4 INCH IN 8 FEET FROM A TRUE PLANE.

B. ROOF PANELS SHALL BE INSTALLED AS FOLLOWS:

PANELS SHALL BE FORMED TO LENGTH. END LAPS WILL NOT BE ALLOWED

COMPLY WITH MANUFACTURER'S PRODUCT DATA, TECHNICAL BULLETINS, AND INSTALLATION INSTRUCTIONS.

INSTALL PANELS PLUMB, LEVEL, AND STRAIGHT AS INDICATED IN THE PROJECT DRAWINGS.

INSTALL PANEL SYSTEM SO THAT IT IS WITHOUT WAVES, WARPS, BUCKLES, OR DISTORTIONS, AND ALLOW FOR THERMAL MOVEMENTS OF THE PANELS.

USE ONLY SHEARING TYPE TOOLS TO CUT PANELS, AS REQUIRED. ABRASIVE DEVICES SHALL NOT BE USED ON OR NEAR ROOF PANELS.

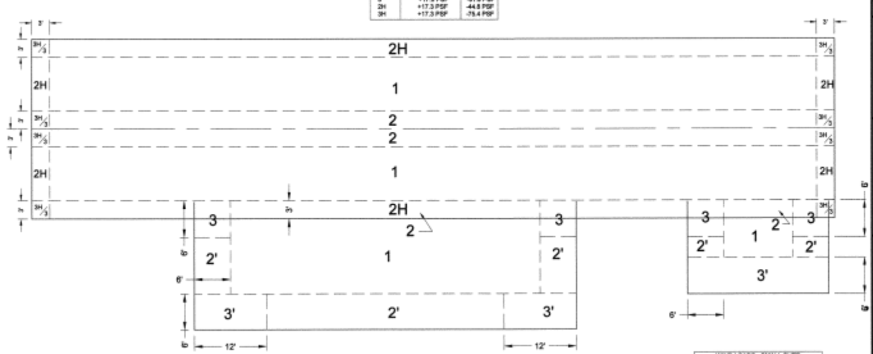
C. FASTENER INSTALLATION:

CONTRACTOR'S QUALITY CONTROL PROGRAM SHALL MONITOR AND ENSURE SELF-TAPPING AND OTHER FASTENERS ARE INSTALLED TO THE PROPER TORQUE, SO AS TO PREVENT UNDER-TIGHTENING OR STRIPPING OUT OF SHEET METAL COMPONENTS.

NAILING SCHEDULE

CONNECTION	FASTENER	NUMBER OR SPACING
JOIST TO BAND JOIST, FACE NAIL	16d COMMON	3
JOIST TO SIL OR GIRDER, TOE NAIL	8d COMMON	3
BRIDGING TO JOIST, TOE NAIL EACH END	8d COMMON	2
LEDGER STRIP	16d COMMON	3 AT EACH JOIST
1x8 OR LESS SUBFLOOR TO EACH JOIST, FACE NAIL	8d COMMON	2
2-INCH SUBFLOOR TO JOIST OR GIRDER, BLIND AND FACE NAIL	16d COMMON	2
SOLE PLATE TO JOIST OR BLOCKING, FACE NAIL	16d COMMON	16" OC
TOP OR SOLE PLATE TO STUD, END NAILED	16d COMMON	2
STUD TO SOLE PLATE, TOE NAIL	8d COMMON	4
DOUBLED STUDS, FACE NAIL	10d COMMON	24" OC
DOUBLE TOP PLATES, FACE NAIL	10d COMMON	16" OC
TOP PLATES, LAP AND INTERSECTION, FACE NAIL	2 - 16d COMMON OR 3 - 10d COMMON	
CONTINUOUS HEADER, TWO PIECES	16d COMMON	16" OC ALONG EACH EDGE
CEILING JOIST TO PLATE, TOE NAIL	8d COMMON	3
CONTINUOUS HEADER TO STUD, TOE NAIL	8d COMMON	
CEILING JOISTS, LAPS OVER PARTITIONS, FACE NAIL	3 - 16d COMMON OR 4 - 10d COMMON	
CEILING JOISTS, TO PARALLEL RAFTERS, FACE NAIL	3 - 16d COMMON OR 4 - 10d COMMON	
RAFTER TO PLATE, TOE NAIL	8d COMMON	3

WIND LOADS - MAIN GABLE ROOF		
ZONE	DOWNWARD	UPLIFT
1	+17.3 PSF	-27.5 PSF
2	+17.3 PSF	-35.6 PSF
3	+17.3 PSF	-51.9 PSF
2H	+17.3 PSF	-44.8 PSF
3H	+17.3 PSF	-75.4 PSF



WIND LOADS - LARGE SHED		
ZONE	DOWNWARD	UPLIFT
1	+10.0 PSF	-26.1 PSF
2	+10.0 PSF	-29.4 PSF
3	+10.0 PSF	-38.7 PSF
2'	+10.0 PSF	-35.5 PSF
3'	+10.0 PSF	-48.9 PSF

WIND LOADS - SMALL SHED		
ZONE	DOWNWARD	UPLIFT
1	+10.0 PSF	-26.1 PSF
2	+10.0 PSF	-28.8 PSF
3	+10.0 PSF	-32.0 PSF
2'	+10.0 PSF	-36.1 PSF
3'	+10.0 PSF	-56.0 PSF

WIND LOADS

MICHAEL B MERRICK
LICENSED PROFESSIONAL ENGINEER
No. 13450S
HAWAII U.S.A.

THIS WORK WAS PREPARED BY ME OR UNDER MY SUPERVISION AND CONSTRUCTION OF THIS PROJECT WILL BE UNDER MY OBSERVATION.

4-30-2010
Signature Expiration Date of the License

DATE	DESCRIPTION
11-2-09	FOR CERL REVIEW

BUILDING 84
KILAUEA MILITARY CAMP

CORROSION RESISTANT ROOF WITH INTEGRATED PHOTOVOLTAIC POWER SYSTEM

KILAUEA MILITARY CAMP, HAWAII

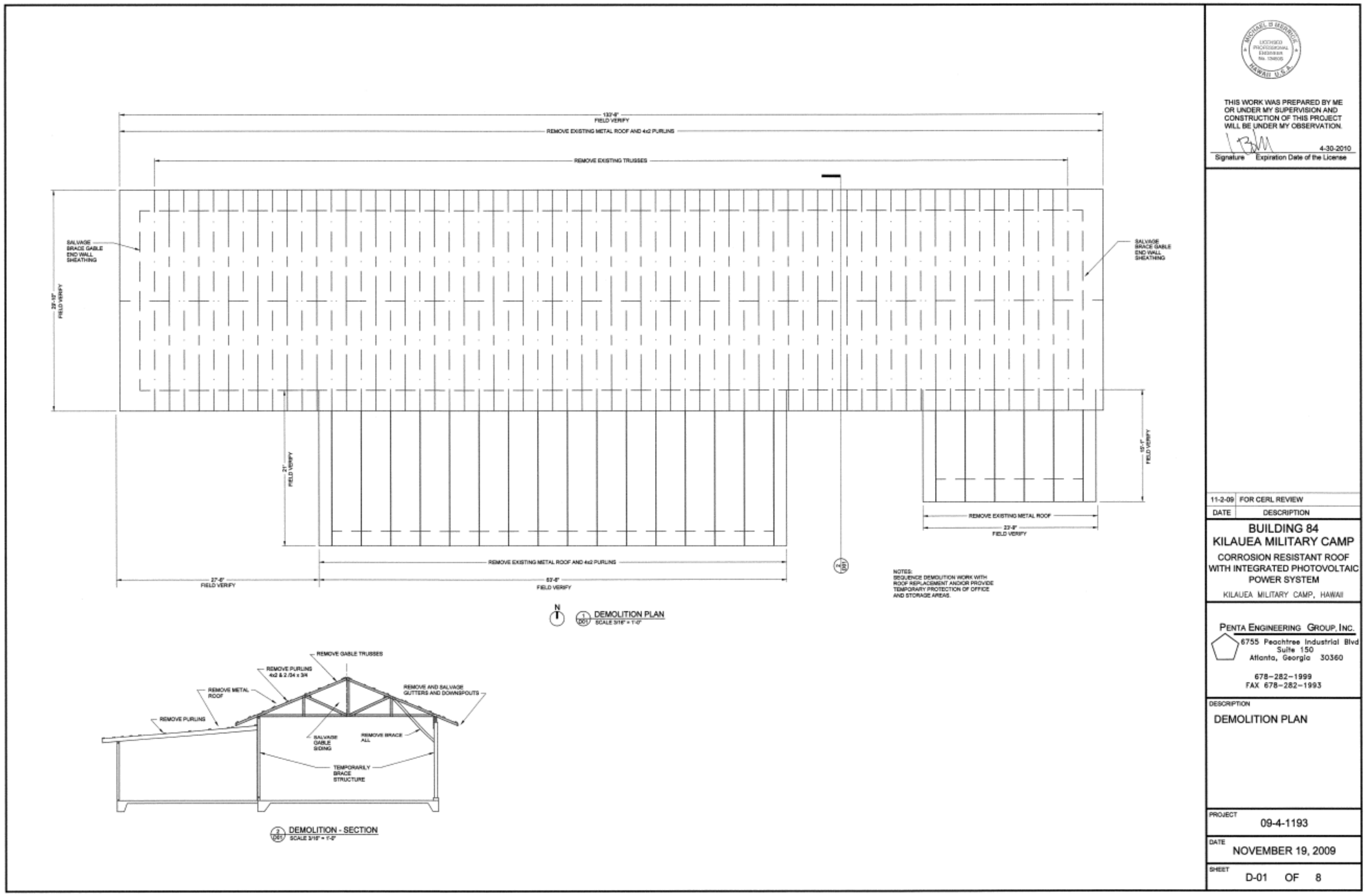
PENTA ENGINEERING GROUP, INC.
6755 Peachtree Industrial Blvd
Suite 150
Atlanta, Georgia 30360
678-282-1999
FAX 678-282-1993

DESCRIPTION
GENERAL NOTES

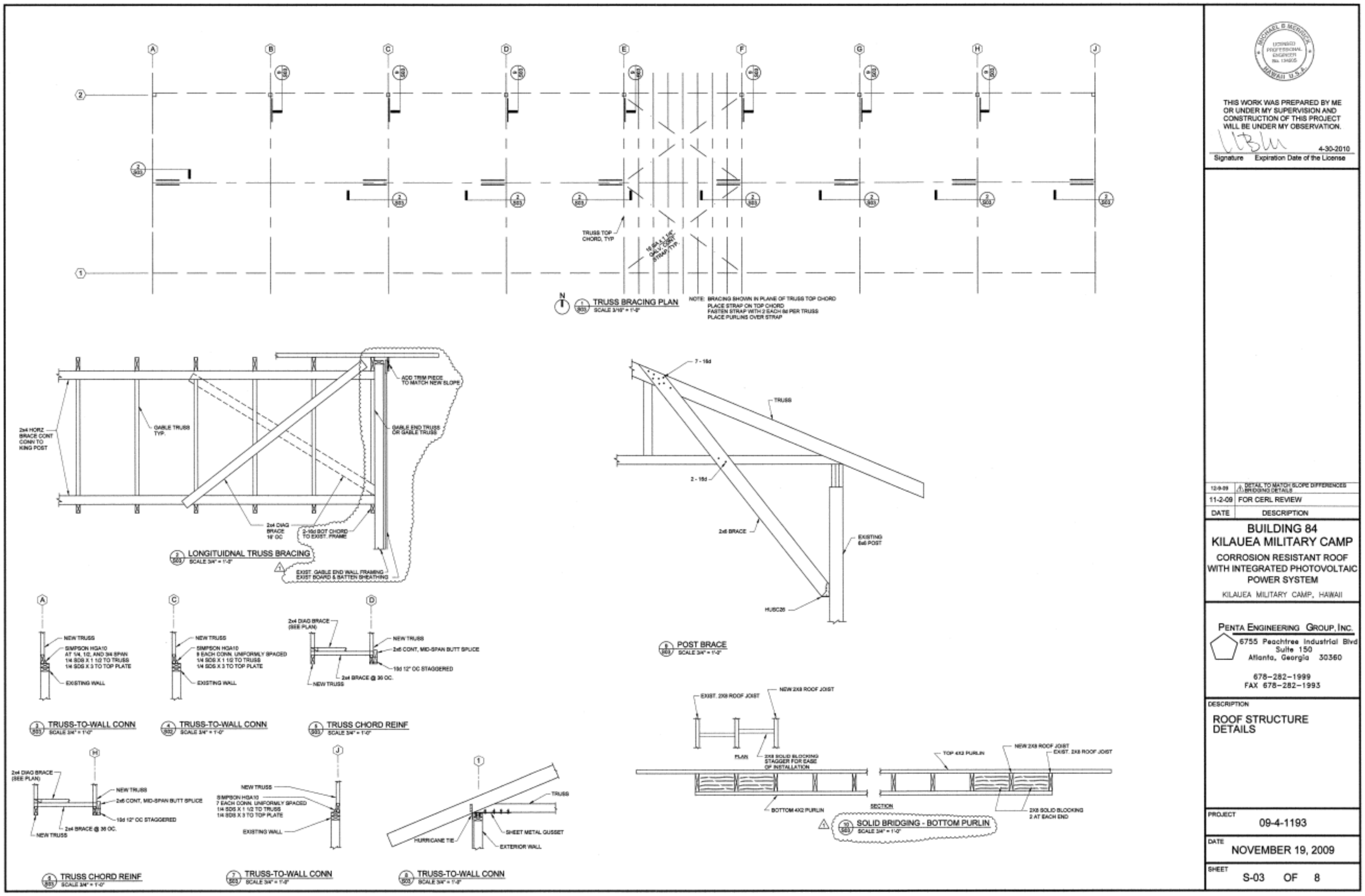
PROJECT
09-4-1193

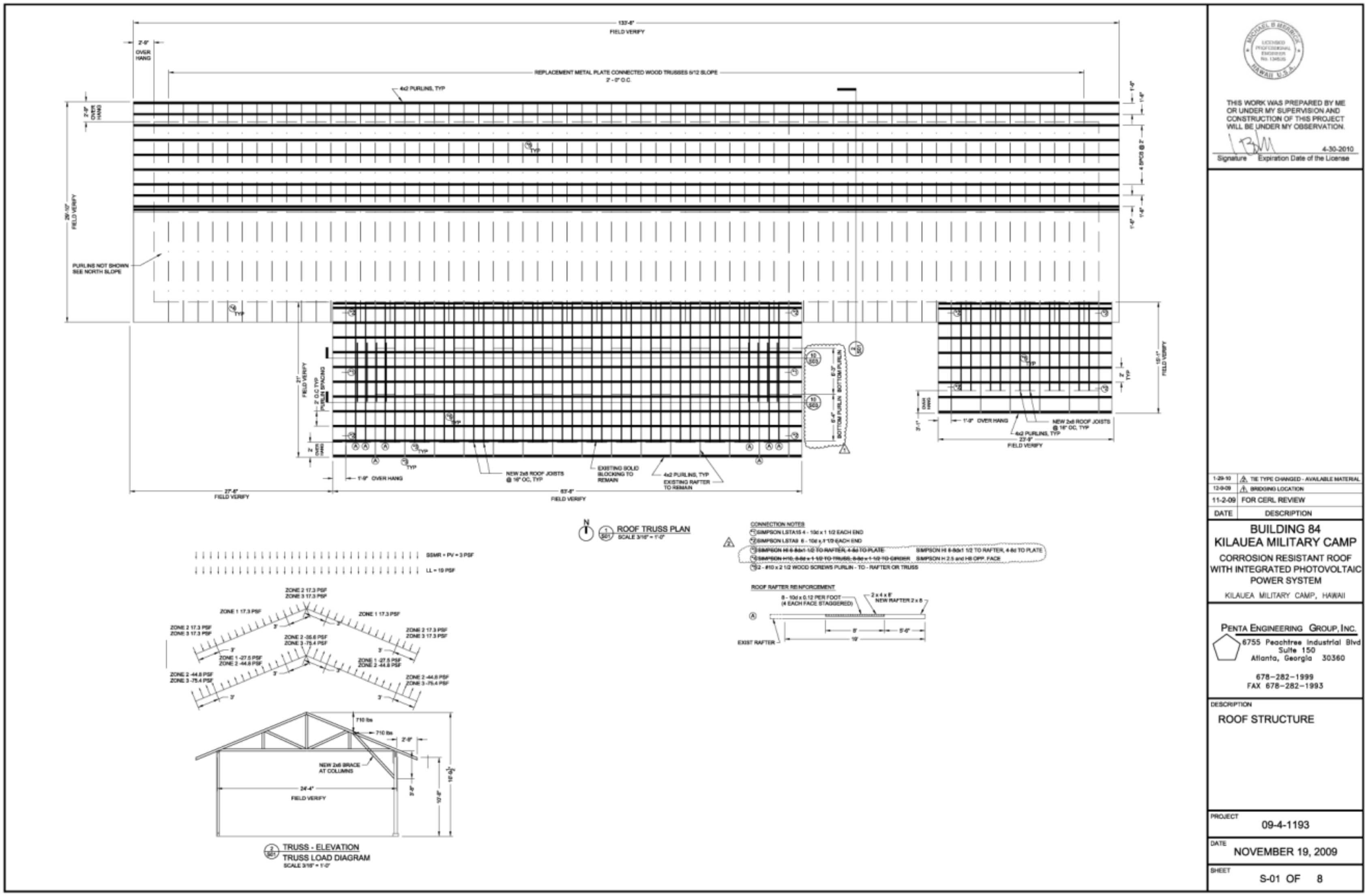
DATE
NOVEMBER 19, 2009

SHEET
G-02 OF 8

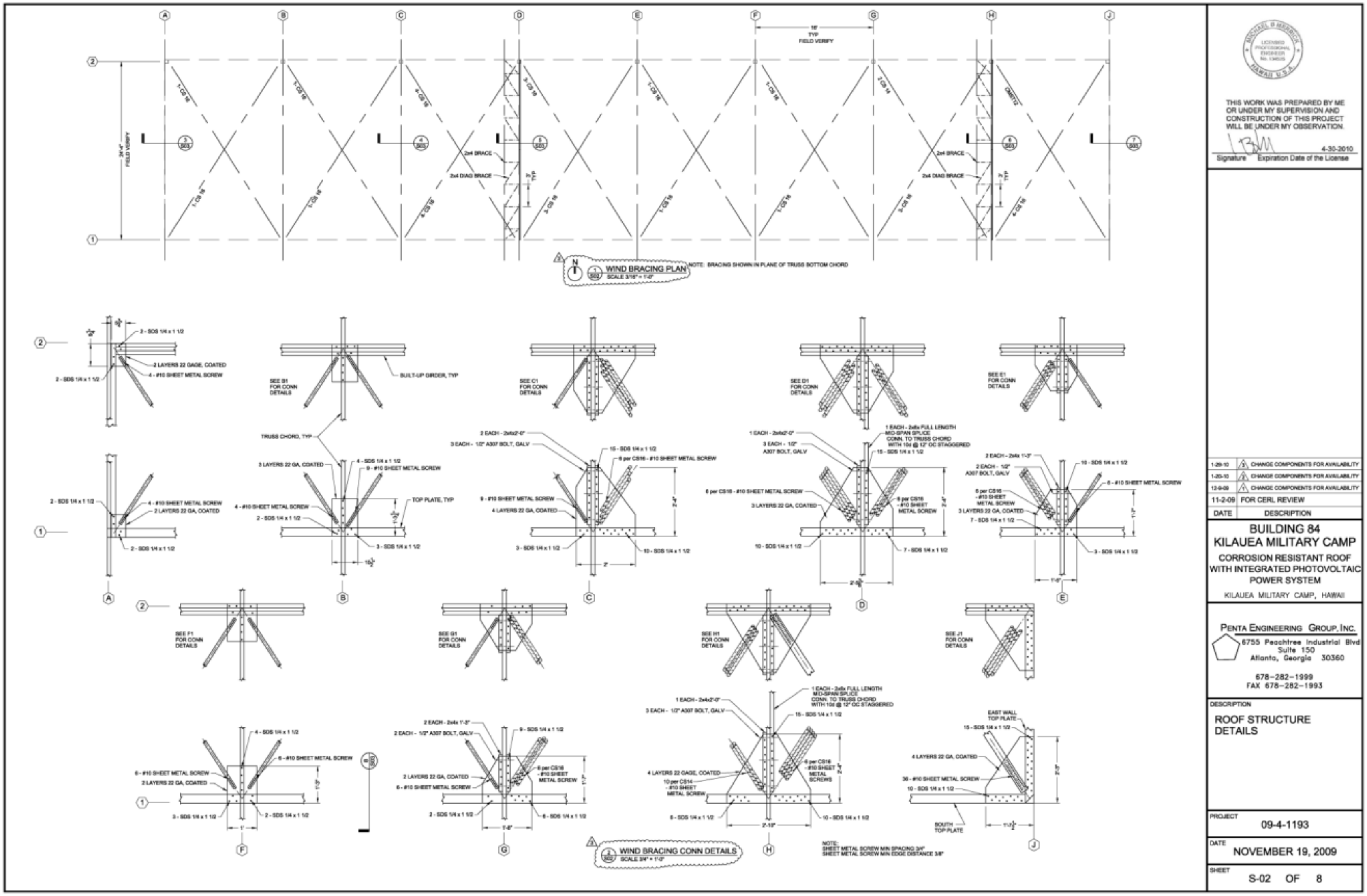


133'-8"
FIELD VERIFY
REMOVE EXISTING METAL ROOF AND 4x2 PURLINS
REMOVE EXISTING TRUSSES
SALVAGE BRACE GABLE END WALL SHEATHING
SALVAGE BRACE GABLE END WALL SHEATHING
FIELD VERIFY
21'
FIELD VERIFY
15'-1"
FIELD VERIFY
REMOVE EXISTING METAL ROOF
23'-8"
FIELD VERIFY
REMOVE EXISTING METAL ROOF AND 4x2 PURLINS
27'-6"
FIELD VERIFY
53'-8"
FIELD VERIFY
NOTES:
SEQUENCE DEMOLITION WORK WITH ROOF REPLACEMENT AND/OR PROVIDE TEMPORARY PROTECTION OF OFFICE AND STORAGE AREAS.
N
1 D01 DEMOLITION PLAN
SCALE 3/16" = 1'-0"
REMOVE GABLE TRUSSES
REMOVE PURLINS 4x2 & 2 /34 x 3/4
REMOVE METAL ROOF
REMOVE AND SALVAGE GUTTERS AND DOWNSPOUTS
REMOVE PURLINS
SALVAGE GABLE SIDING
REMOVE BRACE ALL
TEMPORARILY BRACE STRUCTURE
2 D01 DEMOLITION - SECTION
SCALE 3/16" = 1'-0"
MICHAEL B MERRICK
HAWAII U.S.A.
THIS WORK WAS PREPARED BY ME OR UNDER MY SUPERVISION AND CONSTRUCTION OF THIS PROJECT WILL BE UNDER MY OBSERVATION.
4-30-2010
Signature
Expiration Date of the License
11-2-09 FOR CERL REVIEW
DATE DESCRIPTION
BUILDING 84
KILAUEA MILITARY CAMP
CORROSION RESISTANT ROOF WITH INTEGRATED PHOTOVOLTAIC POWER SYSTEM
KILAUEA MILITARY CAMP, HAWAII
PENTA ENGINEERING GROUP, INC.
6755 Peachtree Industrial Blvd
Suite 150
Atlanta, Georgia 30360
678-282-1999
FAX 678-282-1993
DESCRIPTION
DEMOLITION PLAN
PROJECT
09-4-1193
DATE
NOVEMBER 19, 2009
SHEET
D-01 OF 8


TRUSS BRACING PLAN
SCALE 3/16" = 1'-0"
NOTE: BRACING SHOWN IN PLANE OF TRUSS TOP CHORD
PLACE STRAP ON TOP CHORD
FASTEN STRAP WITH 2 EACH 8d PER TRUSS
PLACE PURLINS OVER STRAP
TRUSS TOP CHORD, TYP
LONGITUIDNAL TRUSS BRACING
SCALE 3/4" = 1'-0"
2x4 HORZ BRACE CONT CONN TO KING POST
GABLE TRUSS TYP.
ADD TRIM PIECE TO MATCH NEW SLOPE
GABLE END TRUSS OR GABLE TRUSS
2x4 DIAG BRACE 16' OC
2-10d BOT CHORD TO EXIST. FRAME
EXIST. GABLE END WALL FRAMING EXIST BOARD & BATTEN SHEATHING
POST BRACE
SCALE 3/4" = 1'-0"
7 - 16d
TRUSS
2 - 16d
2x6 BRACE
EXISTING 6x6 POST
HUSC26
TRUSS-TO-WALL CONN
TRUSS CHORD REINF
NEW TRUSS
SIMPSON HGA10
EXISTING WALL
2x4 DIAG BRACE (SEE PLAN)
2x6 CONT, MID-SPAN BUTT SPLICE
10d 12" OC STAGGERED
2x4 BRACE @ 36 OC.
HURRICANE TIE
SHEET METAL GUSSET
EXTERIOR WALL
SOLID BRIDGING - BOTTOM PURLIN
SCALE 3/4" = 1'-0"
EXIST. 2X8 ROOF JOIST
NEW 2X8 ROOF JOIST
2X8 SOLID BLOCKING STAGGER FOR EASE OF INSTALLATION
TOP 4X2 PURLIN
BOTTOM 4X2 PURLIN
2X8 SOLID BLOCKING 2 AT EACH END
SECTION
PLAN
THIS WORK WAS PREPARED BY ME OR UNDER MY SUPERVISION AND CONSTRUCTION OF THIS PROJECT WILL BE UNDER MY OBSERVATION.
4-30-2010
Signature Expiration Date of the License
12-9-09 DETAIL TO MATCH SLOPE DIFFERENCES BRIDGING DETAILS
11-2-09 FOR CERL REVIEW
DATE DESCRIPTION
BUILDING 84
KILAUEA MILITARY CAMP
CORROSION RESISTANT ROOF WITH INTEGRATED PHOTOVOLTAIC POWER SYSTEM
KILAUEA MILITARY CAMP, HAWAII
PENTA ENGINEERING GROUP, INC.
6755 Peachtree Industrial Blvd
Suite 150
Atlanta, Georgia 30360
678-282-1999
FAX 678-282-1993
DESCRIPTION
ROOF STRUCTURE DETAILS
PROJECT 09-4-1193
DATE NOVEMBER 19, 2009
SHEET S-03 OF 8



137'-8"
FIELD VERIFY
REPLACEMENT METAL PLATE CONNECTED WOOD TRUSSES 5/12 SLOPE
2'-0" O.C.
4x2 PURLINS, TYP
PURLINS NOT SHOWN SEE NORTH SLOPE
BOTTOM PURLIN
NEW 2x8 ROOF JOISTS @ 16" OC, TYP
EXISTING SOLID BLOCKING TO REMAIN
4x2 PURLINS, TYP
EXISTING RAFTER TO REMAIN
1'-9" OVER HANG
27'-8"
FIELD VERIFY
67'-8"
FIELD VERIFY
23'-8"
FIELD VERIFY
ROOF TRUSS PLAN
CONNECTION NOTES
ROOF RAFTER REINFORCEMENT
EXIST RAFTER
SSMR + PV = 3 PSF
LL = 15 PSF
710 lbs
NEW 2x6 BRACE AT COLUMNS
24'-4"
FIELD VERIFY
TRUSS - ELEVATION
TRUSS LOAD DIAGRAM
THIS WORK WAS PREPARED BY ME OR UNDER MY SUPERVISION AND CONSTRUCTION OF THIS PROJECT WILL BE UNDER MY OBSERVATION.
4-30-2010
Signature Expiration Date of the License
1-29-10 TIE TYPE CHANGED - AVAILABLE MATERIAL
12-9-09 BRIDGING LOCATION
11-2-09 FOR CERL REVIEW
DATE DESCRIPTION
BUILDING 84
KILAUEA MILITARY CAMP
CORROSION RESISTANT ROOF WITH INTEGRATED PHOTOVOLTAIC POWER SYSTEM
KILAUEA MILITARY CAMP, HAWAII
PENTA ENGINEERING GROUP, INC.
6755 Peachtree Industrial Blvd
Suite 150
Atlanta, Georgia 30360
678-282-1999
FAX 678-282-1993
DESCRIPTION
ROOF STRUCTURE
PROJECT
09-4-1193
DATE
NOVEMBER 19, 2009
SHEET
S-01 OF 8


WIND BRACING PLAN
SCALE 3/16" = 1'-0"
NOTE: BRACING SHOWN IN PLANE OF TRUSS BOTTOM CHORD
WIND BRACING CONN DETAILS
SCALE 3/4" = 1'-0"
NOTE:
SHEET METAL SCREW MIN SPACING 3/4"
SHEET METAL SCREW MIN EDGE DISTANCE 3/8"
THIS WORK WAS PREPARED BY ME OR UNDER MY SUPERVISION AND CONSTRUCTION OF THIS PROJECT WILL BE UNDER MY OBSERVATION.
4-30-2010
Signature Expiration Date of the License
1-29-10 CHANGE COMPONENTS FOR AVAILABILITY
1-20-10 CHANGE COMPONENTS FOR AVAILABILITY
12-9-09 CHANGE COMPONENTS FOR AVAILABILITY
11-2-09 FOR CERL REVIEW
DATE DESCRIPTION
BUILDING 84
KILAUEA MILITARY CAMP
CORROSION RESISTANT ROOF WITH INTEGRATED PHOTOVOLTAIC POWER SYSTEM
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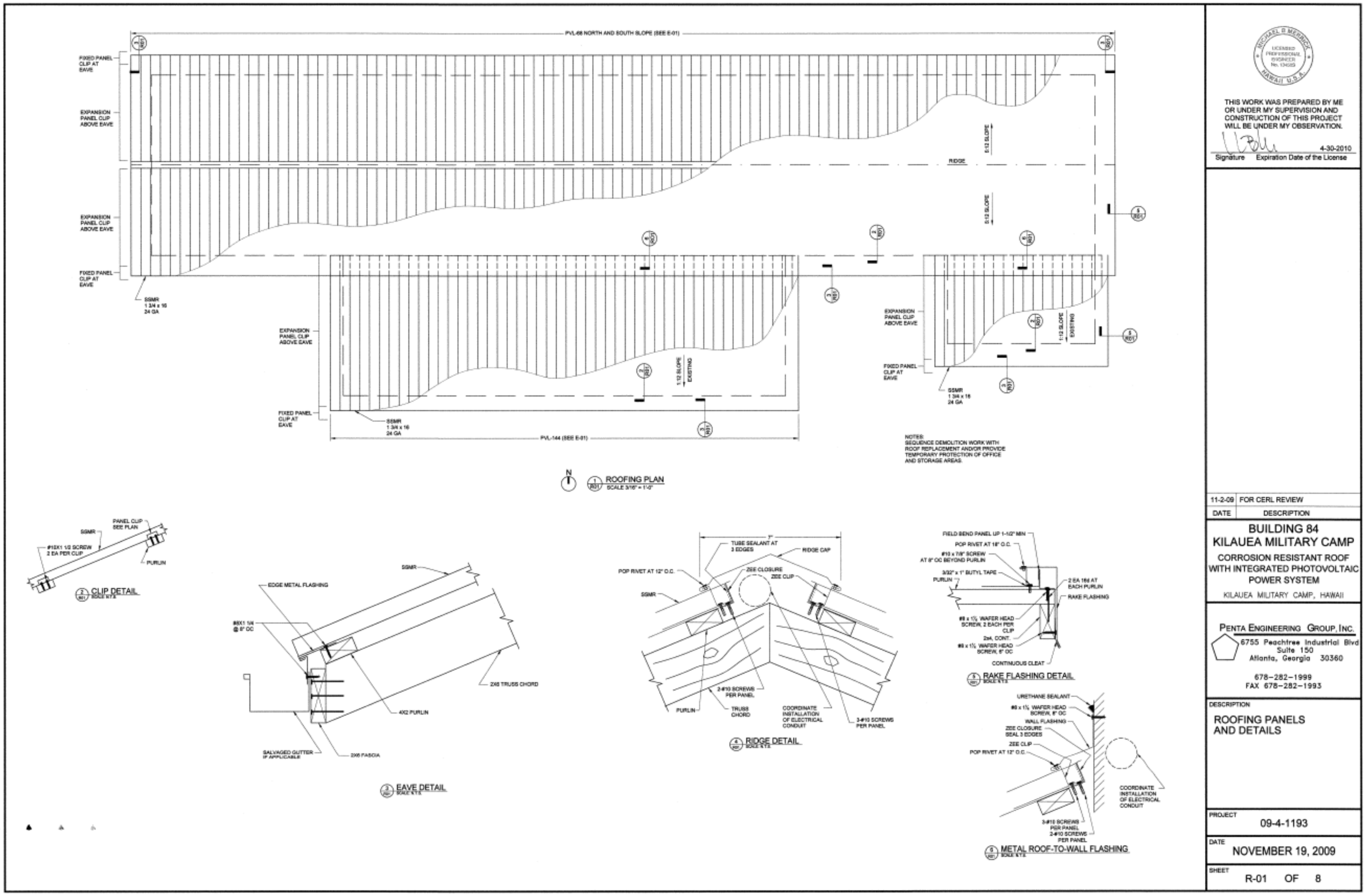
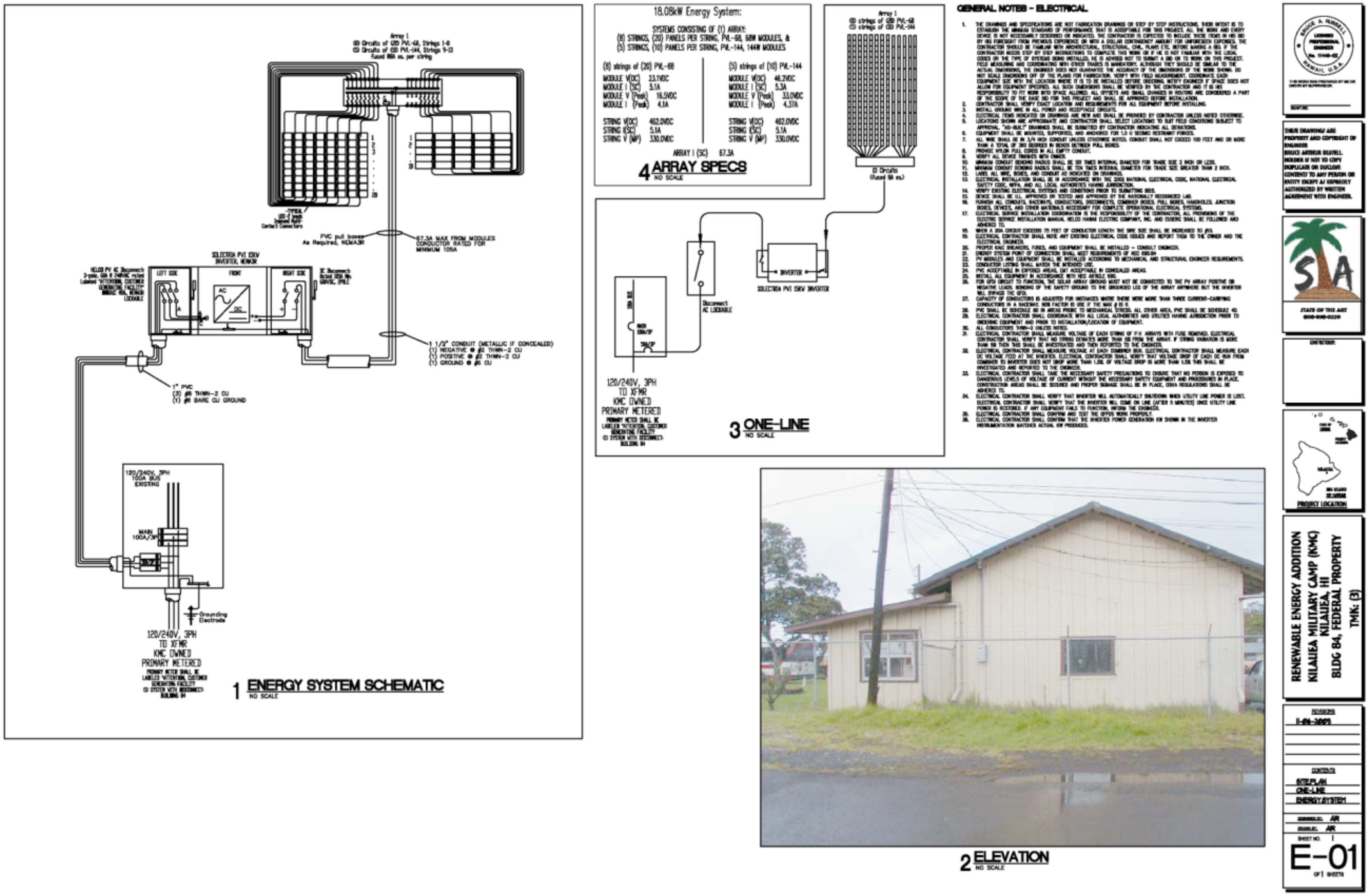
Suite 150
Atlanta, Georgia 30360
678-282-1999
FAX 678-282-1993
DESCRIPTION
ROOF STRUCTURE DETAILS
PROJECT
09-4-1193
DATE
NOVEMBER 19, 2009
SHEET
S-02 OF 8



PVL-68 NORTH AND SOUTH SLOPE (SEE E-01)
RIDGE
5:12 SLOPE
1:12 SLOPE EXISTING
PVL-144 (SEE E-01)
NOTES:
SEQUENCE DEMOLITION WORK WITH ROOF REPLACEMENT AND/OR PROVIDE TEMPORARY PROTECTION OF OFFICE AND STORAGE AREAS.
ROOFING PLAN
CLIP DETAIL
EAVE DETAIL
RIDGE DETAIL
RAKE FLASHING DETAIL
METAL ROOF-TO-WALL FLASHING
THIS WORK WAS PREPARED BY ME OR UNDER MY SUPERVISION AND CONSTRUCTION OF THIS PROJECT WILL BE UNDER MY OBSERVATION.
4-30-2010
Signature Expiration Date of the License
11-2-09 FOR CERL REVIEW
DATE DESCRIPTION
BUILDING 84
KILAUEA MILITARY CAMP
CORROSION RESISTANT ROOF WITH INTEGRATED PHOTOVOLTAIC POWER SYSTEM
KILAUEA MILITARY CAMP, HAWAII
PENTA ENGINEERING GROUP, INC.
6755 Peachtree Industrial Blvd
Suite 150
Atlanta, Georgia 30360
678-282-1999
FAX 678-282-1993
DESCRIPTION
ROOFING PANELS AND DETAILS
PROJECT
09-4-1193
DATE
NOVEMBER 19, 2009
SHEET
R-01 OF 8


18.08kW Energy System:
SYSTEMS CONSISTING OF (1) ARRAY:
(8) STRINGS, (20) PANELS PER STRING, PVL-68, 68W MODULES, &
(5) STRINGS, (10) PANELS PER STRING, PVL-144, 144W MODULES
(8) strings of (20) PVL-68
MODULE V(OC) 23.1VDC
MODULE I (SC) 5.1A
MODULE V (Peak) 16.5VDC
MODULE I (Peak) 4.1A
STRING V(OC) 462.0VDC
STRING I(SC) 5.1A
STRING V (MP) 330.0VDC
(5) strings of (10) PVL-144
MODULE V(OC) 46.2VDC
MODULE I (SC) 5.3A
MODULE V (Peak) 33.0VDC
MODULE I (Peak) 4.37A
STRING V(OC) 462.0VDC
STRING I(SC) 5.1A
STRING V (MP) 330.0VDC
ARRAY I (SC) 67.3A
4 ARRAY SPECS
NO SCALE
1 ENERGY SYSTEM SCHEMATIC
NO SCALE
120/240V, 3PH
TO XFMR
KMC OWNED
PRIMARY METERED
1 1/2" CONDUIT (METALLIC IF CONCEALED)
(1) NEGATIVE @ #2 THWN-2 CU
(1) POSITIVE @ #2 THWN-2 CU
(1) GROUND @ #6 CU
1" PVC
(3) #6 THWN-2 CU
(1) #8 BARE CU GROUND
SOLECTRIA PVI 15KW INVERTER
3 ONE-LINE
NO SCALE
GENERAL NOTES - ELECTRICAL
2 ELEVATION
NO SCALE
RENEWABLE ENERGY ADDITION
KILAUEA MILITARY CAMP (KMC)
KILAUEA, HI
BLDG 84, FEDERAL PROPERTY
TMK: (3)
PROJECT LOCATION
STATE OF THE ART
CONTENTS
SITE PLAN
ONE-LINE
ENERGY SYSTEM
E-01

Appendix B: PV Equipment Documentation

The following four pages of specifications are extracted from the manufacturer's product literature.

UNI-SOLAR

Solar Laminate PVL-Series
Model: PVL-68

- High Temperature and Low Light Performance
- 20 Year Warranty on Power Output at 80%
- Quick-Connect Terminals* and Adhesive Backing
- Bypass Diodes for Shadow Tolerance
- UL 1703 Listed to 600 VDC (UL)
- IEC 61646 v1 certified
- IEC 61646 v2 and 61730, TUV certification pending

Performance Characteristics

Rated Power (P_{max}): 68 Wp

Production P_{max} Tolerance: ± 5 %

Construction Characteristics

Dimensions:	Length: 2849 mm (112.1"), Width: 394 mm (15.5"), Depth: 4 mm (0.2"), 16 mm (0.6") including potted terminal housing assembly
Weight:	3.9 kg (8.7 lbs)
Output Cables:	4 mm^2 (12 AWG) cable with weatherproof DC rated quick-connect terminals* 560mm (22") length.
By-pass Diodes:	Connected across every solar cell
Encapsulation:	Durable ETFE high light-transmissive polymer
Adhesive:	Ethylene propylene copolymer adhesive-sealant with microbial inhibitor
Cell Type:	11 triple junction amorphous silicon solar cells 356 mm x 239 mm (14" x 9.4") connected in series

Qualifications and Safety

(UL) Listed by Underwriter's Laboratories for electrical and fire safety (Class A Max. Slope 2/12, Class B Max. Slope 3/12, Class C Unlimited Slope fire ratings) for use in systems up to 600 VDC.

Laminate Standard Configuration

Photovoltaic laminate with potted terminal housing assembly with output cables and quick-connect terminals*

Application Criterion

- New or qualified new roof installations
- Installation by certified installers only
- Installation temperature between 10 °C - 40 °C (50 °F - 100 °F)
- Maximum roof temperature 85 °C (185 °F)
- Minimum slope: 5/8:12 (3°)
- Maximum slope 21:12 (60°)
- Membrane: Select EPDM and TPO substrates from approved manufacturers only
- Metal: PVDF Coated (Galvalume® or Zincalume®) steel metal roofing pan with flat surface (without pencil beads or decorative stippling) and 406 mm (16") minimum width

Refer to manufacturers installation guide for approved substrates and installation methods

*e.g., Multi-Contact (MC®) Connectors

Flexible

Lightweight

No-Glass

Durable

Shadow Tolerant

High Temp Performance

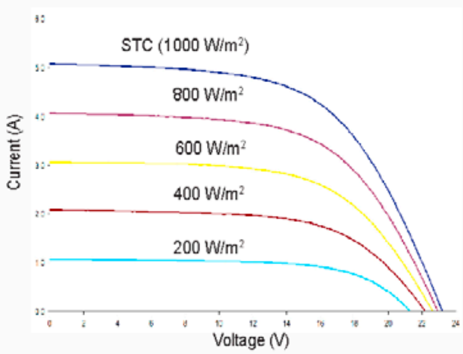
Technical Data Sheet

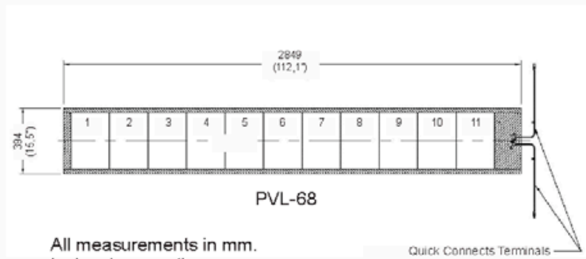
#AA4-3698-03

UNI-SOLAR

Solar Laminate PVL-Series
Model: PVL-68

IV Curves at various Levels of Irradiance at Air Mass 1.5 and 25 °C Cell Temperature





All measurements in mm.
Inches in parentheses.
Tolerances: Length: ± 5 mm (1/4"), Width: ± 3 mm (1/8")

Electrical Specifications

STC

(Standard Test Conditions)
(1000 W/m^2, AM 1.5, 25 °C Cell Temperature)

Maximum Power (P_{max}): 68 W
Voltage at Pmax (V_{mp}): 16.5 V
Current at Pmax (I_{mp}): 4.13 A
Short-circuit Current (I_{sc}): 5.1 A
Open-circuit Voltage (V_{oc}): 23.1 V
Maximum Series Fuse Rating: 8 A

NOCT

(Nominal Operating Cell Temperature)
(800 W/m^2, AM 1.5, 1 m/sec. wind)

Maximum Power (P_{max}): 53 W
Voltage at Pmax (V_{mp}): 15.4 V
Current at Pmax (I_{mp}): 3.42 A
Short-circuit Current (I_{sc}): 4.1 A
Open-circuit Voltage (V_{oc}): 21.1 V
NOCT: 46 °C

Temperature Coefficients

(at AM 1.5, 1000 W/m^2 irradiance)

Temperature Coefficient (TC) of I_{sc}: 0.001/°K(0.10%/°C)
Temperature Coefficient (TC) of V_{oc}: -0.0038/°K (-0.38%/°C)
Temperature Coefficient (TC) of P_{max}: 0.0021/°K (-0.21%/°C)
Temperature Coefficient (TC) of I_{mp}: 0.001/°K (0.10%/°C)
Temperature Coefficient (TC) of V_{mp}: -0.0031/°K (-0.31%/°C)

y = yreference • [1 + TC • (T- Treference)]

Notes:
1. During the first 8-10 weeks of operation, electrical output exceeds specified ratings. Power output may be higher by 15 %, operating voltage may be higher by 11 % and operating current may be higher by 4 %.
2. Electrical specifications are based on measurements performed at standard test conditions of 1000 W/m^2 irradiance, Air Mass 1.5, and cell temperature of 25 °C after stabilization.
3. Actual performance may vary up to 10 % from rated power due to low temperature operation, spectral and other related effects. Maximum system open-circuit voltage not to exceed 600 VDC per UL.
4. Specifications subject to change without notice.

Your UNI-SOLAR® Distributor:

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United Solar Ovonic LLC
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Rochester Hills, MI 48309
Tel: 248.293.0440
Fax: 248.844.1214
Toll Free (USA): 800.528.0617
info@uni-solar.com

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italyinfo@uni-solar.com

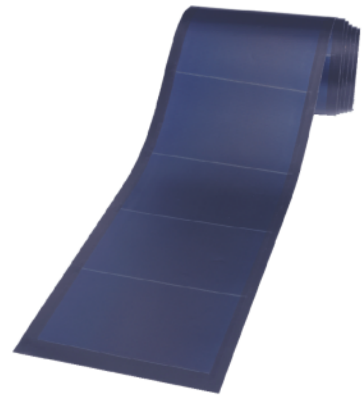
www.uni-solar.com

A subsidiary of Energy Conversion Devices, Inc. (Nasdaq: ENER)

#AA4-3698-03

Solar Laminate PVL-Series
Model: PVL-144

UNI-SOLAR



- High Temperature and Low Light Performance
- 5-Year Limited Product Warranty
- Limited Power Output Warranty:
  92% at 10 years, 84% at 20 years, 80% at 25 years (of minimum power)
- Quick-Connect Terminals and Adhesive Backing
- Bypass Diodes for Shadow Tolerance

Performance Characteristics

Rated Power (P_{max}):	144 Wp
Production P_{max} Tolerance:	± 5 %

Construction Characteristics

Dimensions:	Length: 5486 mm (216"), Width: 394 mm (15.5"), Depth: 4 mm (0.2"), 16 mm (0.6") including potted terminal housing assembly
Weight:	7.7 kg (17.0 lbs)
Output Cables:	4 mm^2 (12 AWG) cable with weatherproof DC-rated quick-connect terminals 560 mm (22") length
Bypass Diodes:	Connected across every solar cell
Encapsulation:	Durable ETFE high light-transmissive polymer
Adhesive:	Ethylene propylene copolymer adhesive sealant with microbial inhibitor
Cell Type:	22 triple junction amorphous silicon solar cells 356 mm x 239 mm (14" x 9.4") connected in series

Qualifications and Safety

c UL us — UL 1703 Listed by Underwriters Laboratories for electrical and fire safety (Class A Max. Slope 2/12, Class B Max. Slope 3/12, Class C Unlimited Slope fire ratings) for use in systems up to 600 VDC.

TÜV Rheinland — IEC 61646 and IEC 61730 certified by TÜV Rheinland for use in systems up to 1000 VDC.

Laminate Standard Configuration

Photovoltaic laminate with potted terminal housing assembly with output cables and quick-connect terminals on top.

Application Criteria*

- Installation temperature between 10 °C - 40 °C (50 °F - 100 °F)
- Maximum roof temperature 85 °C (185 °F)
- Minimum slope: 3° (1/2:12)
- Maximum slope 60° (21:12)
- Approved substrates include certain membrane and metal roofing products. See United Solar for details.

**Detailed installation requirements are specified in United Solar installation manuals.*

Technical Data Sheet

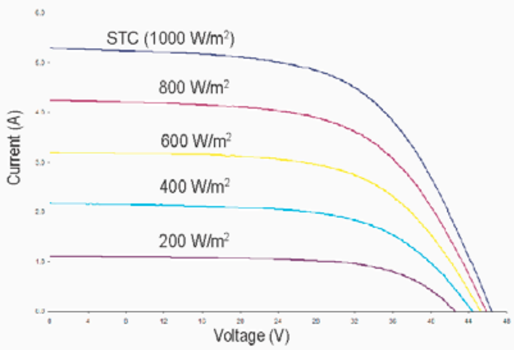
#AA5-3636-03

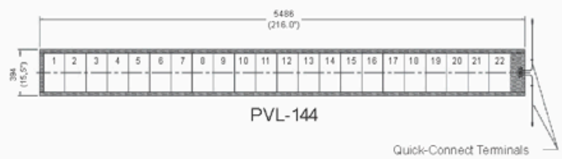
Solar Laminate PVL-Series

Model: PVL-144

UNI-SOLAR

IV Curves at various Levels of Irradiance at Air Mass 1.5 and 25 °C Cell Temperature





All measurements in mm
Inches in parentheses
Tolerances: Length: ± 5 mm (1/4"), Width: ± 3 mm (1/8")

Electrical Specifications

STC
(Standard Test Conditions)
(1000 W/m², AM 1.5, 25 °C Cell Temperature)

Maximum Power (P_{max}): 144 W
Voltage at Pmax (V_{mp}): 33.0 V
Current at Pmax (I_{mp}): 4.36 A
Short-circuit Current (I_{sc}): 5.3 A
Open-circuit Voltage (V_{oc}): 46.2 V
Maximum Series Fuse Rating: 8 A

NOCT
(Nominal Operating Cell Temperature)
(800 W/m², AM 1.5, 1 m/sec. wind)

Maximum Power (P_{max}): 111 W
Voltage at Pmax (V_{mp}): 30.8 V
Current at Pmax (I_{mp}): 3.6 A
Short-circuit Current (I_{sc}): 4.3 A
Open-circuit Voltage (V_{oc}): 42.2 V
NOCT: 46 °C

Temperature Coefficients

(at AM 1.5, 1000 W/m² irradiance)

Temperature Coefficient (TC) of I_{sc}: 0.001/°K(0.10%/°C)
Temperature Coefficient (TC) of V_{oc}: -0.0038/°K (-0.38%/°C)
Temperature Coefficient (TC) of P_{max}: -0.0021/°K (-0.21%/°C)
Temperature Coefficient (TC) of I_{mp}: 0.001/°K (0.10%/°C)
Temperature Coefficient (TC) of V_{mp}: -0.0031/°K (-0.31%/°C)

y = yreference • [1 + TC • (T- Treference)]

Notes:

1. During the first 8-10 weeks of operation, electrical output exceeds specified ratings. Power output may be higher by 15%, operating voltage may be higher by 11% and operating current may be higher by 4%.
2. Electrical specifications are based on measurements performed at standard test conditions of 1000 W/m² irradiance, Air Mass 1.5, and cell temperature of 25 °C after stabilization.
3. Actual performance may vary up to 10% from rated power due to low temperature operation, spectral and other related effects. Maximum system open-circuit voltage not to exceed 600 VDC per UL, 1000 VDC per TÜV Rheinland.
4. Specifications subject to change without notice.

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A subsidiary of Energy Conversion Devices, Inc. (Nasdaq: ENER)

#AA5-3636-03

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
February 2014	Final	

4. TITLE AND SUBTITLE
Corrosion-Resistant Roof with Integrated Photovoltaic Power System: Final Report on Project F09-AR04

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
David M. Bailey, Tarek Abdallah, Karl Palutke, Larry Clark, Rick Miles, and Mike Merrick

5d. PROJECT NUMBER
F09-AR04

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
US Army Engineer Research and Development Center
Construction Engineering Research Laboratory
P.O. Box 9005
Champaign, IL 61826-9005

8. PERFORMING ORGANIZATION REPORT NUMBER
ERDC/CERL TR-14-1

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of the Secretary of Defense (OUSD(AT&L))
3090 Defense Pentagon
Washington, DC 20301-3090

10. SPONSOR/MONITOR'S ACRONYM(S)
OSD

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

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This report documents the demonstration of a self-adhering, thin-film photovoltaic (PV) technology applied to a new aluminum-zinc coated standing-seam metal roof (SSMR) with a high-performance coating. The demonstration took place at Kilauea Military Camp (KMC), HI, which has a uniquely corrosive environment due to the periodic presence of volcanic gases. It also has high electric utility costs and limited grid capacity.

The corrosion performance of the roof and PV solar array was evaluated by periodic visual examination, onsite atmospheric coupon testing, and accelerated weathering laboratory tests of material coupons. Sensors were also installed at the interface between the PV membrane and roofing material, mounted in outdoor exposure at the site, to record any developing signs of corrosion. After a year in service, the PV appliqué modules were found to have no deleterious effect on the new SSMR, and the PV system performed as expected. However, due to the high first-costs related to procuring the thin-film PV components, the 30 year return on investment (ROI) ratio was only 0.19. Although the system is not economical enough to warrant Army-wide implementation, it may be specified in individual cases where energy sustainability is a higher priority than ROI.

15. SUBJECT TERMS
corrosion prevention, photovoltaic technology, evaluation, energy conservation, Kilauea Military Camp, roofing

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(include area code)*
Unclassified	Unclassified	Unclassified		60	