SUNPOWER®

1. TECHNICAL SALES SUMMARY 007.02.19

PHOTOVOLTAIC SYSTEMS: LOWER LEVELS OF GLARE AND REFLECTANCE VS. SURROUNDING ENVIRONMENT

Source paper Title (s):	**Photovoltaic Systems: Lower levels of Glare vs. General Surrounding Environment**
SPWR Technology:	**AR Glass and Light Trapping Technology**
SPWR Advantage:	**Using a higher percentage of available light**
Technical Contact:	**Lydia Seymour**
Intended Exposure (Internal/External)	**Level 1 (L1):** Consumer, Dealer **Level 2 (L2):** Marketing, Sales **Level 3 (L3):** Sales Analysts, UPP Bids

Possible Glare & Reflectance in PV Systems

Abstract

During the recent surge in residential and commercial photovoltaic opportunities, many PV suppliers and installers have fielded questions concerning glare and reflectance levels for PV systems. These questions range from the possible glare and reflectance effect on neighbors, to the glare and reflectance effect on air traffic. This document explains why PV systems are less reflective than typical surrounding buildings or reflective surfaces.

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Executive Summary

Random glare and reflectance which can be observed from the air are a key consideration for sites like airports. PV systems with antireflective glass demonstrate decisively lower glare and reflectance levels from the glare and reflectance generated by standard window glass and other common reflective surfaces such as bodies of water. SunPower has multiple large projects installed near airports or on air force bases[1]. Each of these large projects has passed FAA or Air Force standards and all projects have been determined as "No Hazard to Air Navigation." It is suggested that customers and installers discuss any possible concerns about glare and reflectance with neighbors near the planned PV system installation.

1. Explanation of Reflectance and PV glass

Efficient solar power generation requires absorbing as much light as possible while reflecting as little light as possible, so standard solar panels produce less glare and reflectance than standard window glass. This is pointed out very well in US patent # 6359212[2] which explains the differences in the *refraction* and *reflection* of solar panel glass versus standard window glass. Solar panels use "high-transmission, low-iron" glass, which absorbs more light, producing smaller amounts of glare and reflectance than normal glass. In order to further explain these differences, basic scientific terms used when discussing beams of light impacting surfaces and transitioning from the air to enter a surface.

1.1 Reflection, Refraction and Angles-of-incidence.

The imaginary line at 90^0 to a given reflective surface is called the **Normal.** The original beam of light is called the **incident** beam, and the angle at which it strikes the surface is called the **incident angle**. The quantity of reflected light is called the **reflectance**, and the angle at which it leaves the surface is the **angle of reflectance**. With transparent surfaces, the amount of light which bends slightly as it goes *through* the surface is called the **refracted beam** OR **transmittance.** These basic concepts of **reflection** (return of light *from* a surface) and **refraction** (bending and transmission of light *through* a surface) are pointed out in the first two figures on the next page. Both have a **normal**, an **incident beam** and an **incident angle**;

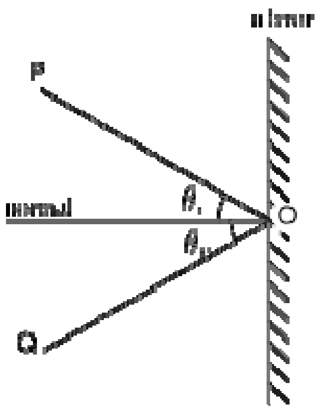

Figure 1-1: **REFLECTION**

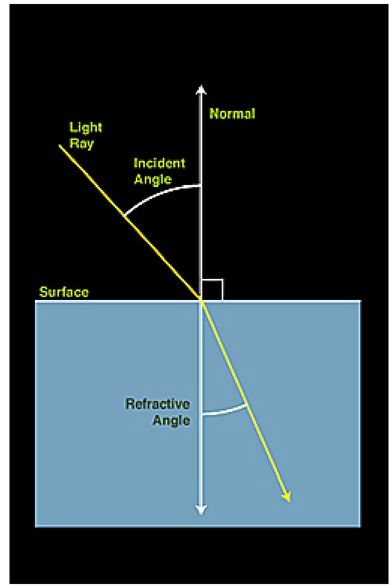

Figure 1-2: **REFRACTION**

Since our main discussion concerns types of glass and sunlight, we will further our explanation using **glass** as the example and speaking in terms of **reflected energy percentages**:

1.2 Incident light and Reflected Energy percentages.

When a beam of light falls on a piece of glass, some of the light is reflected from the glass surface, some of the light passes through the glass (transmitted), and some (very little) is absorbed by the glass.

- *The measure of the proportion of light reflected from the surface is called* ***reflectance (reflection)****.*
- *The measure of the proportion transmitted is the* ***transmittance (****This is where the term* ***high light-transmission*** *glass comes from because the glass is formulated to allow more light to pass through its surface than would pass through a standard glass surface).*
- *The measure of the proportion absorbed is the* ***absorptance (absorption*** *(this amount is very small for clear glass – much, much smaller proportionately, than the other two components)).*
- *Each quantity is expressed as a fraction of the total quantity of light in the beam. If the intensity of the beam is represented by the numerical 1, reflectance by R, absorptance by A and transmittance by T, intensity may be expressed as follows:* ***R + A + T = 1,*** *where glass is*

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*the **glazing material** pointed out in figure 2-2 below. (Figure 2-1 is a rough depiction of the percentages of light for each component of the equation).*

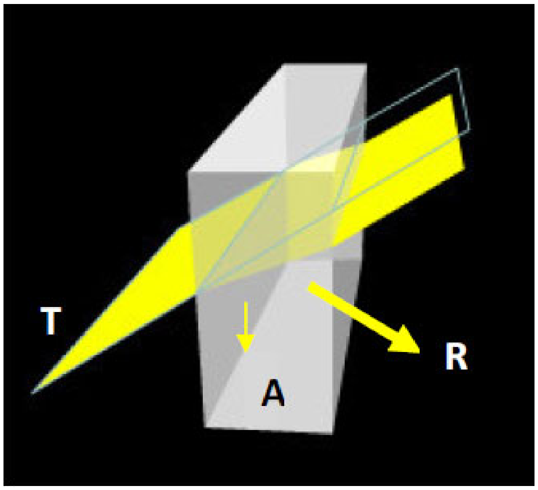

Figure 2-1 Depiction of resultant percentages for incident components

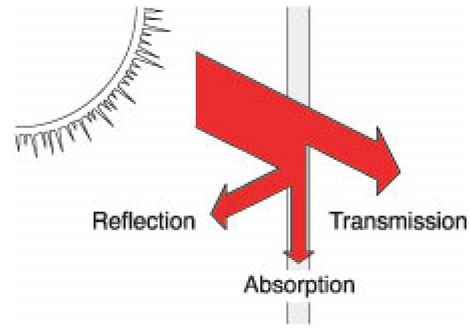

Figure 2-2. Solar radiation through a glazing material is either reflected, transmitted or absorbed

The reflection/refraction behavior of a medium is directly related to its *index of refraction*. The lower the index of refraction for a medium, the less light it reflects because the medium is *allowing more of the incident beam* to pass directly through (in our case, directly through the glass to the solar cells).

Common Reflective Surface	**n**
Steel	2.500
Snow (fresh, flaky)	1.980
Standard Glass	1.517
Plexiglas	1.500
Plastic	1.460
Smooth Water	1.333
Solar Glass (high transmission, low iron)	1.329
Solar Glass (with AR coating)	1.250

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Figure 2.3: Common Reflective Surfaces and Index of Refraction, "n" (the value "n" may vary by reference source, but the hierarchy of "n" values from one material to another will remain the same).

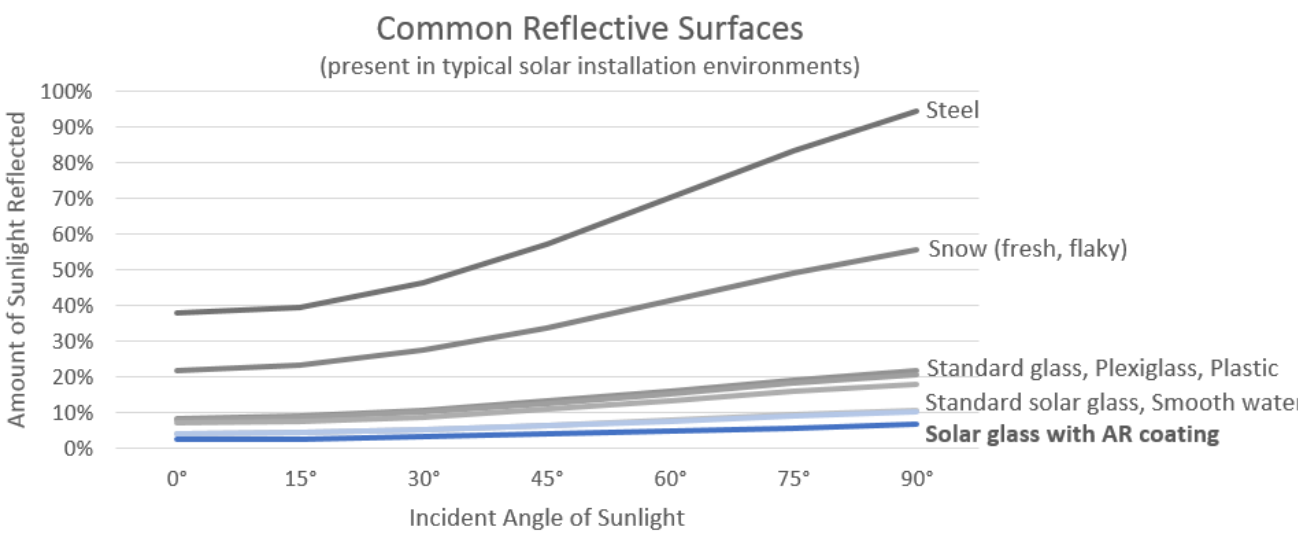

Figure 2.4: Common Reflective Surfaces and reflectance percentages.

In the below it is shown the reflected energy percentages of sunlight, off of some common residential and commercial surfaces. The legend and the graph lists the items from top to bottom in order of the highest percentage of reflected energy; E.g. – 'Steel' reflects more energy than 'Snow'. 'Snow' reflects more energy than 'standard glass', etc. It should be noted from the graph and the table below that the reflected energy percentage of Solar Glass is far below that of standard glass and more on the level of smooth water.

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	Incident angle of Sun						
Common Reflective Surface	**0°**	**15°**	**30°**	**45°**	**60°**	**75°**	**90°**
Steel	38%	39%	46%	57%	70%	83%	94%
Snow (fresh, flaky)	22%	23%	27%	34%	41%	49%	56%
Standard Glass	8%	9%	11%	13%	16%	19%	22%
Plexiglas	8%	9%	10%	12%	15%	18%	21%
Plastic	7%	7%	9%	11%	13%	16%	18%
Smooth Water	4%	4%	5%	6%	8%	9%	10%
Solar Glass (high transmission, low iron)	4%	4%	5%	6%	8%	9%	10%
Solar Glass (with AR coating)	2%	3%	3%	4%	5%	6%	7%

Figure 2.5: Common Reflective Surfaces and Reflectance percentage values.

1.3 AR Coating

Panel reflectivity can be varied for each time step to account for the position of the sun relative to the array. Smooth glass and light textured glass with and without anti-reflection coating, along with deeply textured glass were analyzed to derive accurate functions for computing reflectivity based on sun incidence angle.

PV Glass Cover Type	Fit Function Defined over $0° \le \theta \le 60°$	Fit Function Defined over $60° < \theta < 90°$
Smooth Glass without Anti-Reflection Coating	$y = 1.1977E\text{-}5\,x^2 - 9.5728E\text{-}4\,x + 4.410E\text{-}2$	$y = 6.2952E\text{-}5\,e^{0.1019x}$
Smooth Glass with Anti-Reflection Coating	$y = 1.473E\text{-}5\,x^2 - 9.6416E\text{-}4\,x + 3.2395E\text{-}2$	$y = 4.7464E\text{-}5\,e^{0.1051x}$
Light Textured Glass without Anti-Reflection Coating	$y = 1.5272E\text{-}5\,x^2 - 1.1304E\text{-}3\,x + 4.305E\text{-}2$	$y = 7.3804E\text{-}5\,e^{0.0994x}$
Light Textured Glass with Anti-Reflection Coating	$y = 1.4188E\text{-}5\,x^2 - 1.0326E\text{-}3\,x + 3.9016E\text{-}2$	$y = 7.0179E\text{-}5\,e^{0.0994x}$
Deeply Textured Glass	$y = 6.8750E\text{-}6\,x^2 - 6.5250E\text{-}4\,x + 2.10E\text{-}2$	$y = 4.1793E\text{-}5\,e^{0.0834x}$

Figure 2.6: Reflectance fit functions for PV cover types[3]

[3] Forge Solar Solar Glare Hazard Analysis Tool (SGHAT) Technical Reference Manual

SunPower uses “light textured” glass with AR coating on all modules. Below is also a more comprehensive angle-dependent reflectance data for SunPower commercial glass that shows it is the “light textured” case.

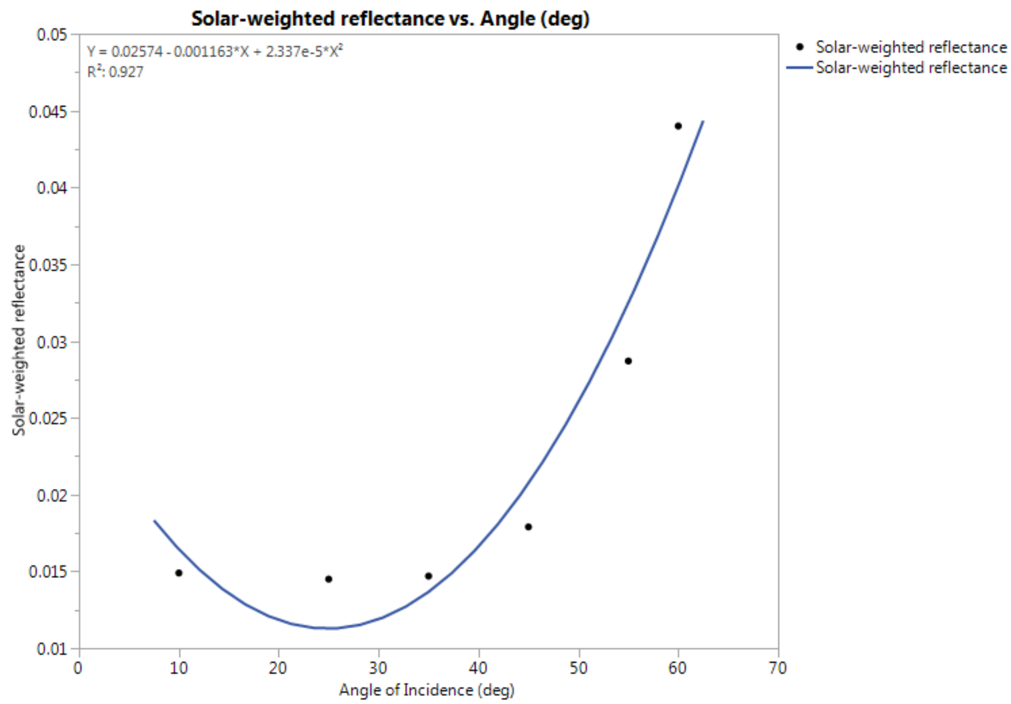

Figure 2.7: SunPower Commercial Glass Reflectance Data

1.4 “Stippled glass” and “light trapping”

In addition to the superior refractive/reflective properties of solar glass versus standard glass, many PV suppliers uses **stippled** solar glass for their panels. Stippled glass is also used with high powered telescopes and with powerful beacons and flashlights. The basic concept behind stippling is for the surfaces of the glass to be “textured” with small types of indentations. As a result, stippling allows more light energy to be channeled/transmitted through the glass while diffusing (weakening) the reflected light energy. “**Light trapping**” is also used by more high-quality PV suppliers. “Light trapping” is the practice of using additional techniques like mirrors and natural surface textures to “trap” light within the layers of the solar cell, allowing even less light to escape by reflection. These concepts are why a reflection of off a SunPower solar panel will look hazy and less-defined than the same reflection from standard glass. This occurs because the stippled and light trapping

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SunPower glass and cell are transmitting a larger percentage of light to the solar cell while breaking-up the intensity of the reflected energy.

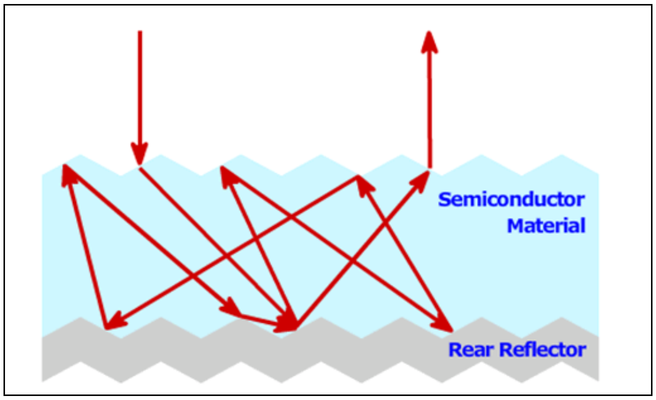

Figure: 3.1: Light Trapping: More light energy is absorbed by the cell with each ensuing reflection of the initial light beam.

Try this basic optical experiment where ever a reflection comparison can be safely made between a high-efficiency/high-quality PV panel and a large window or plate of glass.

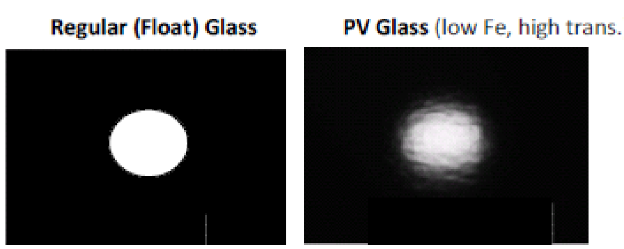

Figure 3.2: Reflection Characteristic example

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2. "No Hazard to Air Navigation"

SunPower has received FAA No Hazard status due to the low levels of glare and reflectance exhibited by its panels. See Appendix A for the list of projects installed in the US Air Force Bases and Appendix B for the reference FAA approval letters. The statement "No Hazard to Air Navigation" is the FAA status consistently applied to the large system arrays and power-plants which are continuously being erected on and around airports and Air Force bases.

3. Conclusion:

In support of the executive summary, the studies, data and physics behind the charts and graphs demonstrate that **solar glass has significantly less glare and reflectance than standard glass**. In addition, SunPower's solar glass is **stippled** and has a **light-trapping,** photon-absorbent solar cell attached to its back side, contributing additional factors which result in even less light energy being reflected.

4. References;

4.1 Center for Sustainable Building Research. College of Design · University of Minnesota. All rights reserved. JDP activity by the University of Minnesota and Lawrence Berkeley National Laboratory.
4.2 H. K. Pulker, Coatings on glass, (1999), 2ed, Elsevier, Amsterdam.
4.3 C. G. Granqvist, Materials Science for Solar Energy Conversion Systems, (1991), Pergamon, G B.
4.4 D. Chen, Anti-reflection (AR) coatings made by sol-gel processes: A review, Solar Energy Materials and Solar Cells, 68, (2000), 313-336.
4.5 P. Nostell, A. Roos, B. Karlsson, Antireflection of glazings for solar energy applications, Solar Energy Materials and Solar Cells, 54, (1998), 23-233.
4.6 M. Fukawa, T. Ikeda, T. Yonedaans K. Sato, Antireflective coatings y single layer with refractive index of 1.3, Proceedings of the 3rd International Conference on Coatings on Glass (ICCG), (2000), 257-264.
4.7 J. Karlsson and A. Roos, Modelling the angular behavior of the total solar energy transmittance of windows, Solar Energy, 69, 4, (2000).
4.8 J. Karlsson, B. Karlsson and A. Roos, A simple model for assessing the energy efficiency of windows, In Press, Energy and Buildings
4.9 Saint Gobain; SG Solar Eclipse for Airport Zones

APPENDIX A

US Air Force bases with PV systems, links;

- **Nellis Air Force base http://www.nellis.af.mil/news/story.asp?id=123079933**
- **Luke Air Force base http://www.bloomberg.com/news/2010-08-10/sunpower-gets-order-to-install-solar-panels-at-air-force-base-in-arizona.html**

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APPENDIX B

COPY of FAA letter for Fed-Ex Oakland, CA project:

Federal Aviation Administration
Bringing Safety to America's Skies

Federal Aviation Administration **Aeronautical Study**

Western Pacific Regional Office **No. 2005-AWP-363-OE**

PO Box 92007-AWP-520

Los Angeles, CA 90009-2007

Issued Date: 1/30/2005

BEN COLCOL - PROJECT MANAGER

FEDERAL EXPRESS CORPORATION

2601 MAIN STREET

IRVINE, CA 92614

**** DETERMINATION OF NO HAZARD TO AIR NAVIGATION ****

The Federal Aviation Administration has completed an aeronautical study under the provisions of 49 U.S.C., Section 44718 and, if applicable, Title 14 of the Code of Federal Regulations, part 77, concerning:

Structure Type: ROOF-MOUNTED SOLAR PANEL ENERGY SYSTEM

Location: OAKLAND, CA

Latitude: 37-43-13.3 NAD 83

Longitude: 122-13-0.4

Heights: 54 feet above ground level (AGL)

44 feet above mean sea level (AMSL)

This aeronautical study revealed that the structure does not exceed obstruction standards and would not be a hazard to air navigation provided the following condition(s), if any, is(are) met:

Based on this evaluation, marking and lighting are not necessary for aviation safety. However, if marking and/or lighting are accomplished on a voluntary basis, we recommend it be installed and maintained in accordance with FAA Advisory Circular 70/7460-1 70/7460-1K.

This determination expires on 7/30/2006 unless:

(a) extended, revised or terminated by the issuing office.

(b) the construction is subject to the licensing authority of

the Federal Communications Commission (FCC) and an application for a construction permit has been filed , as required by the FCC, within 6 months of the date of this determination. In such case, the determination expires on the date prescribed by the FCC for completion of construction, or the date the FCC denies the application.

NOTE: REQUEST FOR EXTENSION OF THE EFFECTIVE PERIOD OF THIS DETERMINATION MUST BE POSTMARKED OR DELIVERED TO THIS OFFICE AT LEAST 15 DAYS PRIOR TO THE EXPIRATION DATE.

This determination is based, in part, on the foregoing description which includes specific coordinates, heights, frequency(ies) and power. Any changes in coordinates, heights, and frequencies or use of greater power will void this determination. Any future construction or alteration, including increase to heights, power, or the addition of other transmitters, requires separate notice to the FAA.

This determination does include temporary construction equipment such as cranes, derricks, etc., which may be used during actual construction of the structure. However, this equipment shall not exceed the overall heights as indicated above. Equipment which has a height greater than the studied structure requires separate notice to the FAA.

This determination concerns the effect of this structure on the safe and efficient use of navigable airspace by aircraft and does not relieve the sponsor of compliance responsibilities relating to any law, ordinance, or regulation of any Federal, State, or local government body.

A copy of this determination will be forwarded to the Federal Communications Commission if the structure is subject to their licensing authority.

If we can be of further assistance, please contact our office at (310)725-6557. On any future correspondence concerning this matter, please refer to Aeronautical Study Number 2005-AWP-363-OE.

Signature Control No: 408559-342482 (DNE)

Karen L Mcdonald

Specialist

Attachment(s)

Case Description Map

ROOF-MOUNTED SOLAR MODULES

Case Description for ASN 2005-AWP-363-OE

Map for ASN 2005-AWP-363-OE

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Federal Aviation Administration
Air Traffic Airspace Branch, ASW-520
2601 Meacham Blvd.
Fort Worth, TX 76137-0520

Aeronautical Study No.
2008-AWP-6779-OE

Issued Date: 12/01/2008

Yasu Hirayama
Koyo USA DeepSeawater
73-4460 Queen Kaahumanu Hwy
Suite 124
Kailua-Kona, HI 96740

**** DETERMINATION OF NO HAZARD TO AIR NAVIGATION ****

The Federal Aviation Administration has conducted an aeronautical study under the provisions of 49 U.S.C., Section 44718 and if applicable Title 14 of the Code of Federal Regulations, part 77, concerning:

Structure:	Building / Koyo USA DeepSeawater
Location:	Kailua-Kona, HI
Latitude:	19-43-03.00N NAD 83
Longitude:	156-02-15.00W
Heights:	33 feet above ground level (AGL)
	110 feet above mean sea level (AMSL)

This aeronautical study revealed that the structure does not exceed obstruction standards and would not be a hazard to air navigation provided the following condition(s), if any, is(are) met:

Based on this evaluation, marking and lighting are not necessary for aviation safety. However, if marking and/or lighting are accomplished on a voluntary basis, we recommend it be installed and maintained in accordance with FAA Advisory circular 70/7460-1 K Change 2.

This determination is based, in part, on the foregoing description which includes specific coordinates, heights, frequency(ies) and power. Any changes in coordinates, heights, and frequencies or use of greater power will void this determination. Any future construction or alteration, including increase to heights, power, or the addition of other transmitters, requires separate notice to the FAA.

This determination does include temporary construction equipment such as cranes, derricks, etc., which may be used during actual construction of the structure. However, this equipment shall not exceed the overall heights as indicated above. Equipment which has a height greater than the studied structure requires separate notice to the FAA.

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A copy of this determination will be forwarded to the Federal Communications Commission if the structure is subject to their licensing authority.

If we can be of further assistance, please contact our office at (310) 725-6557. On any future correspondence concerning this matter, please refer to Aeronautical Study Number 2008-AWP-6779-OE.

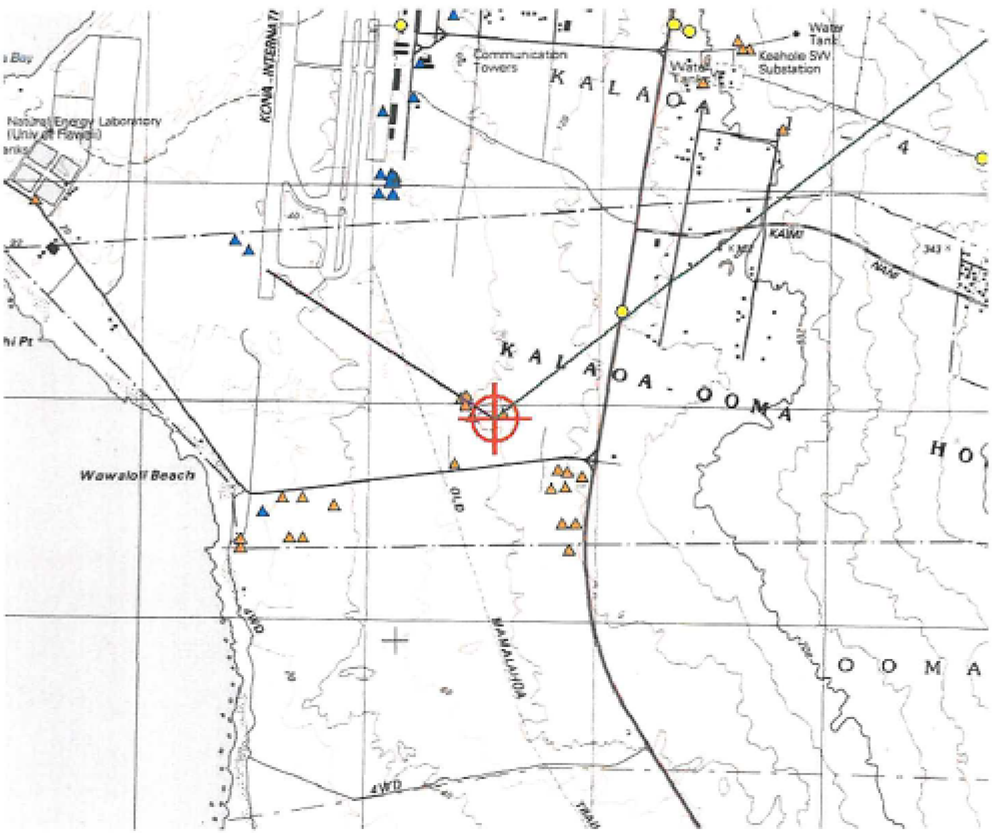
Signature Control No: 606276-103732980 (DNE)
Karen McDonald
Specialist

Attachment(s)
Case Description
Map(s)

Case Description for ASN 2008-AWP-6779-OE

Installation of photovoltaic solar panels on two roof structures totaling 690kw. Attached flat to surface.

Verified Map for ASN 2008-AWP-6779-OE



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