# Historic Preservation Commission Report

Meeting Date: December 4, 2025
General Plan Element: *Arts, Culture & Creative Community*
General Plan Goal: *Identify and protect historic and cultural resources.*

## ACTION

**Case Name:** **Saltzman Solar**
**Case Number:** **57-HP-2025**
**Location:** 6637 E Coronado Rd
**Request:** Certificate of Appropriateness to install Tesla solar tiles along with black metal roof tiles on the roof of an existing home located within the Village Grove 1-6 Historic District with Single Family Historic Property (R1-7 HP) zoning.

## OWNER

Les Saltzman
(480) 231-1855

## APPLICANT CONTACT

Jose Rodriguez
Verde Solaris
(480) 702-3086

## BACKGROUND

### Zoning

The site is zoned Single-family Residential district with Historic Property Overlay (R1-7 HP). The Historic Property designation was approved for Village Grove 1-6 by City Council on June 7, 2005.

### Historic Preservation Plan

Historic Preservation Guidelines for Village Grove 1-6 Historic District were approved by the Historic Preservation Commission on February 8, 2006, as Case #10-HP-2004.

### Context

Village Grove 1-6 is located north of McDowell Road and comprised of a single-family residential development located on approximately 72-acres. The development is bounded by the Arizona Crosscut Canal at N. 66th Place to the west, N. 69th Street to the east, E. Oak Street to the north and E. Almeria Road to the south. Within the Village Grove 1-6 Historic District, there are six (6) subdivision plats and 255 detached single-family homes with an average lots size of 8,500 square feet. The subject site is located east of the North 66th Place and East Coronado Road intersection within Village Grove Two.

Action Taken ______________________________

### Adjacent Uses and Zoning

- North East Coronado roadway with Single-family residences (Village Grove Unit 6), zoned Single-family Residential, Historic Property (R1-7 HP) beyond.
- South Alleyway with single-family residences (Village Grove Unit 6), zoned Single-family Residential, Historic Property (R1-7 HP) beyond.
- East Single-family residences (Village Grove Unit 6), zoned Single-family Residential, Historic Property (R1-7 HP).
- West Single-family residences (Village Grove Unit 6), zoned Single-family Residential, Historic Property (R1-7 HP).

### Key Items for Consideration

- Historic Preservation Guidelines for Village Grove 1-6 Historic District
- Green Building Home Remodeling Guidelines

## DEVELOPMENT PROPOSAL

Village Grove 1-6 is historically significant for being an excellent example of typical post World War II single-family subdivision practices in Scottsdale, Arizona. The neighborhood is one of the best expressions of the planning and marketing philosophies guiding successful, typical tract development in the late 1950s. It is also significant for its design characteristics, including its mass-produced materials and its Simple and California Ranch architectural styles that were the two most common styles in Scottsdale during the postwar era.

The physical characteristic of the subdivision design, including the grid and curvilinear street patterns, alleys, uniformly sized rectilinear lots, paved streets and cement curbs, gutters, sidewalks, and driveways are also representative of common postwar building practices in the late 1950s. In addition, the use of manufactures ‘Superlite’ blocks, brick, precut board and batten wood siding, steel casement windows, pre-hung door units, and pre-constructed roof trusses illustrates the impact of mass production techniques on the housing designs in the development.

The existing home at 6637 East Coronado Road is a Simple Ranch style home that displays block with weeping mortar on the bottom portion and board and baton on the upper portion of the front facade. There is a hip roof with white asphalt shingle roof tiles, windows with grid pattern muntin’s along with a single car carport.

### Goal/Purpose of Request

The applicant is proposing to install solar roof tiles on all sides of the existing pitch roof to achieve energy efficiency from solar power.

### Neighborhood Communication

A sign identifying the project name, number, request and HPC hearing date has been posted on the site along with a hearing postcard sent to all property owners within 750 feet of the property. Staff has not received any public comments on this case.

## HISTORIC PRESERVATION PLAN CRITERIA ANALYSIS

The Historic Preservation Guidelines for the Village Grove 1-6 Historic District includes a set of guidelines that are intended to maintain the established character of the community. Any request to modify the exterior of a residence should implement these guidelines. Specific to this request, the applicable guidelines are identified below and include staff analysis.

**Policy Basis for Preservation Guidelines (page 2):**
The City of Scottsdale has also developed a Green Building Program that is a model for many cities around the country. The goal of the program is to “encourage” energy efficient, healthy and environmentally responsible building in the Sonoran desert region.” These guidelines encourage the revitalization of neighborhoods through remodeling existing homes using Green Building materials and practices. The Green Building guidelines cover a variety of issues from Site Use and Landscaping, Energy Conservation, Kitchen Remodels, Additions and Enclosures – objectives that mesh comfortably with preservation goals. This set of Design Guidelines is meant to supplement the City of Scottsdale, Department of Planning and Development Services, Green Building: Home Remodel Guidelines for Sustainable Building in the Sonoran Desert.

It is important to place these guidelines for 1950’s homes in the context of the 21st Century with different demographics, lifestyles, technology needs, the need for energy conservation and sustainability.

**Chapter 4 Policy 6: Original building materials that have deteriorated beyond repair should be replaced with a similar building material.**

**Applicable Guidelines:**

6.1 Replacement of roof materials should use shingles that are similar in size and texture to those traditionally used in the subdivision.

6.2 Metal, built up or foam roofing and clay or concrete tiles are not appropriate replacements as these materials were not used historically in the subdivision.

**Staff Analysis**
The proposal for solar tiles and metal tiles are a deviation from the Village Grove 1-6 Historic Preservation Guidelines that clearly state that metal roofs are not appropriate. These materials were not used historically in the subdivision.

**Chapter 8 Policy 19: Minimize the visual impact of utilities, accessory structures and equipment and other such fixtures on the streetscape.**

**Applicable Guidelines:**

19.2 When roof-mounting is unavoidable, place items such as solar panels, satellite dishes, antennae or HVAC units, on the rear plane of the roof or in such a fashion to minimize their visibility from the street.

**Staff Analysis**
The Green Building Remodeling Workbook that the Village Grove 1-6 Historic Guidelines refer to, state that a pre-planned south roof area provides for easy installation of future solar panels. The most efficient location for solar is on the southern exposed elevation when the Arizona sun sweeps south during the winter months. The subject site has southern frontage, where the

south side of the roof faces the rear yard, making the proposed solar installation on the south facing side of the hip roof optimal to meet guideline 19.2 which encourages solar to be installed on the rear plane of the roof, in such a way to minimize their visibility from the street. Solar installed on the east and west sides of the roof may be a possible, but may not be as efficient. Removing the proposed location of the solar tiles and metal roofing from the front, north, side of the home and maintaining asphalt shingles is recommended in order to minimize the visual impact form East Coronado Road, see attachment 'A' Stipulations.

Within Village Grove 1-6 there have been ten (10) approved solar installations within the district, seven (7) of which were on the south facing rear of the homes and three (3) of the homes faced south, but had panels installed on the east and west sides of the hip roofs. In addition, there are two (2) homes that received a permit for solar on their street facing south slopes of their roofs without the Historic Preservation review and subsequent Certificate of No Effect nor Certificate of Appropriateness.

## STAFF RECOMMENDATION

**Recommended Approach:**
Staff recommends that the Historic Preservation Commission approve Saltzman Solar, 57-HP-2025 per the attached stipulations, finding that the provisions of the Historic Preservation Plan for Village Grove 1-6 have been met.

## OPTIONS FOR CERTIFICATE OF APPROPRIATENESS

- Approve as submitted with reference to how the project meets the guidelines
- Approve selected elements, deny others, referencing relevant design guidelines for decision
- Approve with stipulations
- Continue case to allow time for additional work or information to be provided
- Deny as submitted with reference to how the project does NOT meet the guidelines

## RESPONSIBLE DEPARTMENT

Planning and Development Services
Historic Preservation Office

## STAFF CONTACT

Ben Moriarity Senior Planner 480-312-2836 E-mail: bmoriarity@ScottsdaleAZ.gov

## APPROVED BY

| | |
|---|---|
| Ben Moriarity, Report Author | 11/14/2025<br>Date |
| Jesús Murillo, Historic Preservation Officer<br>480-312-7849, JMurillo@ScottsdaleAZ.gov | 11/21/2025<br>Date |
| Adam Yaron, Historic Preservation Commission Liaison<br>480-312-2761, AYaron@ScottsdaleAZ.gov | 11/17/2025<br>Date |

## ATTACHMENTS

*A. Stipulations/Zoning Ordinance Requirements*
*1. Applicant's Narrative*
*2. Context Aerial*
*2A. Close-Up Aerial*
*3. Zoning Map*
*4. Site Plan*
*5. Existing Conditions Photo*
*6. Proposed Rendering*
*7. Solar Specifications*

# Stipulations for the
# Historic Preservation Commission Application:
# Saltzman Solar
# Case Number: 57-HP-2025

These stipulations are intended to protect the public health, safety, welfare, and the City of Scottsdale.

## RELEVANT CASES:

### Ordinance

A. At the time of review, the applicable Zoning and Historic Preservation cases for the subject site were: 25-ZN-2004 and 10-HP-2004

## APPLICABLE DOCUMENTS AND PLANS:

### HPC Stipulations

1. In conformance with Village Grove 1-6 Historic Guideline 19.2, the solar and metal roof tiles shall not be located on the front, north, slope of the roof, nor on the front gable dormer above the front door.
2. Asphalt shingles shall be replaced on the front, north, slope of the roof and on the front gable dormer above the front door with an asphalt shingle color to match the new solar tiles and metal tiles on the other sides of the roof.
3. Solar panels may be located on the south, west and east slopes of the roof or an acceptable alternative agreed upon by Historic Preservation staff.
4. Solar tiles shall be low profile and parallel with the plane of the pitched roof.
5. Solar tiles should not be built up above the existing roofing surface. Solar tiles shall be 3 feet below the ridge line.
6. Placement of new solar tiles and metal tiles should be uniform. Match the shape and proportions of the array with the shape and proportions of the roof.
7. No new sub-panel, batteries or electrical conduit shall be installed on the front façade of the historic property.
8. The Shed within the required side yard, not conforming to the Zoning Ordinance standards, shall be removed or moved to an appropriate location to comply to the required district setbacks.

Verde Solaris LLC (Jose Rodriguez)
180 W. Magee RD Suite #116 Oro Valley, AZ 85704
permit@verdesolaris.com
480-702-3086
10/31/2025

To Whom It May Concern,

I am writing to respectfully request consideration for the installation of a Tesla Solar Roof on the property located at 6637 E Coronado Rd Scottsdale, AZ 85257. I fully recognize and appreciate the importance of preserving the architectural integrity and historic character of our community. With this in mind, we have carefully selected a roofing solution that not only honors the aesthetic traditions of our neighborhood but also enhances the durability and sustainability of the home.

The Tesla Solar Roof is designed to resemble traditional shingle-style roofing, with tiles that closely match the size, texture, and appearance of conventional asphalt or architectural shingles. This allows the home to maintain its historic visual appeal while integrating modern technology discreetly and respectfully.

Beyond aesthetics, the Tesla Solar Roof offers unmatched performance benefits that contribute to the long-term preservation of the home. The tiles have received the highest ratings for fire resistance (Class A), wind resistance (up to 166 mph), and hail impact (Class 3), making them one of the most resilient roofing options available today. These features are especially valuable in protecting historic structures from environmental damage and reducing the need for frequent repairs or replacements.

Additionally, the solar functionality of the roof supports environmental sustainability by generating clean energy, reducing reliance on fossil fuels, and lowering utility costs, and providing a truly invisible solar system—all without compromising the historic character of the property.

I believe this solution strikes a thoughtful balance between preservation and progress, and I am committed to ensuring that the installation adheres to all guidelines set forth by the preservation plan. I welcome the opportunity to provide samples, visual renderings, or further documentation to support this proposal.

Thank you for your time and consideration.

Sincerely,

Jose Rodriguez


Context Aerial

57-HP-2025

ATTACHMENT 2


**Close-up Aerial**

**57-HP-2025**

ATTACHMENT 2A

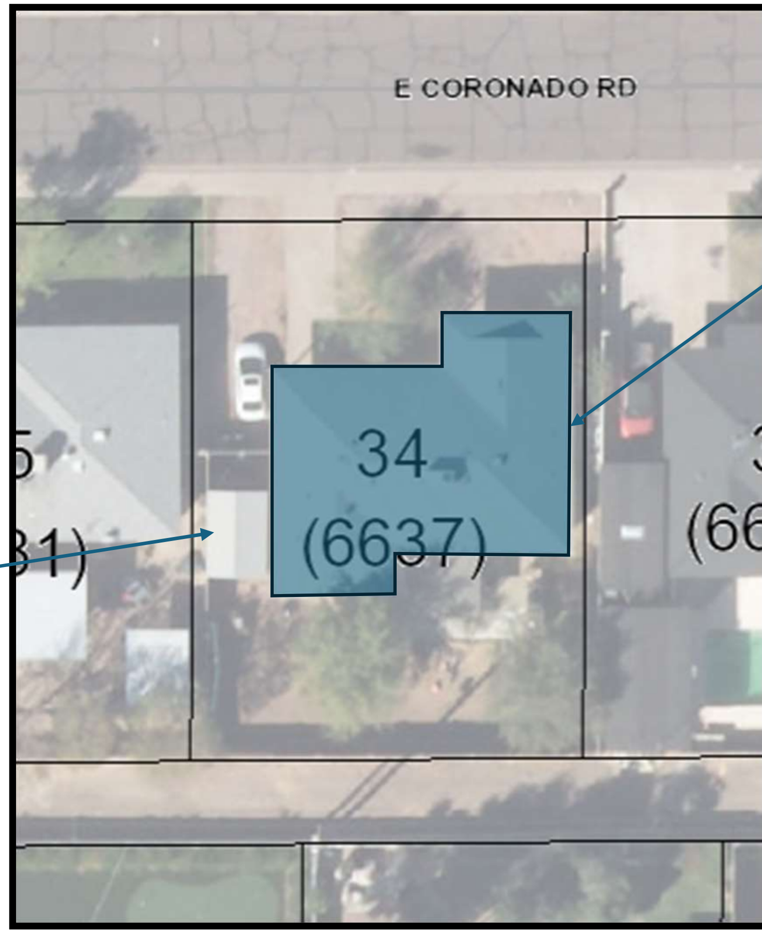

Zoning Aerial

57-HP-2025

ATTACHMENT 3

# Saltzman Solar Site Plan

| Description | Data |
|---|---|
| APN | 129-29-034 |
| Insert Date | 3/5/1994 12:01:35 PM |
| Owners Name | SALTZMAN TRUST |
| Site Address | 6637 E CORONADO RD |
| Zip Code | 85257 |
| QS Num | 13-43 |
| MCR Num | 072-31 |
| Subdivision | VILLAGE GROVE TWO |
| Lot Num | 34 |
| Tract Name | |
| Zoning | R1-7 HP |
| FEMA Flood Zone | X |
| Character Area | SOUTHERN SCOTTSDALE |




Area of proposed solar shingles and metal roof tiles

Electrical panel location in the rear of the home and Tesla batteries to be concealed and not located on the front façade

Non-conforming shed to be moved/removed

ATTACHMENT 4

*Site Graphic Drafted by Historic Preservation Staff*


ATTACHMENT 5


ATTACHMENT 6

## Tesla Solar Roof

The world's leader in electric vehicle and battery technology, Tesla, has introduced a new category to the luxury roofing market with Solar Roof. Bringing together form and function like nothing else, Solar Roof seamlessly combines premium metal and glass tiles that offer exceptional aesthetics, industry leading power generation density and extreme durability with best available system certifications. Available now at participating SRS Distribution locations.

### Primary Components

| | | | |
|---|---|---|---|
| **Underlayment** | Water, Fire and Ice Dam Protection | **Solar Glass Tile** | 72W Output / Made in USA (NY) |
| **Wiring** | Module Interconnection | **Inverter** | Maximum Solar Production |
| **Flashing** | Protection From Water Intrusion | **Tesla App** | Monitor & Control Your System Anywhere |
| **Steel Tile** | 24 Gauge Galvalume, PVDF coated | **Powerwall** | Outage Protection / Energy Independence |

### System Certifications

| | |
|---|---|
| **Hailstone Rating** | Class 4 (Best Rating) |
| **Wind Rating** | Class F (Highest Rating) |
| **Fire Rating** | Class A (Best Rating) |

### Warranty

| | |
|---|---|
| **Tile/Power/Weather** | 25 Years |
| **Inverter** | 12.5 Years |
| **Powerwall** | 10 Years |

### Customer Benefits

| | |
|---|---|
| **Design** | • Beautiful Aesthetics / Extreme Durability / Designed, Engineered and Manufactured by Tesla |
| **Savings** | • Protection Against Rising Utility Costs / Increased Home Value / 30% Federal, State and Local Incentive |
| **Grid** | • Eligible Outage Protection / Energy Independence / Distributed Energy Services |
| **Integration** | • Tesla App Monitoring / Pairs With Powerwall, Tesla Inverter, Wall Connector and Tesla Vehicles |
| **Compliance** | • California Cool Roof / IBHS Fortified Roof / WUI Compliant |
| **Sustainability** | • Reliable and Renewable Energy Source / Reduced Carbon Impact |

T | ENERGY

ATTACHMENT 7

## Talking Points

**Why Invest in Solar Roof**

- The only roof that pays for itself over time.
- Fully eligible for solar tax credits and other local and state incentives that other premium roofs can't offer.
- Protect yourself from rapidly increasing utility rates.
- Make a statement in your neighborhood; if you want the best, buy the best and have the best... Solar Roof is for you.
- Peace of Mind - Combined with Powerwall, Solar Roof offers outage protection for your home and family.

**Installation**

- Solar Roof is a full roof installation (new construction or addition) or roof replacement (retrofit) solution.
- The Solar Roof Certified Installer will start at the decking and install Tesla premium underlayment followed by a combination of metal and solar glass tiles, flashing and electrical components.
- Solar Roof and Powerwall were designed to be the ultimate solution in premium aesthetics, durability and energy security, and the latest Solar Roof was designed for ease of installation for roofing contractors.

**Technology**

- Compact Solar Glass Tiles enable highest power density solution.
- 24-Gauge Galvalume Metal tiles offer elite durability.
- Over the Air Updates add new features and enhance existing ones.

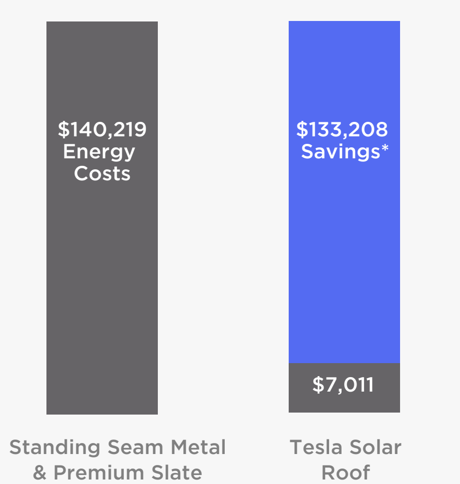
**Maintenance**

- Worry free; Solar roof was designed with ease of maintenance top of mind.
- Glass Tiles can be replaced without removal of neighboring tiles.
- Metal tiles can be easily serviced using "tile skins".

## Customers Save The Most with a Tesla Solar Roof

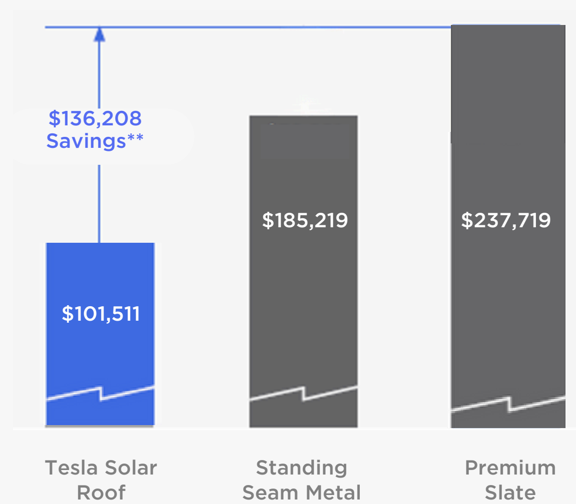
**Compared to leading competitors, Solar Roof results in increased savings and better overall value.**

### 25-Year Energy Bill Savings*




*Based off a $300/mo. electricity bill and annual utility cost increase of 3.5%

### Total Costs, 25 Years**




**Install + energy costs for a 30 square, low complexity roof. Based on $300/mo electricity bill, 3.5% annual utility increase, and 30% IRA tax credit.

TESLA

**Glare and Glint requirements for Flat Plate Photovoltaic Systems & Tesla Solar Roof**

To Whom it May Concern:

The purpose of this letter is to clarify why a glare and glint study is not necessary for the installation of a Tesla Solar System.

Modern solar panels are designed to minimize reflecting light, as any reflected light represents a lost energy. Typical smooth glass photovoltaic panels reflect only around 2% of incoming sunlight, which is less of a glare and glint hazard than glass windows.

Tesla Solar Roof tiles are comprised of texture glass to create a slate like appearance. This textured surface reflects light in a diffused or scattered manner, which will not be received as brightly as a smooth surface reflecting in a direct or specular manner.

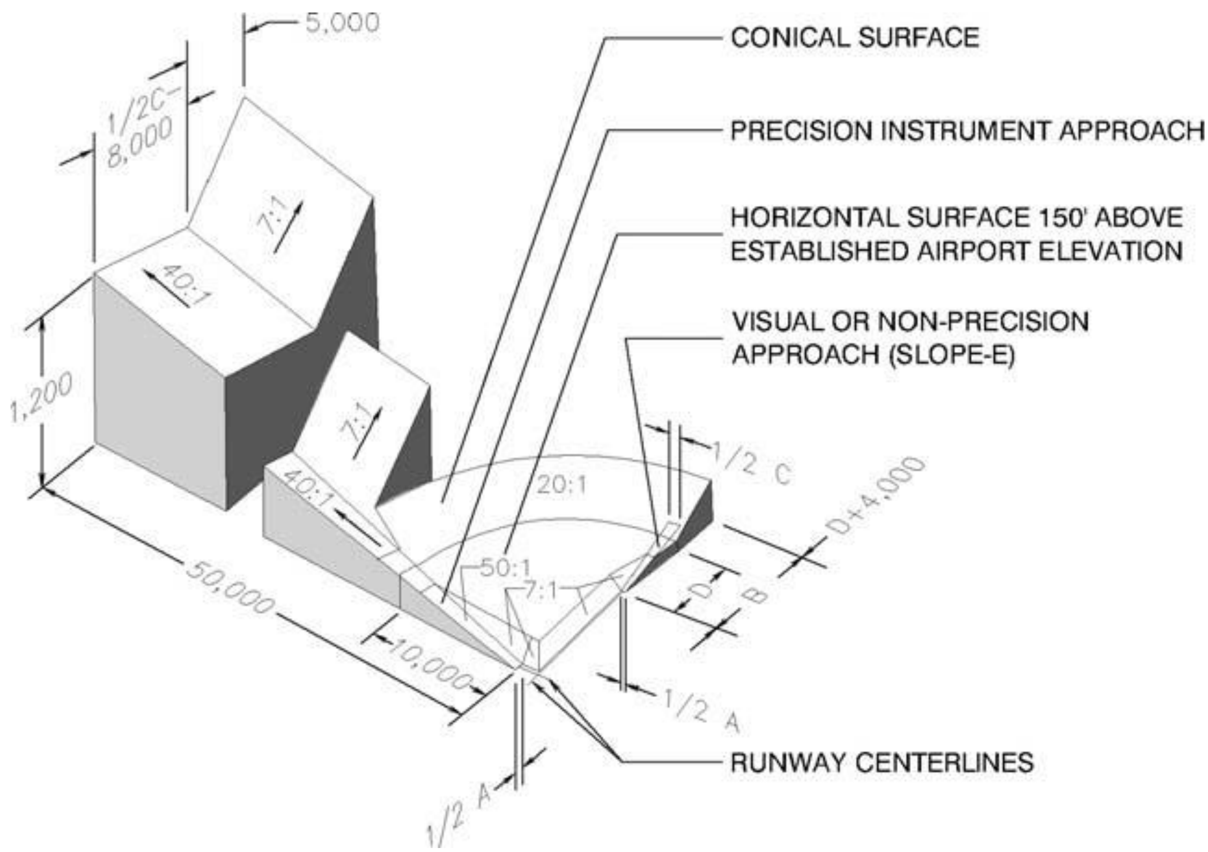
Attached to this letter are independent studies on the subject matter indicating the low glare and glint risk of photovoltaic panels in general and descriptions of the smooth vs. textured reflectivity outlined above.

Please reach out to our permitting and inspections team if you have any further questions.

Sincerely,

Product Approval & AHJ Communication Team
PAACT@tesla.com

**Figure 15: Imaginary Surfaces that Define Navigable Airspace**




Large structures, like communication towers and wind turbines, often exceed 200 feet in height and therefore are required to submit a Form 7460, Notice of Proposed Construction or Alteration. Structures shorter than 200 feet but located within 20,000 feet of a runway may also penetrate navigable airspace. Solar panels, when tilted properly to the south-facing sun, extend to a height of as little as three feet above the ground making it possible for siting close to runways without penetrating an imaginary surface. The low profile of solar panels allows for greater flexibility in finding the most appropriate location on the airport for electricity generation. Projects that have located solar panels in close proximity to runways and taxiways have conducted analyses to ensure that the solar panels do not penetrate the imaginary surface.

### 3.1.2 Reflectivity

Reflectivity refers to light that is reflected off surfaces. The potential effects of reflectivity are glint (a momentary flash of bright light) and glare (a continuous source of bright light). These two effects are referred to hereinafter as "glare," which can cause a brief loss of vision, also known as flash blindness. FAA Order 7400.2, *Procedures for Handling Airspace Matters,* defines flash blindness as "generally, a temporary visual interference effect that persists after the source of illumination has ceased."

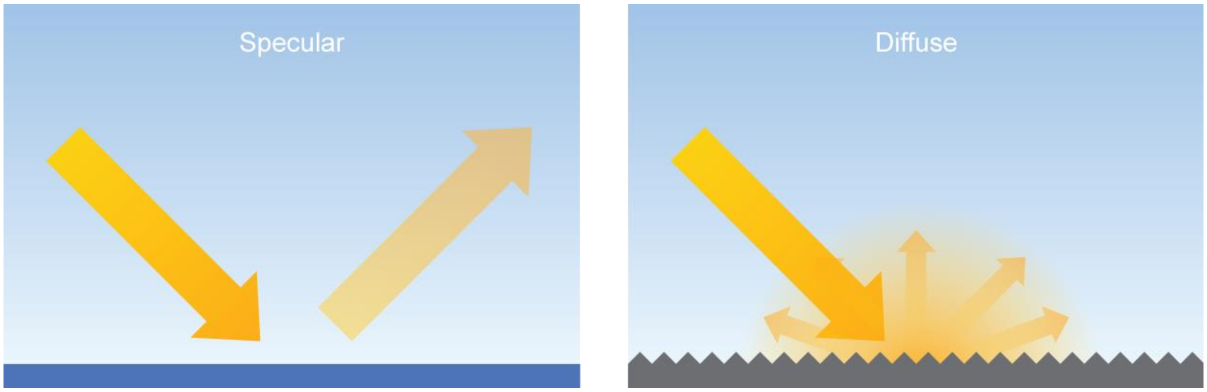
The amount of light reflected off a solar panel surface depends on the amount of sunlight hitting the surface, its surface reflectivity, geographic location, time of year, cloud cover, and solar panel orientation. As illustrated on *Figure 16*, flat, smooth surfaces reflect a more concentrated amount of sunlight back to the receiver, which is referred to as specular reflection. The more a surface is polished, the more it shines. Rough or uneven surfaces reflect light in a diffused or scattered manner and, therefore, the light will not be received as bright.

CSP systems use mirrors to maximize reflection and focus the reflected sunlight and associated heat on a design point to produce steam, which generates electricity. About 90 percent of sunlight is reflected. However, because the reflected sunlight is controlled and focused on the heat collecting element (HCE) of the system, it generally does not reflect back to other sensitive receptors. Another source of reflection in a CSP system is the light that contacts the back of the HCE and never reaches the mirror. Parts of the metal frame can also reflect sunlight. In central receiver (or power tower) applications, the receiver can receive concentrated sunlight that is up to a thousand times the sun's normal irradiance. Reflections from a central receiver, although approximately 90% absorptive, can still reflect a great deal of sunlight.

Solar PV and SHW panels are constructed of dark, light-absorbing materials and covered with an anti-reflective coating designed to maximize absorption and minimize reflection. However, the glass surfaces of solar PV and SHW systems also reflect sunlight to varying degrees throughout the day and year. The amount of reflected sunlight is based on the incidence angle of the sun relative to the light-sensitive receptor (e.g., a pilot or air traffic tower controller). The amount of reflection increases with lower incidence angles. In some situations, 100% of the sun's energy can be reflected from solar PV and SHW panels.

Because solar energy systems introduce new visual surfaces to an airport setting where reflectivity could result in glare that can cause flash blindness to those that require clear, unobstructed vision, project proponents should evaluate reflectivity during project siting and design.

**Figure 16: Different Types of Reflection**




**Completing an Individual Glare Analysis**

Evaluating glare for a specific project should be an iterative process that looks at one or more of the methodologies described below. Airport sponsors should coordinate closely with the FAA's Office of Airports to evaluate the potential for glint and glare for solar projects on airport property. These data should include a review of existing airport conditions and a comparison with existing sources of glare, as well as related information obtained from other airports with experience operating solar projects.

International Scholarly Research Network
ISRN Renewable Energy
Volume 2011, Article ID 651857, 6 pages
doi:10.5402/2011/651857

*Research Article*

# A Study of the Hazardous Glare Potential to Aviators from Utility-Scale Flat-Plate Photovoltaic Systems

**Evan Riley and Scott Olson**

*Black & Veatch Corporation, Energy Division, 650 California Street, Fifth Floor, San Francisco, CA 94108, USA*

Correspondence should be addressed to Evan Riley, rileye@bv.com

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Academic Editors: E. R. Bandala, S. Dai, S. S. Kalligeros, and A. Stoppato



The potential flash glare a pilot could experience from a proposed 25-degree fixed-tilt flat-plate polycrystalline PV system located outside of Las Vegas, Nevada, was modeled for the purpose of hazard quantification. Hourly insolation data measured via satellite for the years 1998 to 2004 was used to perform the modeling. The theoretical glare was estimated using published ocular safety metrics which quantify the potential for a postflash glare after-image. This was then compared to the postflash glare after-image potential caused by smooth water. The results show that the potential for hazardous glare from flat-plate PV systems is similar to that of smooth water and not expected to be a hazard to air navigation.

## 1. Introduction

Before construction of utility scale photovoltaic (PV) power plants near airports or within known flight corridors in the United States, the Federal Aviation Administration (FAA) requires that the glare from the proposed plant not be a hazard to navigable airspace [1]. The purpose of this paper is to demonstrate that glare from flat-plate PV power plants is similar to that of water and therefore does not pose a hazard to navigable airspace.

This was done by calculating the glare potential from a theoretical flat-plate PV power plant located near Las Vegas, Nevada, and comparing that glare to the glare potential of smooth water.

To estimate potential glare from flat surfaces, a model developed which used conservative assumptions. This model is a generalization of work done by Ho et al. [1]. The model calculated glare hourly from 1998 to 2004 to find the times when the possibility for glare would be the greatest. The potential for after-image (hazardous glare) was then compared to the potential for hazardous glare from smooth water which pilots often view while on approach to land.

## 2. Method

A review of published literature on modeling glare was conducted. The effects of glare on humans has been quantified by Metcalf and Horn [2], Saur and Dobrash [3], Severin et al. [4], and Sliney and Freasier [5]. In other studies Brumleve [6], Chiabrando et al. [7], and Ho et al. [1] developed mathematical methods to quantify the potential danger of glare causing flash blindness. Flash blindness is defined by Ho as a "temporary disability or distraction" that can cause an after-image and is understood to be comparable to what a human experiences when viewing the flash of a camera.

Ho explains in detail various methods for modeling glare from concentrating solar systems which use mirrors and lenses to concentrate light onto a central receiver. This technology is different than flat-plate PV modules which directly convert solar energy to electricity. However, the after-image estimation method Ho outlines for concentrating solar systems is easily generalized to flat-plate PV modules. The flow diagram in Figure 1 shows the general method implemented to translate solar radiation to the after-image potential caused by energy received on an observer's retina.

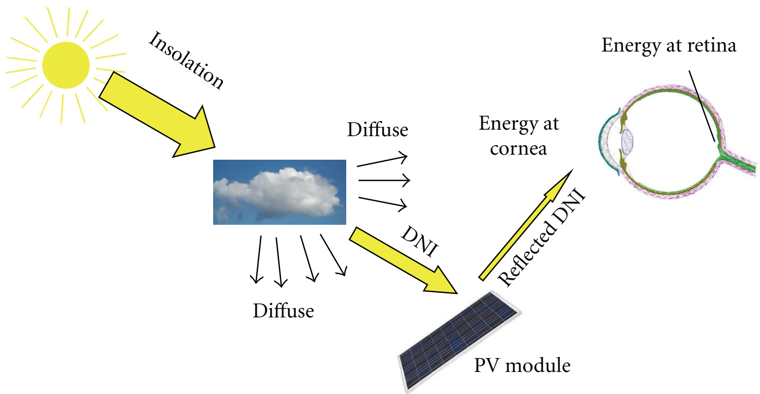


Figure 1: Energy flow diagram.

The subsections below provide more detail for each step of the process.

*2.1. Insolation.* The SUNY-Perez Satellite dataset was used for modeling glare. The National Renewable Energy Laboratory (NREL) compiled this dataset for the years 1998 to 2005 on an hourly basis for a 10 × 10 km nationwide grid.

Solar radiation in the visible spectrum can be broken up into two primary components, diffuse and direct. Diffuse radiation is defined as radiation that has been scattered by the atmosphere. Direct radiation, also commonly referred to as beam, is radiation which moves from the source to the observer via the shortest distance possible without scattering. For example, on a heavily overcast day when the sun is highest in the sky (solar noon), it is probable that all insolation is diffuse. On a clear day at solar noon, most of the insolation reaching earth's surface would be direct. Direct radiation is the component of solar radiation that causes visible glare from flat plate PV systems.

*2.2. PV Module.* The next step in the modeling process was to quantify the amount of visible radiation would be reflected off of a PV module for every hour from 1998 to 2004. The year 2005 was omitted for computational reasons. This was done by multiplying the power (Watts per square centimeter, or $W/cm^2$) of direct radiation with the reflectivity of the PV module at the average incidence angle for each hour evaluated.

Incidence angle is defined as the angle between the direct component of insolation and a ray perpendicular to the module. If the incidence angle is zero, the angle between the surface of the module and the direct component of radiation is 90°. The reflectance at 633 nm of a polycrystalline silicon (p-Si) PV module is a function of the incidence angle as seen below in Figure 2 developed by Parretta et al. [8]. This reflectance as a function of incidence angle was to determine how much of the direct insolation in the visible spectrum would be reflected off of the PV module and thus reach the observer.

The data shown above is for a glass encapsulated p-Si solar cell. The use of this data is a conservative assumption as the glass used to encapsulate the cell was not solar glass and no antireflective coating applied to the p-Si cell. Actual p-Si modules would likely have lower reflectance values as textured glass, and antireflective coatings are often used to reduce reflected irradiance and increase module efficiency.

The power of the reflected direct radiation was calculated hourly from 1998 to 2004 using the reflectivity in Figure 2, satellite data from NREL, and established sun position equations. The use of hourly data allows quantification of how the power of the reflected direct radiation will vary as the sun moves across the sky.

*2.3. Energy at the Cornea.* An assumption was made that the power of the direct radiation reflected off of the PV module was equal to the power incident on the cornea of the pilot. This is a conservative assumption as it ignores atmospheric attenuation, refraction, and further reflection. While it is likely that there will be energy diffusion or absorption due to the atmosphere, cockpit glass, or shielding, these effects were ignored during this initial estimation. Later calculations took these potential mitigation efforts into account, as can be seen in Figure 7.

*2.4. Retinal Irradiance.* The last step in the modeling process was to calculate retinal irradiance hourly from 1998 to 2004. Retinal irradiance can be calculated us a derivation provided by Sliney [9] from the energy incident on the cornea as

$$E_r = E_c \left( \frac{d_p}{f\omega} \right)^2 \tau, \qquad (1)$$

where $E_r$ is retinal irradiance [$W/cm^2$], $E_c$ is irradiance at a plane in front of the cornea [$W/cm^2$], $f$ is the focal length of the eye (∼0.17 cm), $d_p$ is the diameter of the human pupil adjusted to sunlight (∼0.2 cm), $\omega$ is the subtended angle of the image (or apparent size of the image which in the case of the sun is 0.0093 radians), and $\tau$ is the transmission coefficient of the eye (∼0.5). This equation assumes that the arc of a circle $f$ is equal to its chord, which is a good approximation for small angles such as these.

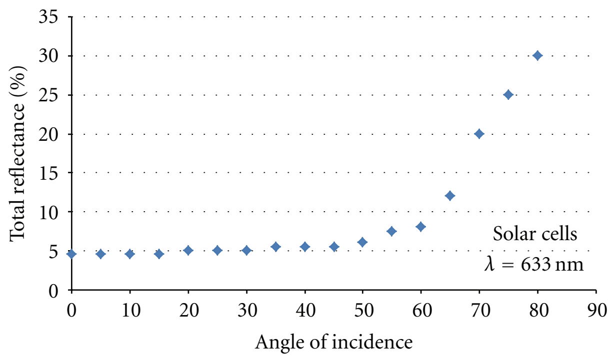


Figure 2: Reflectance as a Function of Incident Angle [8].

## 3. Ocular Safety Metrics

Next, the calculated values of retinal irradiances were compared to known ocular safety metrics. Extensive research has been done on ocular safety metrics and how to calculate the potential for after-image or retinal burns from radiation in the visible wavelengths. The threshold for retinal irradiance corresponding to the potential for retinal burns has been defined as

$$E_{r,\text{burn}} = \frac{0.118}{\omega} \quad \text{for } \omega < 0.118,$$
$$E_{r,\text{burn}} = 1 \quad \text{for } \omega \geq 0.118, \tag{2}$$

where $E_{r,\text{burn}}$ is the retinal burn threshold [W/m$^2$] and $\omega$ is the subtended angle of the sun or 0.0093 radians, Ho et al. [1], and Sliney and Freasier [5]. Ho also compiled data from Metcalf and Horn [2], Severin et al. [4], and Saur and Dobrash [3] to find a fit corresponding to the minimal retinal irradiances that caused after-image (glare). This is calculated by

$$E_{r,\text{flash}} = \frac{3.59 \times 10^{-5}}{\omega^{1.77}}, \tag{3}$$

where $E_{r,\text{flash}}$ is the threshold for potential after image [W/cm$^2$]. Ho then plotted both of these thresholds and the three regions these thresholds define (potential for retinal burn, potential for after-image, and low potential for after-image) which are illustrated in Figure 3.

The subtended source angle is a function of the size of the image viewed. For the purposes of this report, the image is a reflection of the sun which causes the subtended angle to be constant at 0.0093 radians or roughly 10 mrads.

## 4. Results

Retinal irradiance was calculated hourly from the years 1998 to 2004 for a fixed-tilt polycrystalline system under the assumptions illustrated in Table 1. These results were then compared to the same results from smooth water.

The assumption of a fixed-tilt system is conservative because, as seen in Figure 2, the reflected component of irradiances increases as incidence angle increases. Having the system held at a fixed tilt increases the average incident angle and therefore the average reflected irradiance.

Table 1: Retinal irradiance assumptions.

| | |
|---|---|
| Module type | Polycrystalline silicon (p-Si) |
| Module Tilt/Azimuth | 25°/0° |
| Atmospheric attenuation between the module and the pilot's eye? | No |
| Subtended angle of the sun | 0.00093 radians |
| Diameter of the pupil in sunlight | 0.2 cm |
| Focal length of the eye | 0.0017 cm |
| Transmission coefficient of the eye | 0.5 |

Table 2: Retinal irradiances.

| | Median* [W/cm$^2$] | Maximum [W/cm$^2$] |
|---|---|---|
| Fixed-tilt p-Si | 0.23 | 0.45 |
| Smooth water | 0.13 | 0.38 |
| Low potential for an after-image <0.10 W/cm$^2$ | | |
| Potential for after-image = 0.10 to 12.7 W/cm$^2$ | | |
| Potential for retinal burn ≥12.7 W/cm$^2$ | | |

*The median is calculated as the median of all hours with direct insolation greater than 0.

The results of the calculations are displayed in Figure 4 and Table 2. Figure 4 shows retinal irradiances for all hours in the six-year period when direct radiation was present. For example, the blue bar furthest to the left in Figure 4 represents the number of hours in the years 1998 to 2004 where retinal irradiance was between 0 and 0.02 W/cm$^2$ (approximately 2250 hours). The potential for an after-image corresponding to the different retinal irradiance powers are shown based on the zones defined in Figure 3. The ranges of these zones are quantified in Table 2, showing that a potential for an after-image for both PV panels and smooth water exists but is slight.

Table 2 shows that the median values of both distributions reside in the region "potential for an after-image." The histogram in Figure 4 shows that 79 to 88 percent of hourly retinal irradiances from smooth water and fixed PV modules fall in this region. However, all calculated retinal irradiances fall in the bottom 5% of the region, indicating that although

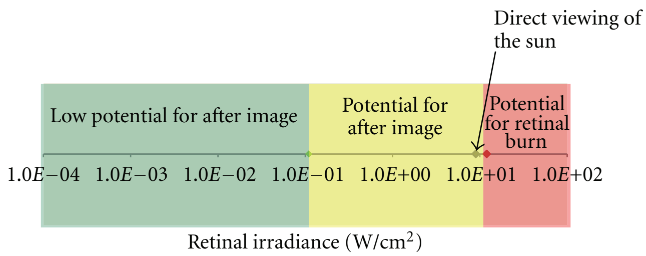


Figure 3: Potential impacts of retinal irradiance for a 0.15 s exposure from Ho et al. [1].

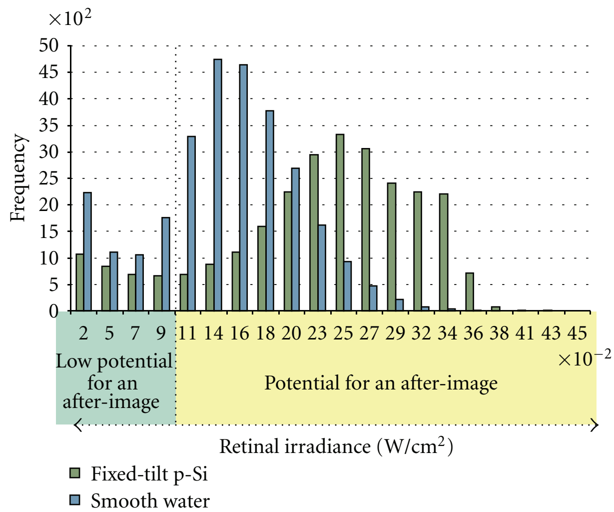


Figure 4: Frequency distribution of retinal irradiance 1998 to 2004.

the glare hazard exists, it is relatively low. Figure 5 illustrates this point by expanding the $x$-axis to the entire range of retinal irradiances that would be classified as "potential for an after-image." The major difference between this figure and the one developed by Ho in Figure 3 is the use of a linear, not logarithmic scale.

Figure 6 displays the *maximum* value of hourly glare (highest retinal irradiance) from smooth water and fixed tilt p-Si PV modules plotted onto Figure 3.

As can be seen from Figure 6, the maximum glare from a solar PV array using conservative assumptions is expected to be comparable to that of smooth water. This maximum value is in the region defined as "potential for after-image" where a potential exists, but the potential is on the low end of the range.

The nuisance of glare for pilots cannot be completely avoided. Therefore, it is typically mitigated using darkened visors, sunglasses, and glare shields. If these objects are manufactured to meet American National Standards Institute (ANSI) Standard Z80.3-2001 [10], they will reduce the intensity of retinal irradiance by roughly 70 percent. A 70 percent reduction of retinal irradiances from radiation reflected off of water and PV modules move all retinal irradiance values below 0.14 W/cm$^2$ as displayed below in Figure 7. Under these conditions, 92 percent of the hours over the six-year period investigated for solar PV would now be in the "low potential" zone in Las Vegas.

## 5. Conclusions

The potential flash glare a pilot could experience was modeled from a proposed 25-degree fixed-tilt flat-plate polycrystalline PV array installed outside of Las Vegas, Nevada. Hourly insolation data measured onsite via satellite from the years 1998 to 2004 was used to perform this modeling. These results were then compared to the potential glare from smooth water under the same assumptions. The comparison of the results showed that the potential for glare from flat plate PV systems is comparable to that of smooth water and not expected to be a hazard to air navigation.

Glare from ground-based objects can be a nuisance to pilots if proper mitigation procedures are not implemented. Portland white cement concrete (which is a common concrete for runways), snow, and structural glass all have reflectivities greater than water and flat plate PV modules as shown by Levinson and Akbari [11], Nakamura etal. [12] and Hutchins et al. [13]. Pilots viewing these objects under specific conditions may experience a distracting level of glare.

The nuisance of glare cannot be completely avoided. Therefore, it is typically mitigated using darkened visors, sunglasses, and glare shields. If these objects are manufactured to meet ANSI Standard Z80.3-2001 [10], they will reduce the intensity of retinal irradiance by roughly 70 percent. A 70-percent reduction of retinal irradiances from radiation reflected off of water and PV modules move all retinal

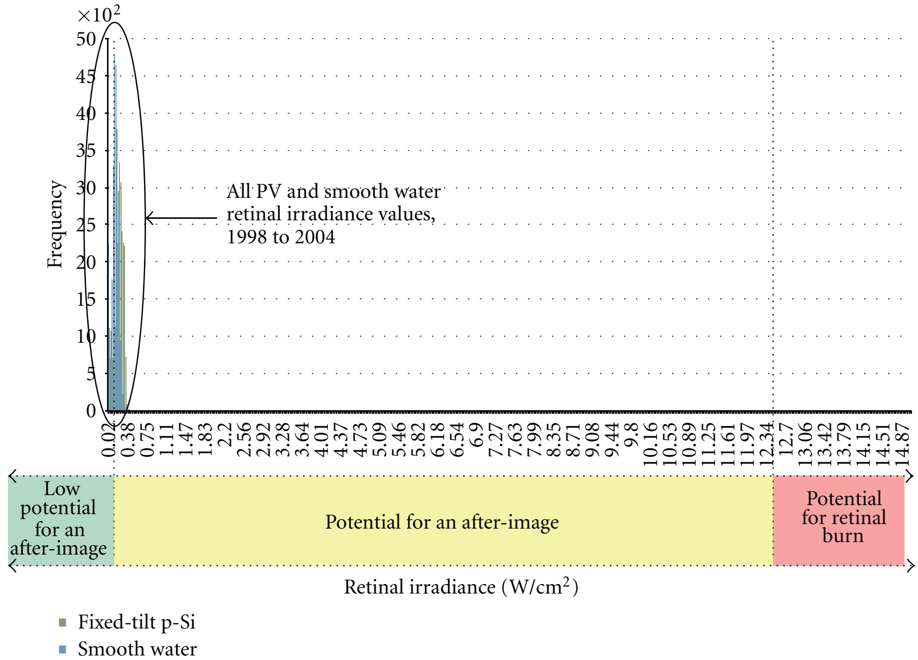


Figure 5: Linearly scaled frequency distribution of retinal irradiance.

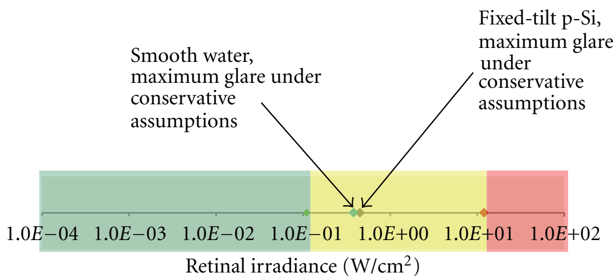


Figure 6: Calculated maximum glare at Nellis [1].

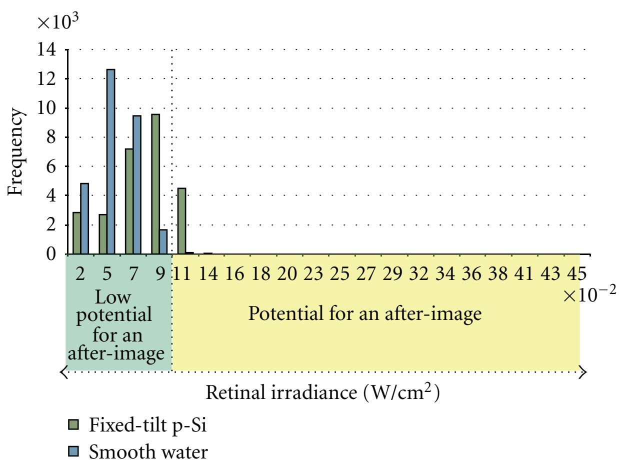


Figure 7: Frequency distribution of retinal irradiance with mitigation.

irradiance values below 0.14 W/cm$^2$. Under these conditions, 92 percent of the hours over the six-year period investigated for solar PV would now be in the "low potential" zone at Las Vegas.

## Highlights

(i) Ocular safety metrics were used to quantify the potential for hazardous glare from a photovoltaic system hourly.

(ii) The results show that the glare hazard from smooth water and flat plate photovoltaic systems are similar.

(iii) Glare mitigation is common and significantly reduces glare hazards.

## Abbreviations

ANSI: American National Standards Institute
NREL: National Renewable Energy Labs
PV: Photovoltaic
p-Si: Polycrystalline silicon.

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## References

[1] C. Ho et al., "Methodology to assess potential glint and glare hazards from concentrating solar power plants: analytical models and experimental validation. s.l.," ES2010-90054, Sandia National Laboratories, 2010.

[2] R. D. Metcalf and R. E. Horn, "Visual recovery times from high intensity flashes of light. s.l.," Wright Air development Center Technical Report 58232, Air Force Aerospace Medical Research Lab, 1958.

[3] R. L. Saur and S. M. Dobrash, "Duration of after-image disability and viewing simulated sun reflections," *Applied Optics*, vol. 8, no. 9, pp. 1799–1801, 1969.

[4] S. L. Severin, N. L. Newton, and J. F. Culver, "An experimental approach to flash blindness," *Aeromedica acta*, vol. 33, pp. 1199–1205, 1962.

[5] D. H. Sliney and B. C. Freasier, "Evaluation of optical radiation hazards," *Applied Optics*, vol. 12, no. 1, pp. 1–24, 1973.

[6] T. D. Brumleve, "Eye hazard and glint evaluation for the 5-MWt solar thermal test facility," SAND76-8022, Sandia National Laboratories, Livermore, Calif, USA, 1977.

[7] R. Chiabrando, E. Fabrizio, and G. Garnero, "The territorial and landscape impacts of photovoltaic systems: definition of impacts and assessment of the glare risk," *Renewable and Sustainable Energy Reviews*, vol. 13, no. 9, pp. 2441–2451, 2009.

[8] A. Parretta, A. Sarno, P. Tortora et al., "Angle-dependent reflectance measurements on photovoltaic materials and solar cells," *Optics Communications*, vol. 172, no. 1, pp. 139–151, 1999.

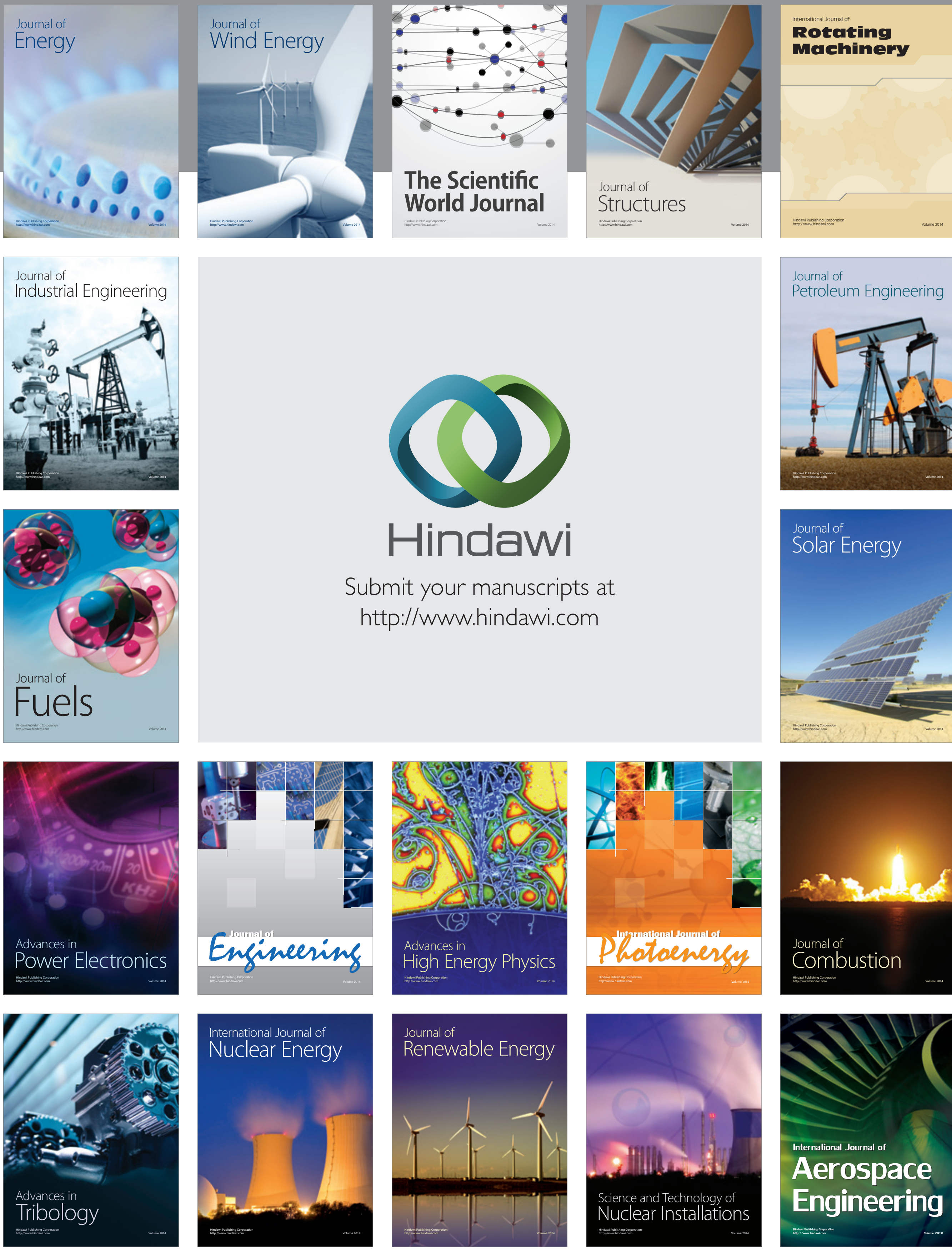
[9] D. H. Sliney, "An evaluation of the potential hazards of the point focusing solar concentrators at the JPL-Edwards test site," JPL Consulting Agreement no. JF 714696, California Institute of Technology, Pasadena, Calif, USA, 1980.

[10] ANSI, "Ophthalmics—nonprescription sunglasses and fashion eyewear—requirements," ANSI Z80.3-2001. s.l., American National Standards Institute, 2001.

[11] R. Levinson and H. Akbari, "Effects and composition and exposure on the solar reflectance of portland cement concrete," LBL-48334, Lawerence Berkley National Laboratory, Berkley, Calif, USA, 2001.

[12] T. Nakamura, O. Abe, T. Hasegawa, R. Tamura, and T. Ohta, "Spectral reflectance of snow with a known grain-size distribution in successive metamorphism," *Cold Regions Science and Technology*, vol. 32, no. 1, pp. 13–26, 2001.

[13] M. G. Hutchins, A. J. Topping, C. Anderson et al., "Measurement and prediction of angle-dependent optical properties of coated glass products: results of an inter-laboratory comparison of spectral transmittance and reflectance," *Thin Solid Films*, vol. 392, no. 2, pp. 269–275, 2001.



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