PRODUCT AWARENESS NOTIFICATION # 008.02.10

Title:	**Possible Glare and Reflectance in PV Systems**
Scope:	**Commercial and Residential PV Systems**
Group:	**Product Management**
Technical Contact:	**Mark Shields**
Intended Exposure	**External**

Objective: The objective of this document is to increase awareness concerning the possible glare and reflectance impact of PV systems on their surrounding environments (Additional reference for differences between AR Glass and non-AR, in Appendix II).

Background: During a few recent residential and commercial project opportunities, SunPower customer interface personnel have fielded questions concerning glare and reflectance levels from PV systems. These questions have ranged from the possible glare and reflectance effect on neighbors to the glare and reflectance effect on air traffic.

Executive Summary: The glare and reflectance levels from a given PV system are decisively lower than the glare and reflectance generated by the standard glass and other common reflective surfaces in the environments surrounding the given PV system. Concerning random glare and reflectance observed from the air: SunPower has several large projects installed near airports or on air force bases. Each of these large projects has passed FAA or Air Force standards and all projects have been determined as “No Hazard to Air Navigation” (see FAA copy letter in Appendix I). Although the possible glare and reflectance from PV systems are at safe levels and are usually decisively lower than other standard residential and commercial reflective surfaces, SunPower suggests that customers and installers discuss any possible concerns with the neighbors/cohabitants near the planned PV system installation.

Explanation: In general, since the whole concept of efficient solar power is to absorb as much light as possible while reflecting as little light as possible, standard solar panels produce less glare and reflectance than standard window glass. This is pointed out very well in US patent # 6359212 (*Method for testing solar cell assemblies and second surface mirrors by ultraviolet reflectometry for susceptibility to ultraviolet degradation*), which explains the differences in the *refraction* and *reflection* of solar panel glass versus standard window glass. Specifically, on a more technical level, 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, we will need to explain some basic scientific terms that are used when discussing beams of light impacting the surfaces of other mediums, as the light beams leave air to enter the other mediums.

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**;

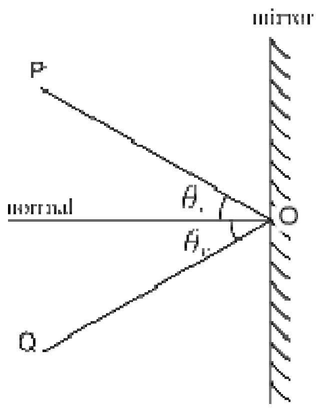


Figure 1-1: **REFLECTION**

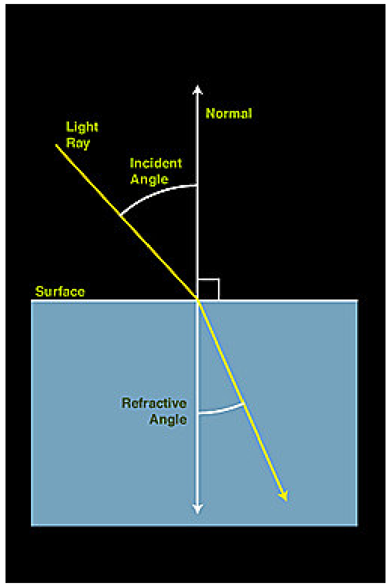


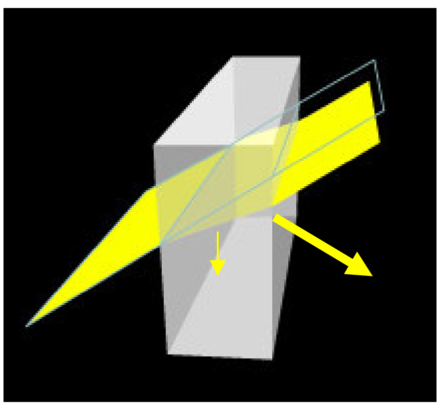
Figure 1-2: **REFRACTION**

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**:

- 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, and some is absorbed in 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 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



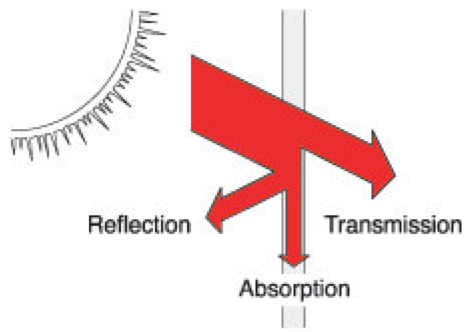
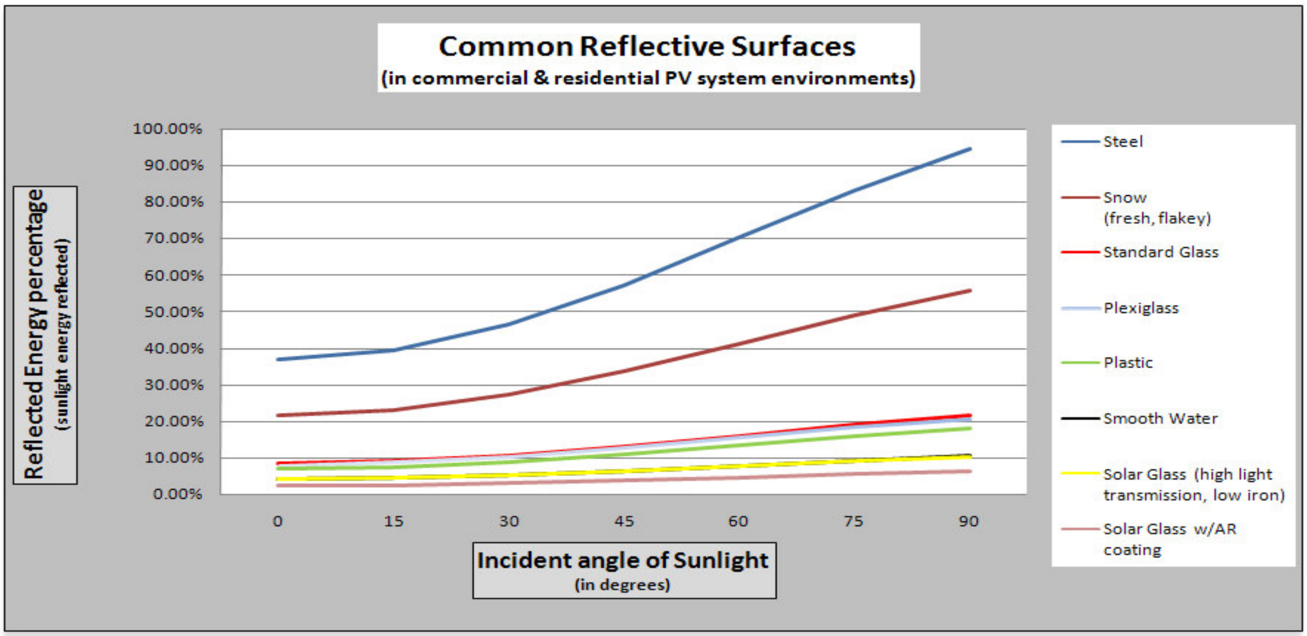


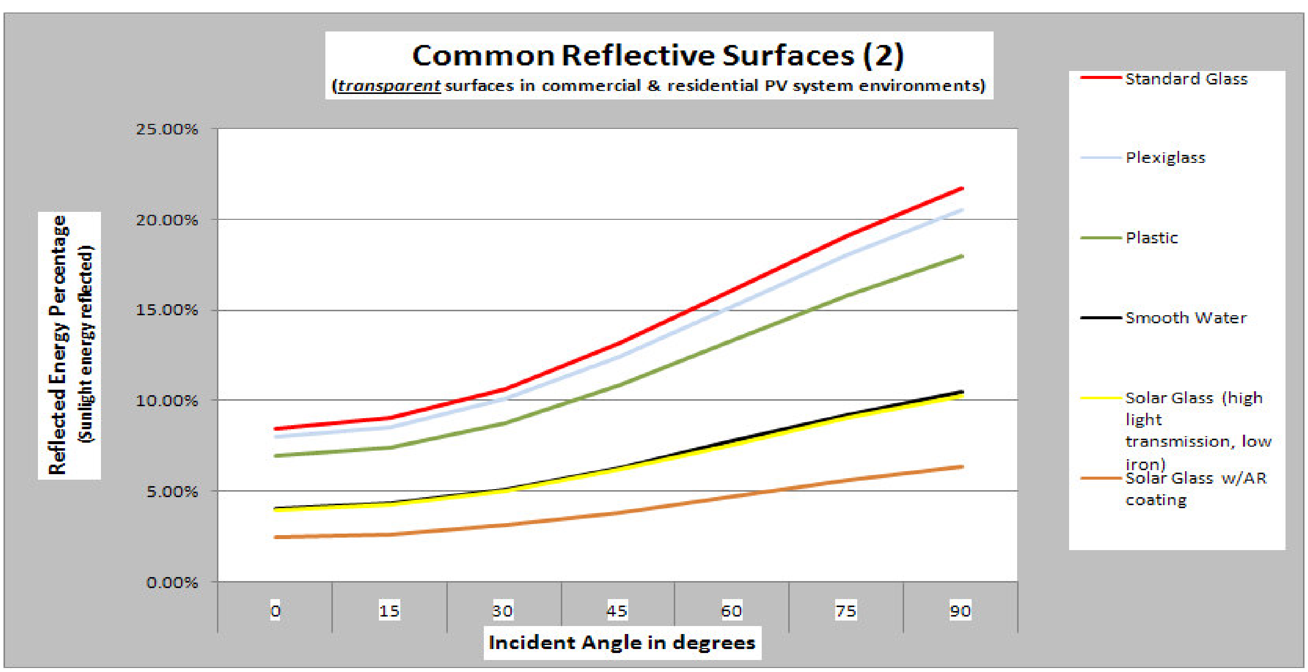
Figure 2-2. Solar radiation through a glazing material is either reflected, transmitted or absorbed

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).

In the graph below we show 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 that the reflected energy percentage of Solar Glass is far below that of standard glass and more on the level of smooth water. We can get a better look at the ratios when we remove 'Steel' and 'Snow' from the chart:



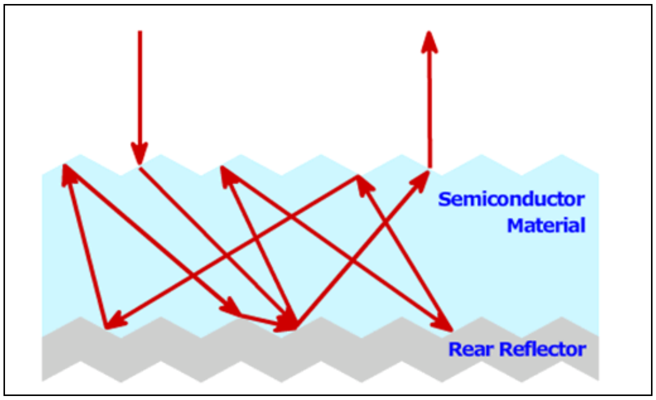
Light-beam physics resolves that the **least amount of light energy is reflected** when the beam is the **normal**, in other words, the least light energy is reflected **when the beam is at 0 degrees to the normal**. Greater quantities of incident beam light energy are reflected as the beam approaches 90 degrees to the normal – when the incident beam approaches parallel with the surface. Consequently, as the incident angle of the light beam increases, the transmission percentages of the light beam decrease, and the reflected energy percentages of the incident light increase. The previous charts are a result of the light-beam physics calculations from the table below:

Common Reflective Surfaces (in surrounding environments for PV systems)		Incident angle in degrees						
		0	15	30	45	60	75	90
Material Reflectivity (percent of incident light reflected)	Steel	36.73%	39.22%	46.34%	57.11%	70.02%	83.15%	94.40%
	Snow (fresh, flakey)	21.63%	23.09%	27.29%	33.63%	41.23%	48.96%	55.59%
	Standard Glass	8.44%	9.01%	10.65%	13.12%	16.09%	19.10%	21.69%
	Plexiglass	8.00%	8.54%	10.09%	12.44%	15.25%	18.11%	20.56%
	Plastic	6.99%	7.46%	8.82%	10.87%	13.33%	15.83%	17.97%
	Smooth Water	4.07%	4.35%	5.14%	6.33%	7.76%	9.22%	10.47%
	Solar Glass (high light transmission, low iron)	3.99%	4.26%	5.03%	6.20%	7.61%	9.03%	10.26%
	Solar Glass w/AR coating	2.47%	2.64%	3.12%	3.84%	4.71%	5.59%	6.35%

(Note: Index of refraction values may vary slightly depending on suppliers and reference documentation. The values for the above calculations are averages or single values obtained from the list of references for this document).

Important references – "stippled glass" and "light trapping": In addition to the superior refractive/reflective properties of solar glass versus standard glass, SunPower uses **stippled** solar glass for our panels. Since the initial release of this document, many PV suppliers have moved to stippled glass. 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 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 SunPower glass and cell are transmitting a larger percentage of light to the solar cell while breaking-up the intensity of the reflected energy. Try this basic optical experiment where ever a reflection comparison can be safely made between a SunPower panel and a large window or plate of glass.

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



Conclusion: In support of the executive summary, the studies, data and light-beam physics behind the charts and graphs prove beyond a reasonable doubt that solar glass has less glare and reflectance than standard glass. The figures also make it clear that the difference is very decisive between solar glass and other common residential and commercial glasses. In addition, not to be lost in the standard light/glass equations and calculations, the SunPower solar glass is **stippled** and has a **light-trapping,** very photon-absorbent solar cell attached to its back side, contributing additional factors which result in even less light energy being reflected. Additional information is available in the Appendix letter from the FAA.

The above reflectance charts also make a clear case for the enhanced absorption ability of Anti-Reflective glass (a.k.a., AR Glass). Appendix II points out some of the differences and advantages of AR glass over standard PV glass.

REFERENCES;

- 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.
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- J. Karlsson, B. Karlsson and A. Roos, A simple model for assessing the energy efficiency of windows, In Press, Energy and Buildings

APPENDIX I:

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

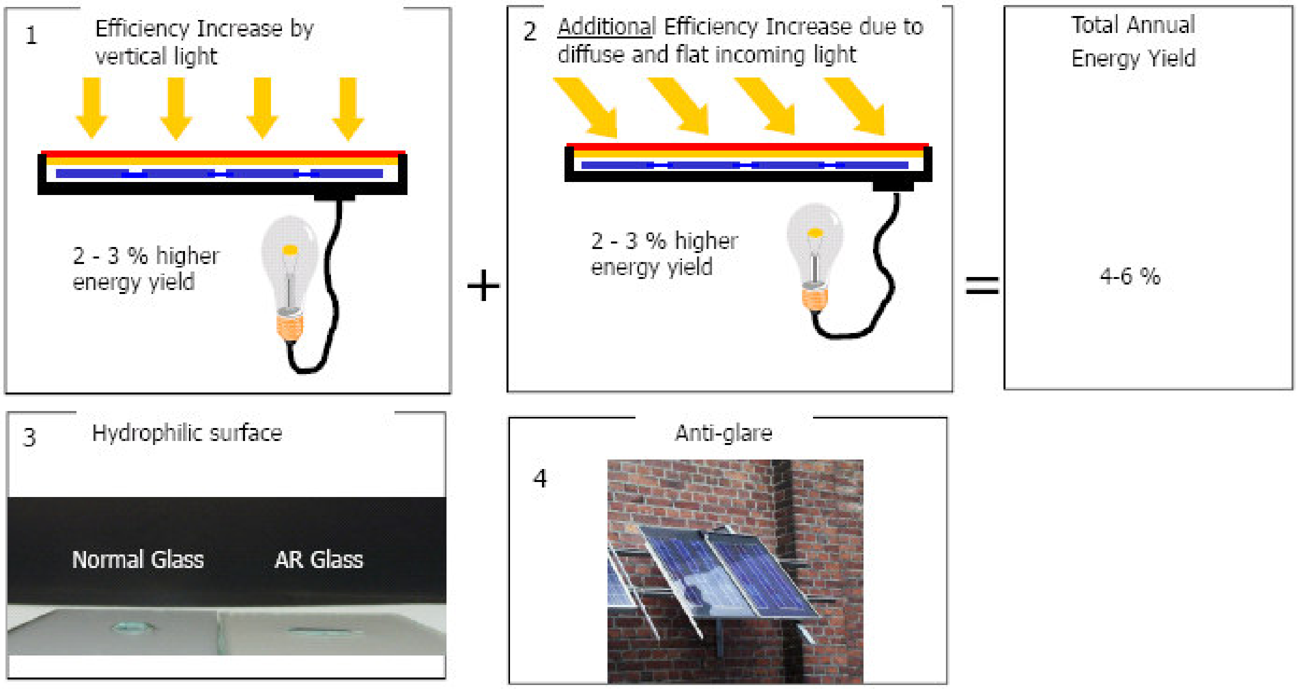
ROOF-MOUNTED SOLAR MODULES

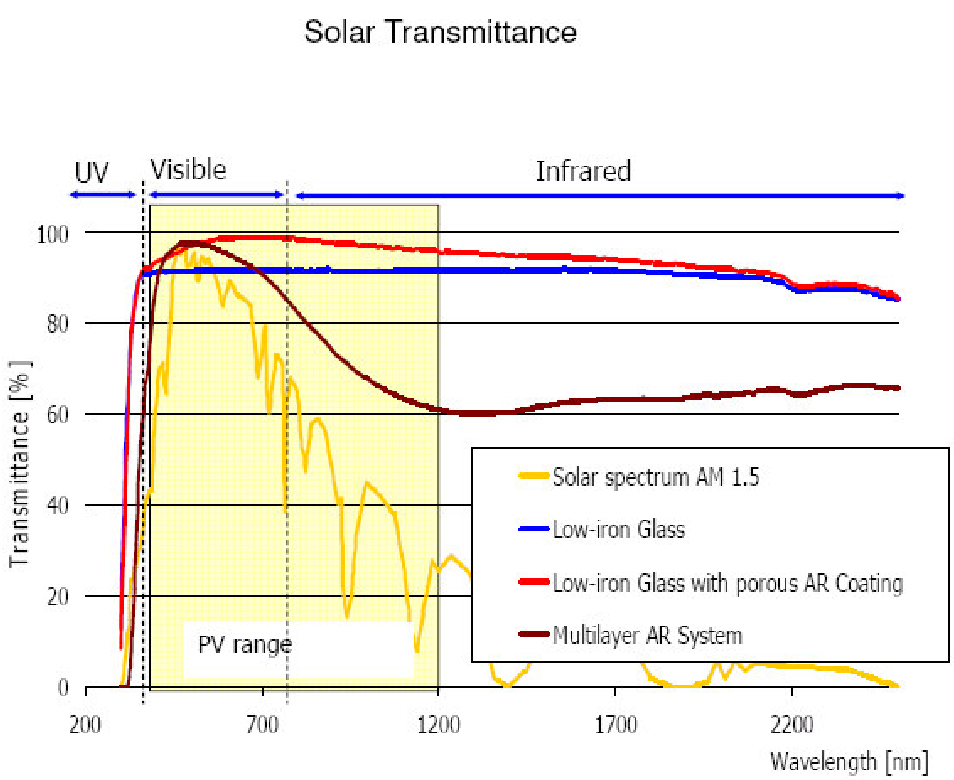
Case Description for ASN 2005-AWP-363-OE

Map for ASN 2005-AWP-363-OE

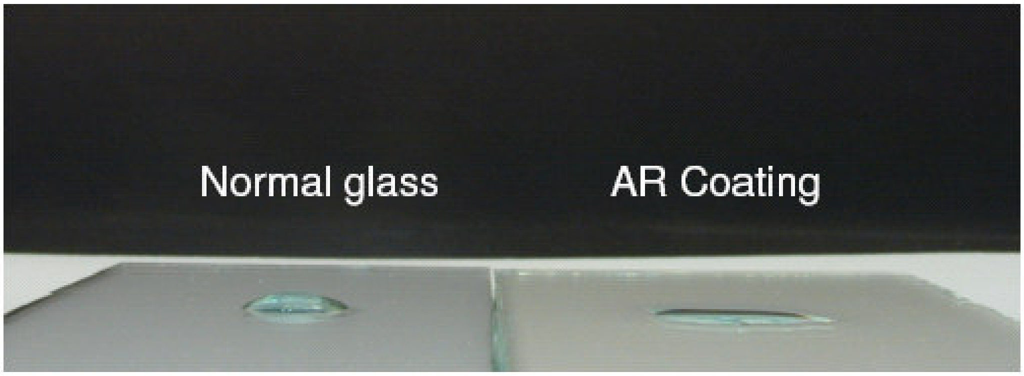
APPENDIX II:

AR and non-AR comparison of basic properties





Hydrophilic Character of the Antireflective Coating



- Low contact angle (10°)
- Excellent wetting of the glass surface and spreading of water droplets
- Generation of an uniform water layer
- Infiltration and removal of soil
- Quick evaporation of dew and water droplets