Proceedings

Winning Hands for Today's Building Envelope Consultants

MASTERING THE DESIGN ISSUES OF INSTALLING SOLAR PHOTOVOLTAICS ON EXISTING ROOFS

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ABSTRACT

PV installations on existing roofs have grown rapidly, while roofing consultants' capability in addressing roof design, longevity, and roof structure loading has not always kept pace.

This paper discusses types of PV systems, design impacts on the watertightness and structural capacity of roofs, what PV installation means to roof longevity, selected appropriate design approaches for the various systems, and pitfalls to avoid. The presentation includes a case study and descriptions of panelized systems affixed to mounting assemblies, peel-and-stick products for existing metal roofs, thermally applied or laminated PV systems for single-ply roofs, and solar PV cells integrated into roof shingles.

SPEAKER

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Mastering the Design Issues of Installing Solar Photovoltaics on Existing Roofs

INTRODUCTION

Installations of solar photovoltaic (PV) systems on existing roofs have grown rapidly in number and are expected to continue to grow over the next decade. This explosion has been created by building owners who want to reduce electricity bills as utility rates go higher and higher, by the concurrent development of more cost-efficient PV materials and components, by the desire of building owners to "go green" to reduce carbon footprints, and by time-limited governmental and utility company incentives. And when properly planned and financed, PV systems will (on certain properties) increase property values for potential buyers and investors.

Roof consultants must keep pace with changing design implications and become current with their understanding of rapidly evolving technology in PV materials and components. All solar PV systems have unique installation issues relating to roof design, watertightness, and roof longevity; and have structural complexities caused by higher dead and live loads, wind uplift, and seismic/thermal movement.

A review of recent history provides an example of the need for the roof consultant to pay attention to design implications of solar PV. In the 1970s, rapidly increasing prices in electricity, natural gas, and fuel oil directly created rapid increases in the number of solar PV systems installed on existing roofs. Unfortunately, lack of proper design details led to premature roof failures and other problems that could have been avoided.

In order to learn from history, provide the roof consultant a technical outline of solar PV types, and to provide an intermediary level overview of design issues, this paper will present characteristics of PV systems now on the market, including the design implications for each type. It will suggest some roof assessment techniques to use before solar PV is installed on existing roofs and will explore the impacts of the installation of various solar PV types on the watertightness of roofs.

The paper will review what PV installation means to existing roof longevity. It will also review selected structural, electrical, civil, and mechanical issues, and will show some of the pitfalls to avoid.

The solar PV systems discussed in this paper are based on crystalline and thin-film materials manufactured into solar panels. Also discussed are applications whereby thin film is affixed to metal and single-ply roofs or utilized in building-integrated PV (BIPV) in curtain walls, roof shingles, and other building components.

The author will discuss structural impacts caused by the additional roof load caused by panels or thin film, how to design for various types of popular systems and assemblies now on the market, and some simple financing strategies to convince owners to install PV systems.

Briefly discussed is how financial issues are interconnected with design issues. For example, successful applications for power purchase agreements (PPAs), lease-backs, governmental incentives in the form of tax rebates, and utility company incentives, all demand detailed calculations of how the solar PV system is being designed and how reduced energy costs will pay for at least a portion of the solar PV system.

The paper includes lessons learned from actual case studies and real-life examples of design issues faced by the roof consulting professional, in the following format:

INTRODUCTION

1. Definition and description of solar PV systems
2. Brief overview of solar thermal systems
3. Types of solar PV materials
   - A. Thin film
   - B. Crystalline silicon
4. Mounting systems for roof installation of solar PV
   - A. Low-slope solar PV thin-film adhered systems
   - B. Low slope solar PV panel systems
   - C. Solar PV panels mounted to standing-seam metal roofs
   - D. Solar PV systems mounted via penetrating mounts
   - E. Nonpenetrating, nonballasted solar PV panel roof-mounting racks
   - F. Nonpenetrating ballasted solar PV panel roof-mounting racks
   - G. Snow loadings and snow drift mounting and load issues
   - H. Carport-mounted, shade-structure mounted, ground-mounted and tower-mounted tracking solar panels.
   - I. Other types of solar PV systems – concentrators
   - J. Building integrated PV (BIPV)
5. A brief list of solar PV manufacturers
6. Design issues faced by the roof consultant
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   - C. Solar PV and new roof warranty
   - D. Sustainability of solar PV system over time
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   - F. Fire code design issues
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7. Financing solar
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   - C. Key things to remember for the economic case
   - 8. Contractors and suppliers
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   - B. What questions should be asked?
   - C. Safety criteria
   - D. Roof and site integrity – can the firm provide it?
   - E. Roofing and construction experience

CONCLUSION

1. DEFINITION AND DESCRIPTION OF SOLAR PV SYSTEMS

A solar PV system generates electrical power through the conversion of solar ener-

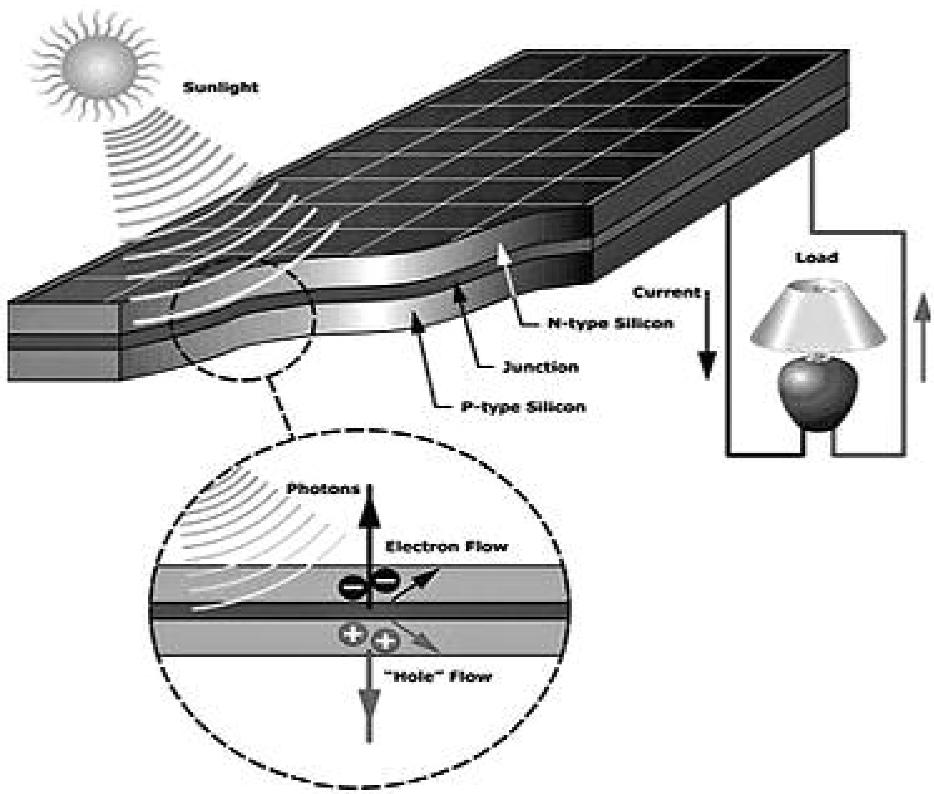

Figure 1 — How electricity is generated in a solar PV system.

gy – first into direct current (DC) electricity, and then into alternating current (AC) electricity.

In conversion to DC electricity, sunlight falls on a material such as crystalline silicon (C-Si), either in the form of mono-crystalline silicon or poly-crystalline silicon. Other PV materials include amorphous silicon (a-Si), cadmium telluride (Cd-Te) and copper indium selenide/sulfide (CIGS). See *Figure 1* depicting the process that converts sunlight into electricity.

Crystalline silicon and cadmium telluride cells are typically assembled into a PV panel. These panels are then mounted on ballasted racking systems or penetrating standoffs on the roof. PV thin-film sheets containing amorphous silicon are integrated into PV panels and roof membrane products; cylindrical roof-mounted products containing copper indium selenide/sulfide are installed on racks; and building-integrated PV (BIPV) components containing various materials are integrated into curtain walls and even roof shingles.

PV panel systems can be mounted on carports and other ground mounts and can be installed on tracking systems rotating in one or more axes to take maximum advantage of the sun as the earth rotates.

The power generated by PV panels, roof membrane systems, cylindrical products, and BIPV products varies by system type and manufacturer. Panels—sometimes called "modules" in the industry—are connected in "strings" or "arrays." Multiple arrays and strings are connected together at a combiner box.

The power output from PV systems is highest on a bright day with relatively mild ambient temperatures and drops as the modules heat up (such as on a very hot day). There is no power output in the dark and there is no stored energy in the panels/modules themselves.

Panels are oriented in a manner to provide the best access to sunlight. This means they are typically mounted on the south or southwest roof plane of a steep-sloped roof. On a low-slope roof, panels can be laid flat, but the power conversion efficiency is reduced below the efficiency of steep roof systems. To take best advantage of sunlight on a low-slope roof, PV panels are mounted on racks tilted to the sun at the "azimuth" angle and compass direction appropriate for the geographical area and site.

The desired azimuth angle (the orientation of the panel or module to the sun) varies by latitude of the site, but actual installed azimuth angle will vary, due to factors such as amount of space available for the array, wind uplift issues, and aesthetic issues.

At the earth's equator, flat panels would be at the most efficient angle to the sun. In the continental United States, the most efficient azimuth angle of orientation to the sun varies between approximately 26° and 47° from horizontal, depending on latitude (See *Figure 2* for a solar resource map of the United States).

The typical roof area required for single-family home use is about 400± sq ft,

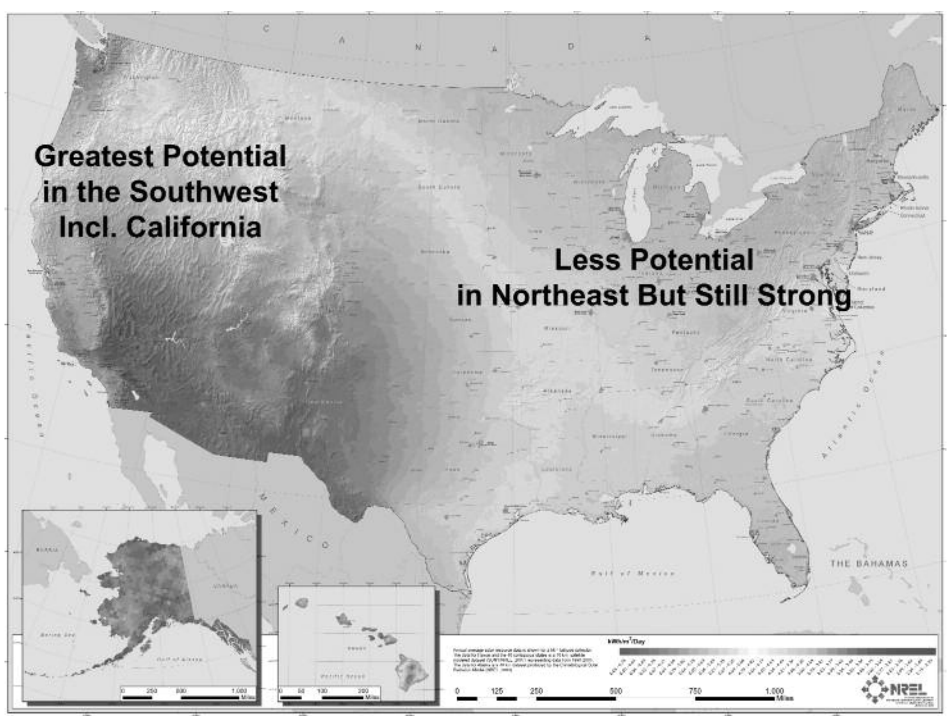

Figure 2 — Solar resource map of the United States produced by the National Renewal Energy Laboratory for the U.S. Department of Energy.

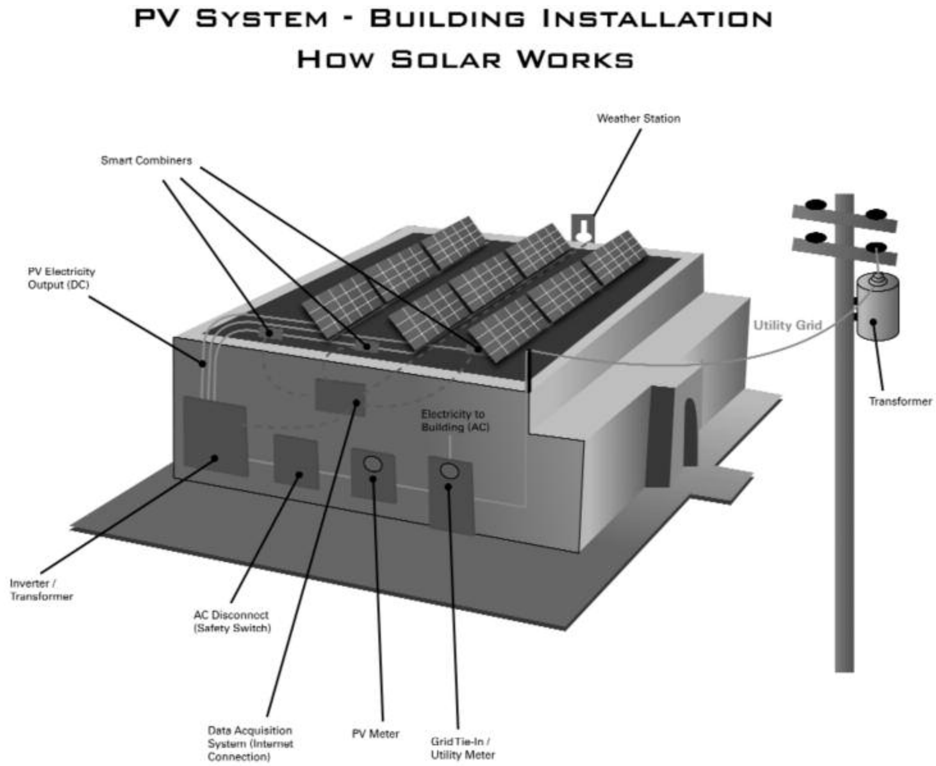

Figure 3 – Typical components of a roof-mounted solar PV system.

depending on location, generating approximately 2,500± watts. For commercial and large-scale applications, the required roof area will vary, based on electrical load and the size of the available roof area (shading, mechanical equipment, etc.).

PV panels and other components come in a large number of sizes, shapes, and uses, with products available across the country from more than 25 manufacturers. Panels are installed by hundreds of contractors and "integrators."

Not only are the method of mounting and type of system important to the roof consultant; so, too, are the method of installation and type of the complete PV system – including the wires and conduits carrying the DC power away from the panels, the inverter system that converts DC power into AC power, the utility company connection, and other support components. PV-generated electricity is most often used only for supplying the electrical needs of a user, although surplus power can also be sold to electrical utility companies. See *Figure 3* showing the typical components of a roof-mounted solar PV system.

2. BRIEF OVERVIEW OF SOLAR THERMAL SYSTEMS

In addition to PV technology, solar thermal energy (STE) systems also take advantage of sunlight in order to generate heat and are available in the low-, medium-, and high-heat ranges. Low-heat systems (less than 100°) are typically used in pool heating, space heating, and process heating. Medium-temperature systems (100 - 204°) are typically used for domestic or commercial hot water. High-temperature systems (under 1500°) are usually large-scale utility-company-owned systems, designed to concentrate sunlight to make steam to drive turbines.

STE systems are not covered in depth in this paper, although some of the same design issues (structural load, wind load, impact on the roof assembly, roof longevity, and roof maintenance) come into play.

3. TYPES OF SOLAR PV MATERIALS AND PANELS

These thin-film and crystalline materials transform solar energy to electricity.

A. Thin Film

Thin film began to see widespread commercial deployment in the early 2000s, whereas crystalline silicon panels saw widespread commercial use in the 1970s. Thin films are available from a number of different manufacturers and can cost less per watt than traditional silicon panels; however, they can require significant additional space due to their lower power efficiency, leading to higher overall system costs.

Thin film, when integrated into solar panels, is used in roofing retrofit situations; however, when integrated into single-ply roofing materials for retrofits, a complete reroof may be required, depending on the individual circumstances and condition of the roof.

Thin-film materials, whether mounted into panels, directly applied to roofs, integrated onto single-ply roofing, or integrated into BIPV, are available in these raw forms:

- Amorphous silicon (a-Si)
- Copper indium gallium selenide (CIGS)
- Cadmium telluride (CdTe)

See *Figure 4.*

Amorphous silicon (a-Si)

Amorphous silicon (a-Si) applications have a lower efficiency rating, often by half, compared to crystalline silicon (c-Si), but are more flexible in their applications. Thin-film applications thus require larger roof space but provide cost efficiencies and some weight savings, as a-Si layers can be made thinner than crystalline applications. During the manufacturing process, a-Si is deposited at very low temperatures (as low as 75°). This allows for deposition not only on glass, but plastic as well. This makes it a candidate for a roll-to-roll process.

The weights of a-Si applications in single-ply roofing vary from manufacturer to manufacturer. And as noted, relatively larger roof space is required.

Figure 4 — Flexible thin film on a large roof.

Copper Indium Gallium Selenide

CIGS cells tend to be less expensive, due to lower material costs and potentially lower fabrication costs (although crystalline technology is also dropping in production cost). A research paper prepared by the U.S. Department of Energy showed an efficiency of nearly 20% research testing (higher efficiency levels than a-Si and crystalline silicon); electricity production efficiencies may be lower, however, depending on application and installation.

One CIGS manufacturer makes cells to take advantage of direct sunlight, diffuse sunlight, and reflected sunlight from the roof surface. With a white roof, these panels can capture up to 20% more light than a black roof, according to the manufacturer. Thus, the reflectivity of an existing roof is a critical factor for this type of system. Roofs lacking the required reflectance due to age or soiling or both may require a significant increase in cleaning frequency, increasing costs and affecting long-range economic returns.

Also, there is a relatively short commercial deployment history of cylindrical CIGS modules compared to traditional crystal silicon panels.

Cadmium Telluride

CdTe cells are not as cost efficient as crystalline, but are suitable for large-scale production. CdTe is the only thin-film PV technology to surpass crystalline in cost effectiveness when used in utility scale applications.

As with other thin film, the weight per sq ft of these systems varies by manufacturer.

Concern with the toxicity of the cadmium has been expressed by many potential users. See *Figure* 5.

B. Crystalline Silicon (c-Si)

Crystalline silicon (c-SI) materials come in two types: monocrystalline and polycrystalline. It is used by the semiconductor industry and is the material used in over 80% of all PV today. Generally, it provides 12% to 21%+ cell efficiency, generates 13 to 17 watts per sq ft, and has extremely low degradation/reduction in efficiency over time. As one of the original PV technologies, it has a history of over 40 years of field-deployed, successful installation. For retrofits, this is the most practical system, assuming the roof is in good condition, because the system can be relatively easily set on an existing roof.

Figure 5 — Typical CdTe panel.

Monocrystalline (Single Crystal)

Monocrystalline is the original PV technology invented in the 1950s and has over 40 years of history and reliability behind it. Monocrystalline modules are composed of cells cut from a piece of continuous crystal cylinder sliced into thin circular wafers. Because each cell is cut from a single crystal, it has a uniform, dark blue color (see *Figure 6*).

Polycrystalline (Multi Crystal)

Polycrystalline entered the market in 1981, but is similar in history, performance, and reliability. Polycrystalline cells are made from silicon material, but instead of being grown into a single crystal, are melted and poured into a mold. This forms a square block that is then cut into square wafers with less waste of space and material than round single-crystal wafers. As the material cools, it crystallizes in an imperfect manner, forming random crystal boundaries. The efficiency of energy conversion is slightly lower. The size of the finished module is slightly greater per watt than most monocrystalline modules. The cells are also different in appearance from single crystal cells. The surface has a jumbled look with many variations of blue color.

In the United States, mono and polycrystalline panels are available from at least 25 manufacturers. The so-called "typical" panel has a size of approximately 14-17 sq ft, generates <200 to >240 watts, and weighs approximately 40 pounds—or, from a very Rough Order of Magnitude point of view—2-3 pounds of dead load per sq ft of panel, not including wires, connectors, conduits, other equipment, and loads created by wind, seismic, or thermal movement. See *Figure 7*.

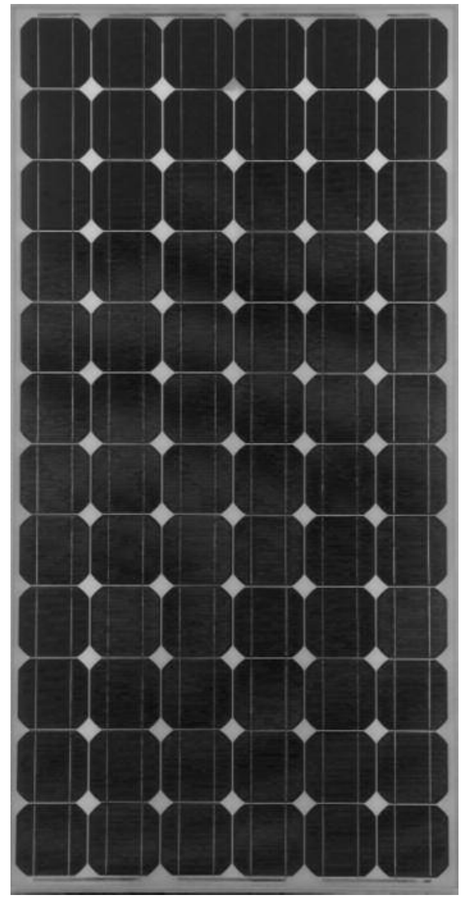

Figure 6 – Typical monocrystalline panel. Because the sizes and outputs vary, the designer needs to check manufacturer specifications.

4. MOUNTING SYSTEMS FOR ROOF INSTALLATION OF SOLAR PV

Low-slope Solar PV Thin-Film Adhered Systems

Single-ply thin-film solar PV roofing systems are applied directly to the roof, either in the factory or in the field. For example, thin-film solar PV has sometimes been adhered with adhesive to existing metal roofs or has been factory-applied to single-ply roof membranes. Single-ply and other low-slope adhered systems are limited in application due to the condition of the existing roof membrane and insulation, how

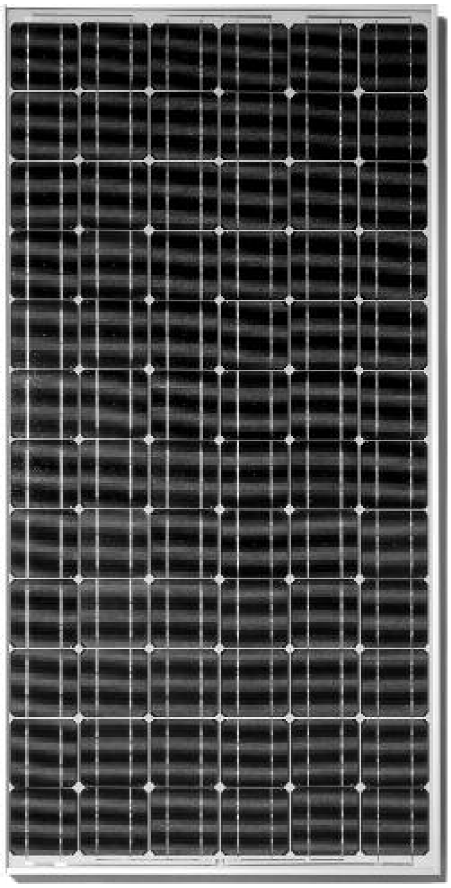

Figure 7 — Typical polycrystalline panel. The dimensions of these panels vary widely, depending on the manufacturer. One of the more common sizes is a panel approximately 39 inches wide, 65 inches in length (approximately 17 sq ft), and 1.8 inches thick. The shipping weight is approximately 40 pounds. Because sizes vary so widely, the designer must check specifications with each manufacturer.

Figure 8 — Panel mounting on standing seam metal roof.

Figure 9 — Penetrating roof mount on gravel ballasted BUR. The same detail would be applicable to an embedded aggregate roof.

many roof membranes are already in place (as limited by local code), how many roof penetrations must be dealt with, wind uplift, and similar factors. However, thin-film systems, either in single ply or manufactured into the panelized systems described above, offer significant weight and structural advantages.

Low-Slope Solar PV Panel Systems

These panel systems are laid flat on the roof or are secured or ballasted in place, often by only their own weight, with or without separate protection pads. If laid flat on the roof without being secured, wind uplift and ventilation of these panels can be problematical if not properly designed. In a retrofit situation, this can have a serious impact on remaining roof life and the safety of the panels.

Solar PV Panels Mounted to Standing Seam Metal Roofs

Panel systems can be mounted to standing seam metal roofs with clips (see *Figure 8*), although clips are not approved by all governmental agencies (for example, California Division of the State Architect, involving K-12 schools and some other local government-owned buildings in California).

See *Figure 9*.

Solar PV Systems Mounted via Penetrating Mounts

Penetrating roofing systems for roof retrofits include specialized mounts affixed to the roof structure, although this does cause the membrane to be cut, possibly affecting the existing warranty.

The system providing the best answer to wind load, thermal movement and azimuth angle issues, is the system attached to the roof structure or building frame. This method does require additional roof penetrations, although with proper design can be accommodated – see *Figure 10* for one example of a penetrating mount on an existing gravel ballasted built up roof. The roof consultant will need to review and implement NRCA recommendations regarding clearances, on a case-by-case basis.

Figure 10 – Roof-mounted, ballasted solar panel system with polycrystalline panels. Note the limited clearance between the panels and the roof deck, possibly creating the need to remove the panels for the purposes of roof replacement or possibly even for normal roof maintenance, leak repair, or cleaning.

Figure 11 — Building integrated PV (BIPV) in a curtain wall.

Nonpenetrating Nonballasted Solar PV Panel Roof-Mounting Racks

Nonpenetrating nonballasted roof solar racks consist of PV panels being set in metal frames placed on the roof over rubber or EPDM pads. These systems are somewhat similar to ballasted systems, but instead of ballast being added, take advantage of the weight of the solar PV system and the racks themselves. Some of manufacturers claim their systems can sustain winds of 90 to 120 miles per hour; however, some manufacturers claim only the capacity to accommodate a 30-degree angle from the roof deck at such wind speeds, an angle that may be less efficient in generating power in some parts of the country where an azimuth angle of up to 47° from horizontal may be necessary for optimal solar efficiency.

Nonpenetrating Ballasted Solar PV Panel Roof-Mounting Racks

These ballasted systems consist of metal frames with the addition of weight in the form of bricks or other engineered material. The manufacturers of some ballasted systems claim ballasted systems can withstand a greater tilt angle. The roof consultant should exercise due diligence by asking for backup engineering calculations from the manufacturer. Both nonballasted and ballasted roof racks create additional weight, possibly causing the entire system to exceed the limits for the roof structure. Regardless of the PV type installed, the live and dead loads need to be calculated to determine if the roof structure can accommodate them.

Snow Loadings and Snowdrift Mounting Issues

In some parts of the country, solar PV installations will result in greater roof loads from the weight of fallen or drifting snow, the weight of the racks, and the weight of the panels. Taken all together, the roof structure may not accommodate the extra weight.

Carport-Mounted, Shade-Structure-Mounted, Ground-Mounted, and Tower-Mounted Tracking Solar Panels

In addition to the roof mountings of the solar PV systems discussed above, PV systems can be mounted on existing or new carports, shade structures, ground mounts, and tower mounts to provide for tracking of the sun for greater efficiency.

Other Types of Solar PV Systems – Concentrators

Concentrator systems are not covered in great detail in this paper; however, these are some of the concentrator systems now available, typically for large-scale, utility-company-sized systems.

Heliostat concentrators are special towers used to concentrate the sun's energy, typically in the form of heat, on a central point to generate steam to drive turbines, creating electricity.

Concentrated solar panels use a series of lenses to concentrate the sun. These panels are thicker and heavier than the typical solar panel. Concentrated solar panels may also be mounted on sun-tracking, ground-mounted towers or panels.

Building integrated photovoltaic systems (BIPV). Solar panels, thin-film systems and other solar PV are now found in:

- Curtain walls (see *Figure 11*).
- Roof shingles, where the solar component is also the shingle.
- Shade structures.

5. A BRIEF LIST OF SOLAR PANEL AND SYSTEM MANUFACTURERS

There are many, many manufacturers of solar PV panels. A not all-inclusive, but rapidly changing list:

Advent Solar
Amonix Inc.
Atlantis Energy System, Inc.
BP Solar International, LLC
Canrom Photovoltaics, Inc.
DayStar Technologies, Inc.
Duro-Last Roofing Inc.
Energy Photovoltaics Inc.,
Evergreen Solar Inc.
First Solar LLC
Global Solar Energy Inc.
Innergy Power Corporation
Iowa Thin Film Technologies
Kyocera Solar Inc.
Matrix Solar Technologies
Mitsubishi Electric & Electronics USA
Mitsui Comtek Corp.
Nanosolar
Pacific SolarTech
RWE Schott Solar Inc.
SANYO Energy (USA) Corporation
Sanyo Semiconductor Corporation
Sharp Manufacturing Company of America
Shell Solar Industries LP
Solar Power Industries, Inc.
Solar World-USA
SolyNdra, Inc.
Spire Corporation
Sunpower Corporation
Sunwatt Corporation
Sunwize Technologies LLC
Terra Solar Global, Inc.
Trina Solar
Tideland Signal Corporation
United Solar Ovonic LLC.
Yingli
And many more!

Each of these manufacturers offers varying sizes, dimensions, power output, configuration, ease or lack of ease of roof installation, design issues to be addressed, familiarity to the installer, and warranties. These differences will have an impact on the design and how the roof consultant goes about preparing plans for installation.

6. DESIGN ISSUES FACED BY THE ROOF CONSULTANT

The information shown below is not intended to be an all-inclusive list of every issue faced by the roof consultant when dealing with solar PV installations on an existing roof. As with all building components, issues dealing with solar PV are complex and extensive. But based on our firm's experience reviewing existing roofs for their capacity and capability for solar installations, we have prepared a brief overview of design issues to consider. The buildings we have reviewed include airports, multifamily residential properties, schools, and commercial buildings.

A. Roof Assessment.

Roof age. What is the age and condition of the existing roof? Does it need to be replaced now?

Remaining Service Life. Will the remaining roof life be concurrent with the service life of the solar PV system? Will it need to be replaced before the service life of the solar PV system ends, creating more costs? Solar PV manufacturers provide estimates of service life. These need to be compared to the remaining roof life during the design process.

Existing Warranty. What is the impact to the existing roof warranty? Who was the manufacturer, and what is the actual warranty? What are the rules and requirements about penetration? Some warranties are also voided if a new type of roofing material is joined to the existing material.

Watertightness. Are there issues to be addressed before solar is installed, and will these issues be worsened by the installation of solar? Have all existing leak conditions been repaired?

Drainage. Is the existing drainage system adequate, and will it be made worse or even made better (not likely) by the solar installation?

Chemical Compatibility. Will the existing operations, especially in manufacturing or food operations, be compatible with the roof life, the solar PV material, and the solar PV system installation? Will contaminants or particulants discharged from the building cause problems?

Impact on Structural Load. The roof consultant needs to collect weight data on the entire solar PV system to determine if the existing roof can accommodate the new live and dead loads. If the roof consultant is not a licensed structural engineer or architect, a licensed professional will need to be retained in order to provide those answers.

B. Physical Constraints.

These issues to be addressed are fairly straightforward and as follows.

Adequate Roof Space. Is there sufficient roof space available on the roof to handle the entire electrical need?

Existing Mechanical Equipment. How much mechanical equipment is on roof? Will it conflict with the panels, and if so, can it be moved or removed?

Distances Between Solar PV Components. How is the design of clearances and separations between solar PV panels and other equipment impacted by local fire codes?

Power Runs. Are conduit runs possible from solar to electrical tie-in?

Additional Space on Ground for Solar PV. Is space required on the ground for a partial or complete ground-mount system, and is the space adequate in size to accommodate what cannot be accommodated on the roof?

Ground Enclosures for Solar PV Equipment. Will new ground structures be required and can these ground structures take the form of parking shade structures?

Locations of Ground Enclosures. Where will space on the ground or inside the building be provided for an inverter and equipment mounting system, and is it sufficient in size, location, and proximity to the solar PV system? Is a separate building required for this equipment?

Trenching. Will trenching be required from the solar PV system to the electrical tie-in point?

C. Solar PV and New Roof Warranty

Before the purchase, obtain a copy of the warranty from both the solar PV system and the roof manufacturers, and address these issues:

Ongoing Maintenance. What continued maintenance of the roof and solar PV is required as a condition of the warranty? Is the purchaser required to sign an agreement requiring annual or other periodic maintenance, and is such maintenance necessary?

Financial Strength of Company Holding Warranty. Is there financial strength behind the solar PV warranty, or is it an insurance policy from an insurance company?

Extreme Environment Exceptions. Is maritime or extreme environment deployment approved in the warranty?

Fine Print. What does the fine print say?

D. Sustainability of Solar PV System Over Time

Compatibility Between Service Lives. Will the roofing last the term of the solar PV financing? How long will the PV system last?

Obsolescence of Solar PV System. Will

Figure 12 — A solar "garden."

Figure 13 — Possible roof maintenance issues created by thermal movement.

the solar PV and all associated systems maintain their manufactured integrity and last the term of the solar PV financing or warranty?

E. Structural Loads Created by the Solar PV System

The structural load can take the form of dead load caused by the weight of the panels, wires, collectors, connectors, conduits, mounting racks, and other materials. Live-load issues can be created by wind loadings, thermal movement, and other factors. Design requirements to address these issues vary by state and local conditions. Some examples of dead loads have been provided in this paper; however, the manufacturers should be contacted for specific engineering details.

Building officials from California to New York may, upon submittal of a building permit application, request calculations of the ability of the affected lateral system components to resist additional seismic loads and the impacts of thermal movement created by the solar PV system equipment.

Figure 14 — Possible maintenance and safety issues caused by conduit lying on roof.

F. Fire Code Design Issues

Markings. Solar PV systems, including the individual components, should normally be marked with weatherproof materials indicating they are solar systems in order to provide safety from electrical shock to those working around the systems, such as firefighters in the case of a roof fire, for example. Many jurisdictions require nameplates displaying voltage ratings of the components. Many jurisdictions also require locations of power disconnects to be clearly marked.

Access and Pathways. Fire codes in most jurisdictions require adequate access to panels, adequate paths of travel between roof-mounted solar PV equipment, access to the roof from the ground level (varies by jurisdiction), and emergency egress from the roof. Some jurisdictions have been known to require a 6-ft wide safety path around the perimeter of the roof. Some jurisdictions require the path of travel to be over structural elements.

Size of Arrays. Some jurisdictions limit the size of individual arrays.

Nonhabitable Buildings. In some jurisdictions, the fire requirements do not apply to nonhabitable structures such as carports, shade structures, and other ground-mounted arrays, although a vegetation-free area of 10 ft is required in some jurisdictions.

Impact on Fire Rating of Roof Assembly. The designer needs to determine if and how the PV system will impact the fire rating of the existing roof assembly; this information may be required when permits are requested.

G. Electrical, Mechanical, and Other Design Disciplines

Solar PV systems are unique, requiring design by electrical engineers of adequate wiring sizes and conduits; design by mechanical engineers to provide for existing roof-mounted mechanical equipment; design by structural engineers for structural issues; and civil engineering design of trenching, etc. Solar system power modulation, ground-fault, and short-circuit potential need to be studied, including how well wires are protected in metal and other raceways and how they are protected from the weather. Thermal movement also impacts conduit runs.

H. Peer Review of Design

Solar PV installations, being so complicated, are an excellent candidate for peer review by other engineers.

I. Maintenance of the PV System and the Roof

One of the issues often forgotten by the designer is maintenance, including that of the roof, the PV system itself, the electrical conduits, and the racks, to name a few. *Figures 12-14*, showing some of the possible long-term problems. The answer to these problems can be found in proper design.

J. Nonengineering Design Issues

- Use appropriate materials; reflected light is an issue on campus settings. For example, solar installations on a single-story building can reflect glaring light into existing or planned taller buildings.
- Sizing matters.
- Aesthetics are important.
- As they say: location, location. Solar can go anywhere, right? No.
- Make sure the PV system remains in continuous operation.
- Beware of security issues during installation and operation.

7. FINANCING SOLAR

How and why to finance solar need not be difficult if the following issues are taken into consideration:

A. Price

What's the best way to pay for solar PV, and is the price reflective of all needed options? The overall question is: Does solar make financial sense for the given unique situation? The big picture is: Utility costs are increasing rapidly, utility costs are and will continue to be volatile, rebates and tax credits are limited, and money spent on energy is money not spent on growth. So solar enables a consultant to control and predict utility costs and save money.

B. Alternative Financing Methods

Cash Purchases. These are great. . . if you have the money. Some financial analysts have shown a 10-18% return on investment and an 80% to 98% reduction in energy costs.

Federal and State Incentives.

Traditional Financing Using a Capital Loan or Lease.

Municipal Leases for Municipal Bonds.

American Recovery and Reinvestment Act (ARRA) Stimulus Funds.

Power Purchase Agreements (PPA). This financing method allows control of utility costs without capital investment, providing increased savings over time. Municipalities that cannot otherwise benefit from tax incentives can, in effect, allow others to reap the benefits at much lower costs to the municipality.

- The finance company installs, owns, and operates the solar plant on the owner's site. There are a number of different PPA providers, prices and terms can vary greatly, and the proven ability to commit and close as promised is critical.
- The building owner does not pay for the equipment or its maintenance.
- The building owner is buying energy, not equipment.
- Owners buy energy from the system, and only as much energy as the system produces.
- Because this is an agreement to buy energy, not a lease or a loan, the financing agreement is not reflected on the client's balance sheet.
- Credit quality is key: can the parties fulfill their obligations for 20 years?

C. Key Things to Remember for the Economic case

- Utility costs are increasing unpredictably.
- Incentive levels decline over time, often much faster than expected, so there is urgency to act quickly.

8. CONTRACTORS AND SUPPLIERS

A. Criteria for Selecting a Contractor

The issues to be addressed when selecting a contractor follow:

- Is the "contractor" an integrator or a contractor? Is the work self-performed or is the work performed by a subcontractor?
- What is his quality of construction and experience with similar projects?
- Does the contractor/integrator have a strong balance sheet?
- Are good communication practices, procedures, and methodologies in place?
- Are safety procedures and practices in place?
- How many subcontractors will he have?
- What are the quality standards to reduce future costly repairs?
- What methods does the contractor use to avoid delays and problems, increasing enthusiasm for the project within the community/constituency, reducing stress on business operations, reducing the business/organization's risk for on-site accidents, improving the integrity of the roof or site, and eliminating repair disruptions in years to come?

B. What Questions Should be Asked?

- Is this integrator/contractor experienced in construction?
- Does this integrator/contractor understand the whole building?
- Will the integrity of the roof system be protected?
- Does this integrator/contractor deliver quality construction on time and on budget?
- Is this integrator/contractor an expert in every step of analysis, design, sourcing, and cost-control?
- Can this integrator/ contractor be trusted to work safely and prevent costly accidents?
- Does the firm have the ability to execute on time and on budget?

C. Safety Criteria

- Are there full-time safety managers?
- Is there a written safety plan?

- Are there on-site audits?
- Are personal fall-arrest systems in place?
- What is the Experience Modification Rate (EMR)?
- How do rates compare?

D. Roof and Site Integrity – Can the Firm Provide it?

E. Roofing and Construction Experience Criteria

- Is infrastructure in place to support complex projects?
- Is there construction planning and operations excellence?
- Is there a local, cross-trained workforce?
- Are managers experienced with solar projects?
- Are the appropriate licenses held? (In California, for example, B, C-10, and C-46 contractor's licenses.)
- Are there NABCEP certified technicians?
- Are project superintendents highly qualified?

CONCLUSION

Installation of solar PV on existing roofs is complicated, complex, and ambitious, but worth the time and effort through cost savings and the ability to have a positive impact on the environment. Most importantly, the issues addressed and answered in this paper will assist the roof consultant in keeping pace with the rapidly changing practices in the installation of solar roofing systems. The financial means and methods do exist to allow installation of solar PV systems on many existing roofs across the United States. Following these simple guidelines will lead to a successful, rewarding project.