FEMP
Technology Focus
A New Technology Demonstration Publication
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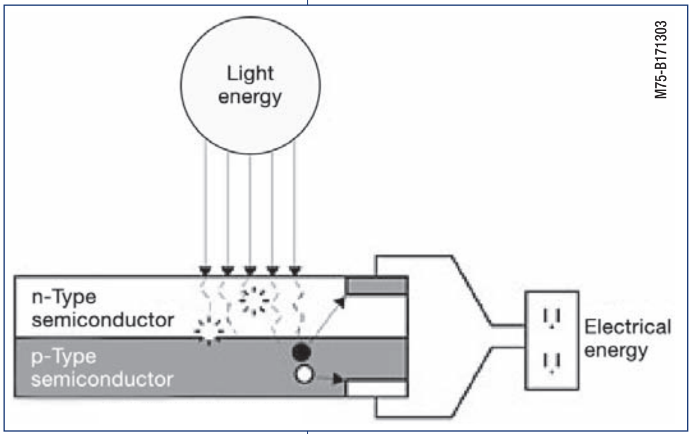
Federal Energy Management Program

Leading by example, saving energy and taxpayer dollars in federal facilities

Current Applications and Research in Photovoltaic Technology for Buildings

Three case studies illustrate different benefits

The federal sector continues to be a leader in the implementation and demonstration of photovoltaic (PV) technology. Installing PV systems helps meet the goals of Executive Order (EO) 13123, which encourages each federal agency to “expand the use of renewable energy within its facilities and in its activities by implementing renewable energy projects and by purchasing electricity from renewable energy sources.” PV systems, like those presented in this report, help meet the goal of the Million Solar Roofs Initiative for the federal government to install 20,000 solar energy systems at federal facilities by 2010. Installing PV systems can also help reach the government’s renewable energy goal—to have the equivalent of 2.5% of federal facilities’ electricity consumption supplied from new renewable energy sources by 2005.



Photovoltaic device.

Although most cost-effective PV installations in the past have been for remote, off-grid power applications, current installations include a variety of high-value grid-connected applications that provide reliable power, lower energy consumption and costs, and reduce harmful emissions. It may be more difficult for grid-connected projects to meet traditional cost-effectiveness criteria (e.g., brief payback periods) if only energy cost savings are considered. However, economics is not the single factor, and not always the most important factor, in determining whether to implement alternative, renewable energy systems such as PV.

Besides reducing energy costs, PV may provide benefits such as reducing harmful emissions from power plants, reducing peak demands for the facility and on the electrical grid, enhancing energy security, as well as, aiding the development of renewable sources of energy. Agencies that can place a dollar value on benefits such as those will be better able to justify installing these systems on the basis of cost.

Technology Description

PV technology converts radiant light energy (photons) to electricity (voltage). PV cells (also called solar cells) are the basic building blocks of this energy technology. PV cells are made of semiconducting materials similar to those used in computer chips. Single-crystal silicon is the semiconductor material most commonly used. Polycrystalline silicon, in the form of a thin film or coating on an inexpensive base of glass or plastic, is also used, as well as thin films of amorphous (noncrystalline) silicon. Although the cells are typically less efficient than the crystalline silicon technologies, the amorphous silicon cells are usually less expensive to manufacture because they require less silicon and the process is simpler. Combinations of other materials, such as cadmium, copper, indium, gallium, selenium, and tellurium, are also used to manufacture PV devices. Sunlight is the most common source of radiant energy used by PV cells to produce an electric current.

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The amount of electricity a PV cell produces depends on its size, its conversion efficiency, and the intensity of its light source. PV cells often power calculators and watches, but they also supply electricity for much larger loads, such as residences and commercial buildings. For those loads, cells are connected together to form larger units called panels (or modules). Panels, in turn, are connected to form arrays, and arrays can be interconnected to generate electricity for still larger loads, such as a group of buildings. A PV energy system usually includes at least a panel or an array and the structural hardware needed to install it. Depending on the specific nature of the load, a PV system may also include

- Batteries to store electricity for use when the sun is not shining
- Battery-charge controllers to protect the battery by preventing overcharge and over-discharge
- Inverters to convert direct current (dc) electricity to alternating current (ac) electricity
- Converters to convert PV system voltage to a higher or lower voltage
- Solar trackers to optimize the solar gain of the PV array by tracking the sun
- Engine generators (for hybrid systems) to provide backup power and power for charging batteries.

Panels are typically installed on or near a building or other structure, such as covered parking. They can also be specially designed as an integral part of a building's roof, wall, skylight, or other element as building-integrated PV. Roof-mounted panels can be either offset-mounted above the roof or laminated directly to the roof membrane.

The dc electricity generated by a PV system must be inverted to ac electricity for use in typical commercial applications. PV systems can be either off-grid (not connected to a utility grid) or grid-connected. (The applications discussed in this technology focus are all ac applications and all grid-connected.) Off-grid systems must include some type of energy storage or backup power source to supply power when the sun is not shining. For grid-connected systems, the utility grid serves as a backup.

As noted in case study 1, the following design elements are key to the successful installation of any PV system:

- Quality wire and conduit with no exposed wiring or wire connections
- Appropriate thermal management design of the solar array and the inverters
- Appropriate panel tilt and orientation to enhance sunlight capture and to mitigate soiling effects
- Correct fusing, switching, and other safety considerations
- A system design that incorporates functionality and serviceability
- Appropriate attachment details and assembly procedures
- Professional workmanship and use of proper tools
- Comprehensive system inspection, testing, and commissioning
- Experienced program management and project oversight

Benefits

Benefits of installing PV systems at federal facilities include these:

- Reliability—they operate for long periods with little maintenance.
- Low operating costs—the fuel is free, and there are few, if any, moving parts.
- Low environmental impact—they are quiet and nonpolluting (no greenhouse gas emissions) and require no air permitting.
- Standalone capability—they can operate in remote areas far from power lines.
- Modularity—power output can be increased by adding more panels.
- Safety—they are not flammable and meet National Electric Code requirements.
- Versatility—they operate well in almost any climate.
- Ease of installation—no heavy construction equipment is required.
- Grid support—they provide energy security in areas where electricity shortages are anticipated.

In addition, as discussed in case study 3, offset-mounted rooftop PV systems shade their roofs and so may reduce solar heat gain and the extra cooling that it makes necessary. At facilities where energy requirements are increasing, installing PV to handle the growth in demand may be less costly than expanding existing electric distribution equipment. PV systems can also provide grid support in areas where electricity blackouts are possible or shortages are expected. In most of the country, peak electrical demand occurs during the sunniest times of the day, which is when PV energy production is at its peak. PV can be used to offset demand during those hours, reducing the stress on the grid and avoiding extra cost for power purchased during peak demand periods.

PV systems can be highly cost-effective in off-grid applications because the cost of extending utility lines can easily exceed $10,000 per mile for flat areas where lines are strung on poles. In the mountains, taking lines through the rough terrain can easily cost $40,000 to $60,000 per mile. Many places require buried lines, and if rock is present, the cost of laying lines can soar. PV systems are already used in many of the government's off-grid applications, such as emergency call boxes near interstate highways.

Grid-connected applications have the advantage of not requiring the use of expensive battery storage or backup power systems, because the utility grid acts as the backup power source. Often, grid-connected systems are sized to provide only a portion of the facility's overall load, further reducing capital cost. It is more difficult to make systems cost-effective in grid-connected applications, where PV systems often compete with inexpensive utility-supplied electricity especially for federal facilities.

PV systems can easily be procured by federal agencies via General Services Administration supply schedules that cover most major makes of PV system components as well as complete systems. In addition, many electric utility companies that offer PV service programs will provide PV systems. Still, capital cost remains a major challenge to widespread implementation. Although the cost of PV panels has dropped from more than $100 per watt in the mid-1970s to less than $6 per watt today, making use of rebate programs and identifying the ancillary benefits that PV systems can offer is crucial to finding cost-effective applications. Some ways of improving the economics of PV systems include

- Recognize and value the ancillary benefits of PV installations, such as reduced emissions or more reliable power
- Integrate PV into the building itself—for example, installing a PV system during a regular roof replacement or considering a PV carport when new covered parking is needed so building material costs are offset
- Obtain rebates for PV systems (available only in some parts of the country) to reduce the capital costs
- Use federal financing mechanisms such as energy savings performance contracts to reduce the initial cost of grid-connected PV systems

Besides being the smart thing to do in any facility, integrating energy efficiency into a facility before installing PV also helps to reduce capital costs, because lower building energy consumption requires a smaller PV array and therefore less capital expenditure. As system costs continue to decrease and utility costs increase, PV should become more cost-effective.

Case Studies

The case studies discussed in this report highlight some recent federal PV installations: a grid-connected PV power system for mission-critical National Weather Service radar sites; a roof-mounted, grid-connected PV system for the U.S. Postal Service; and a roof- and wall-mounted, grid-connected PV system that quantifies the benefits such systems provide in reducing building cooling loads. These projects represent the current evolution of PV systems, as well as ways PV might be used in the future. The information provided in the case studies can be used to help facility managers determine if PV is right for a particular facility.

Case Study 1: Grid-Connected, 10-kW Solar PV System at a National Weather Service Facility

Overview

The U.S. Department of Commerce, the National Oceanic and Atmospheric Administration (NOAA), and the National Weather Service (NWS) requested technical assistance from FEMP in designing a 10-kW PV system for the NEXRAD (NEXt-generation RADar) system at NWS Miramar in California. NWS hopes to have PV systems installed at each of its nearly 150 NEXRAD sites in the coming years. PV systems offer reliable power with no emissions and can help in meeting federal energy reduction and renewable energy implementation goals.

The pilot project at NWS Miramar consisted of designing and installing a PV system for demonstration and evaluation. Based on the pilot system's performance, NWS plans to install additional PV systems at other NEXRAD sites. The system design developed in this project will serve as a standard design for the remaining installations, thereby capitalizing on the lower cost associated with a repeat design installation. During fiscal year 2001, FEMP distributed a Technical Assistance Call for Projects, and NOAA was selected to receive funding. FEMP provided technical assistance using the National Renewable Energy Laboratory (NREL) to support the project. Subsequently, NREL worked with NOAA and the Bonneville Power Administration (BPA) to determine the optimum system size and how best to contract the design and installation. BPA continues to monitor the system performance.

Background

NWS has more than 150 nearly identical NEXRAD installations throughout the United States and overseas. NEXRAD is used to warn the public about dangerous weather and its location, using Doppler radar technology. The distinguishing feature of these radar sites is a 30-foot-diameter ball on top of a 100-foot-high platform, as shown in Figure 1. The typical radar station uses around 180,000 kWh of electricity per year with a peak load of approximately 30 kW. A large revolving radar dish and necessary computer equipment make up the load, as well as cooling needed to keep the high-tech equipment within its allowable operating temperatures. Currently, all systems are grid-connected, and each uses an uninterruptible power supply (UPS) and backup generator set for continuous power during grid outages.

Why install PV at all if these sites are currently grid-connected? There are several advantages.

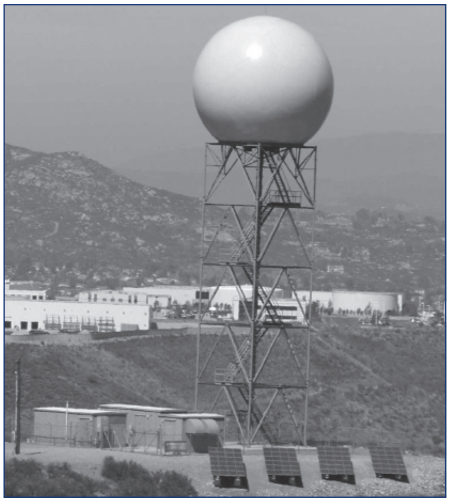

Figure 1. NWS radar site with the 10-kW PV system shown in the foreground.

- Overall electricity consumption and costs are reduced. Also, the long operating life of PV systems means the energy and cost savings can be expected for 20 years or more with low maintenance requirements.
- Emissions from fossil fuel consumption are reduced, including smog-forming nitrogen oxides, CO_2, and acid-rain-forming sulfur oxides.
- PV systems can offset new energy needs at a facility, avoiding costly expansions to existing electric distribution equipment. Grid-connected PV systems can also provide grid support in areas of the country where electricity blackouts are possible or shortages are expected.
- Because the electric grid acts as the backup power source in grid-connected PV installations, the costs of battery installation, maintenance, and repair can be avoided completely.
- In most parts of the country, peak electrical demand occurs during the sunniest times of the day, which is when PV energy production is at its peak.

The Miramar NEXRAD site receives electricity from the local utility, San Diego Gas and Electric. To operate through power outages, the facility has a UPS system housed in an air-conditioned building and a backup diesel generator in another building. A transfer switch connects the UPS to the utility when the utility is up and running or to the generator when the utility goes down. The radar dome and buildings are fenced inside a 60 x 90-foot area with open space surrounding the perimeter. The design goal for this project was to have a robust system design that required virtually no maintenance and did not interfere with the site's primary mission—all at the lowest cost possible. Furthermore, the system design had to be replicable for future installations in a variety of geographic locations. The following design elements helped to achieve these goals and are critical to the successful installation of any PV system:

- Quality wire and conduit with no exposed wiring or wire connections
- Appropriate thermal management design of the solar array and the inverters
- Appropriate panel tilt and orientation to enhance sunlight capture and to mitigate soiling effects
- Correct fusing, switching, and other safety considerations
- A system design that incorporates functionality and serviceability
- Appropriate attachment details and assembly procedures
- Professional workmanship and use of proper tools
- Comprehensive system inspection, testing, and commissioning
- Experienced program management and project oversight

A violation of any one of these components inevitably leads to higher turnkey costs, higher maintenance costs, increased downtime, and hence poorer economic performance. Although the total number of required PV panels for a specific radar site might change as a result of variances in the solar resource in different locales, the basic design of the system, along with the installation and commissioning procedures, is standardized.

PV System Description

The first step in developing a PV system design for NWS Miramar was to determine the appropriate system size. The essential elements that drive the size of any PV system are

- available real estate or roof space for placing the solar array
- annual energy use by the site and estimated energy delivery by the PV system
- budget and net turnkey price
- cost of electrical energy to the facility

Mounting the system on the roof spaces of the existing outbuildings was considered but dismissed. Such an installation was not optimally oriented for solar exposure and would have subjected the PV array to shading from the radar tower. The available land at the Miramar site was limited by the sloping hill on the south side of the fenced facility. Fortunately, the natural tilt of the slope and its perfect size to accept 10 kW of PV were well suited to this first of potentially many repeatable installations.

Analysis showed that a PV system sized at approximately 110 kW could supply 100% of the annual energy used by the facility, but it would have required more land than was available. The 10-kW system will supply approximately 9% of the facility's yearly electrical needs. This smaller-scale installation has a manageable cost and allows NWS staff to familiarize themselves with the system's operation and determine if broader implementation is warranted.

The 10-kW PV array consists of four relatively large panels sized approximately 4.7 x 28 ft. Each panel comprises 24 Kyocera KC 120-1 solar panels wired in series to yield approximately 2.5 kW per panel. The four panels, or subcircuits, are combined in parallel to form one 10-kW array feeding into a 10-kW inverter, Trace Technology model PV-10208 (see Figure 2). The inverter converts the dc power into 208-volt, 3-phase ac power, which is fed through an isolation transformer into the utility grid at the site's main service-disconnect switch.

The PV system is just outside the fence, and its associated switchgear and inverter (Figure 3) is just inside the fence. Because it is connected electrically to the utility side of the transfer switch, the system cannot interfere with the generator, or vice versa. If the utility power goes down or out of tolerance, the code-compliant inverter immediately shuts itself off and waits for the utility to remain on and in tolerance for 5 minutes before it reconnects itself. The existing UPS and backup generator function to provide standby power during such a grid outage, while the PV system is electrically isolated and also ceases to generate power.

The design team took full advantage of the terrain at the Miramar radar site. The PV array support was engineered to use the natural south-facing slope of the hill on the south side of the radar dome. This minimized the environmental impact of grading. In addition, there is no risk of shading the PV panels because there are no trees, and the tall radar dome is north of the panels.

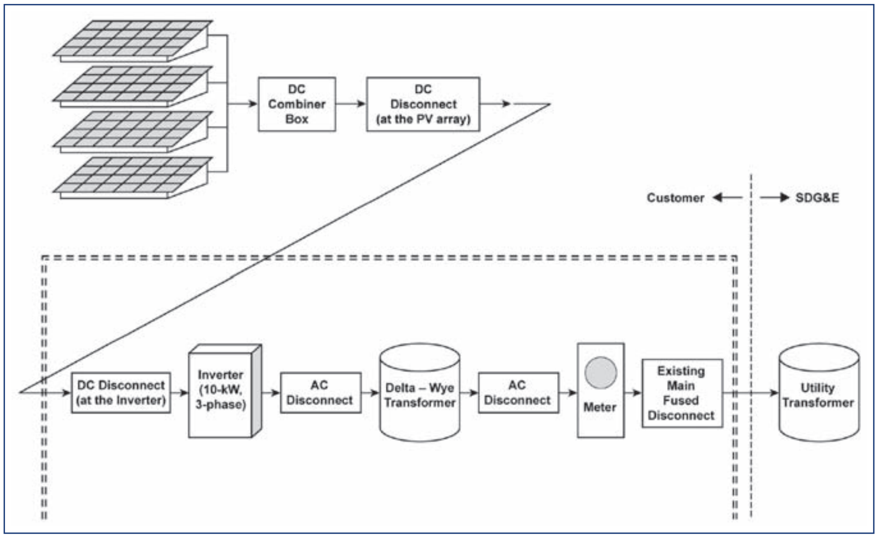

Figure 2. Layout of PV array, switchgear, and balance of system components.

Figure 3. Balance of system components, including switchgear and inverter.

A salient design feature of this system is the panel-mounting scheme, which relies on two 28-ft-long steel I-beams upon which the 2.5-kW solar panels are mounted. The I-beams are mounted onto two concrete footings, one at each end. The standard design routine is to place concrete footings every 4 to 8 feet, not difficult if the ground is flat and fairly even. However, since it was known ahead of time that this 2.5-kW building block would have to adapt to many different landscapes, flexibility was engineered into the mechanics of the system by having only two points of contact with the ground. This allows for versatility in adapting to the varying terrain that may be encountered from one radar site to the next. Furthermore, the I-beams are less expensive than numerous concrete footings. Figure 4 presents an aerial view of the beams, one set with the 2.5-kW solar panel attached.

Because the installation is on a south-facing, downward-sloped hill, the I-beams are also naturally sloped toward the south, thereby permitting the solar panels to be attached flat onto the beams. In a flat-ground installation, the I-beams would simply be oriented east-west and would accept the attachment of a racked assembly of solar panels; the racking system tilts the solar panels upward from the horizontal, toward the south. Using this standardized, but flexible, mounting system helps to control costs in future installations.

Economic Analysis

Three main elements determine the economics of a grid-connected PV system like this one:

- The net installed cost ($)
- The annual energy generation in kilowatt-hours per year (kWhac)
- The value of displaced energy in dollars per kilowatt ac-hour ($/kWhac)

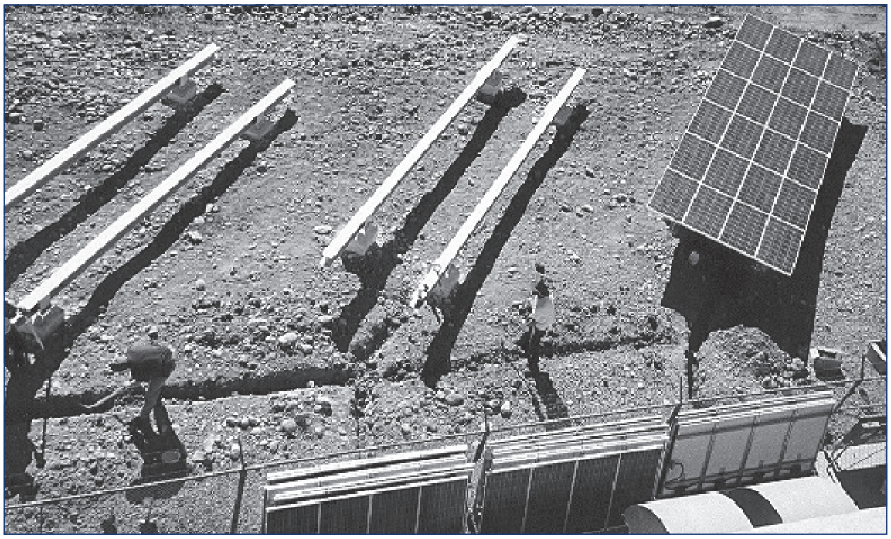

Figure 4. Aerial view of mounting structure showing I-Beams on concrete footings.

The installed or turnkey cost is best expressed in terms of dollars per installed watt ac ($/Wac). The ac rating is derived using the Photovoltaics for Utility-Scale Applications (PVUSA) dc rating for the PV panel provided by the California Energy Commission (CEC), multiplied by the number of panels and the inverter's rating.

The annual energy generated by the system is determined by the available solar radiation incident on the array, the system size in rated Watts ac, and the parasitic losses such as PV panel mismatch, wire resistance, inverter efficiency, transformer efficiency (if applicable), average soiling, and general yearly degradation.

The customer's electric bill determines the value of displaced energy. The cost of energy at the NWS Miramar site at the time of the PV system design and installation was $0.17/kWh. This is a relatively high rate for electricity compared with some federal sites, which makes using alternative energy sources such as PV more cost-effective. Table 1 summarizes the cost parameters affecting the system economics.

During the first year of operation, the system is expected to produce 16,233 kWh of ac electricity at a cost savings of $2760. Although the PV system may reduce the site's peak demand charges, that is not guaranteed. Therefore, demand savings were not considered in this analysis. The overall installed cost of the system was $84,792, not including the cost of engineering and validation, which is a nonrecurring fee for additional future installations using the same design. The CEC awarded a sizable rebate for this project equal to $4.50 per installed Wattac, or $43,380. Considering the rebate, the final turnkey cost of the system was $41,412, about half the usual cost of a similarly sized PV system.

To assess the economics of the project, a life-cycle cost analysis was completed using the Building Life-Cycle Cost (BLCC) software tool. Even considering the substantial CEC rebate and the high costs of energy at the NWS Miramar site, the project is marginally cost-effective. The savings-to-investment ratio (SIR) computed for the project is 0.96; an SIR greater than 1.0 denotes a life-cycle cost-effective project, according to federal regulations specified in 10 CFR 436. The simple payback period is 18 years.

Table 1. Economic analysis parameters and input data.

Description	Input	Result
Module rating at PVUSA test conditions (W_{dc})	105.7	
Number of modules	96	10.147 kW_{dc}
Measured inverter efficiency	0.95	9.640 kW_{ac}
Measured transformer efficiency	0.97	9.351 kW_{ac}
Available sunlight, average daily hours	5.6 hours/day	52.364 kWh/day
Number days/year	365	19,113 kWh/yr
Module mismatch factor	0.97	18,540 kWh/yr
Wire resistance loss factor	0.97	17,984 kWh/yr
Average soiling loss factor	0.94	16,905 kWh/yr
Estimated tare loss of transformer during non-sun hours	-672 kWh/yr	16,233 kWh/yr
Annual degradation factor[a]	0.99/yr	—
Estimated energy savings in year 1		***16,233 kWh***
Facility energy cost at time of case study	$0.17/kWh	—
Total cost of engineering/validation (non-recurring fee)[b]	$1.56/W	$15,000
Total cost of system (supply and build)[c]	$8.80/$W_{ac}$	$84,792
CEC rebate amount[d]	$4.50/$W_{ac}$	-$43,380
Turnkey cost, after rebate[e]	***$4.30/$W_{ac}$***	***$41,412***

[a] Degradation does not impact system performance until year 2 and for all subsequent years over the life of the system; system performance in year 2 is calculated as 0.99 x 16,406 kWh/yr = 16,242 kWh/yr; performance in year 3 is 0.99 x 16,242 kWh/yr = 16,080 kWh/yr; and so on

[b] Design, engineering, and performance validation was funded by the Federal Energy Management Program through the National Renewable Energy Laboratory (one-time fee, not included in economic analysis)

[c] Turnkey price (excluding nonrecurring engineering fees) for complete installation

[d] Actual rebate amount provided by the California Energy Commission (CEC)

[e] This final price excludes nonrecurring engineering fees, because future systems can capitalize on the preexisting nonrecurring engineering and should be lower in price.

However, traditional economics are not the sole determinant in the implementation of alternative energy systems such as PV. Besides simply reducing energy costs, the NWS Miramar system provides additional benefits, such as protecting the environment by reducing emissions, providing a renewable source of energy, preserving natural resources, and reducing dependency on foreign petroleum products—all of which are consistent with both NOAA and DOE missions.

Performance Summary

The system was officially started up on August 6, 2002. To ensure that the system was operating as designed, energy output and peak power output were measured for several months after start-up. BPA supplied a digital watt-hour meter and communications module to monitor the ac energy production of the system. Energy production data (in kWh) and peak power output of the system (in kW) were collected in 15-minute periods and downloaded each night. The data were then analyzed, reduced to daily averages, and charted for comparison. Figure 5 shows the system power and energy production during the monitoring period of August 6, 2002, through October 6, 2002.

The data indicate that the system is operating well within its expected performance range. The data also indicate that the system exceeded expected performance on some days, as demonstrated by the daily peak power exceeding the system-rated power. During the first 25 days of operation, the system actually outperformed expectations by 9.8%, averaging 61.53 kW_{ac} per day from August 7 through August 31, 2002. The expected average daily output for this same period is 56.01 kW_{ac}. Of course, actual performance is influenced predominantly by local weather conditions that can cause fluctuations in solar radiation from day to day and year to year. Actual performance can exceed rated performance when the solar insolation and/or the ambient temperature fall outside the PVUSA standard test conditions (by which the system rated power is calculated). Data collection continues on this project, and system performance can be viewed on the BPA Energy Efficiency web site at www.bpa.gov/Energy/N/tech/eemeteringdata/Federal/index.cfm.

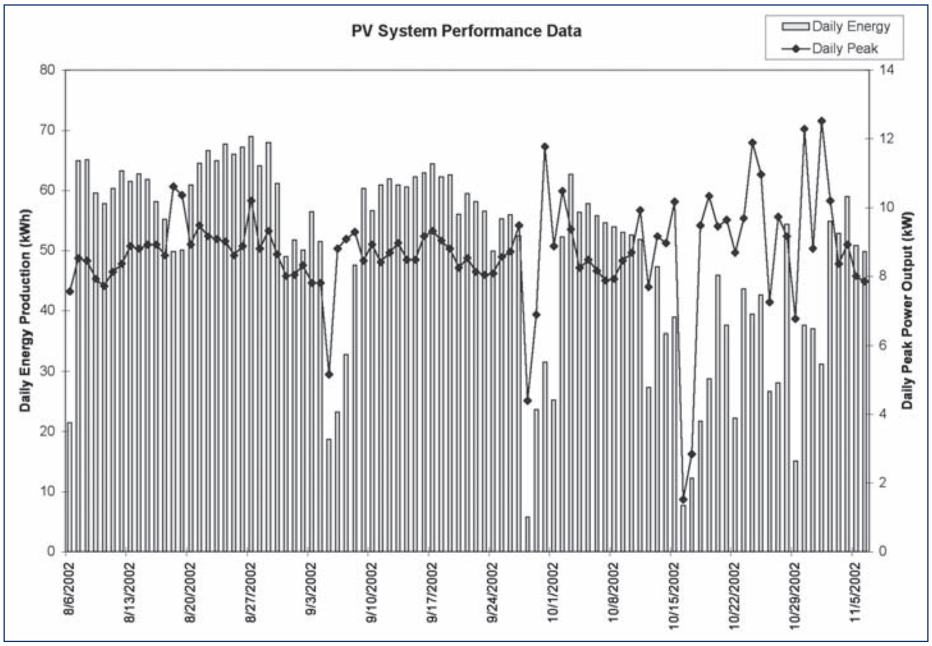

Figure 5. Daily measured PV energy production and peak power.

The value of performance validation of grid-connected PV systems cannot be overemphasized. In off-grid systems, PV system performance can often be judged partly by the performance of other peripheral equipment. For instance, excessive generator run-time or battery usage might suggest the PV array was not performing as expected. However, it can be difficult to know if grid-connected systems are performing as designed without regular data collection and analysis, because the grid acts as a fairly constant and reliable source of backup energy. By continually monitoring system performance, the NWS can be assured that the system is operating as designed and continuing to save energy and costs.

Conclusion

The 10-kW PV system installed at NWS Miramar is providing reliable power with zero emissions. The modular design can be adapted to any environment to match the load requirements of each specific facility in any area of the country. Now that the system design, performance, risk, and execution have been proved, future systems at other NEXRAD sites can be implemented quickly, at low risk, and at a lower installed cost.

The robust, flexible PV system design developed for the NWS can serve as the model for an off-the-shelf system for hundreds of future clone sites. The identical 10-kW system could be installed at any one of the NEXRAD sites, with actual performance depending on site weather conditions. Systems for other sites that use this design approach should be less costly, since most of the nonrecurring engineering can be apportioned to all sites. The 10-kW_{ac} electrical one-line diagram, the mounting details, and the bill of materials (i.e., parts list) already exist; engineering at clone sites will be limited to determining the best orientation/location for the site. Only site-specific drawings will need to be generated.

Even if NWS decides to consider a larger 30-kW system, the modular design approach used in this project can simplify future installations. For example, the PV system design is simplified by the 2.5-kW panel building block template and mounting structure. This modular design approach would also apply to systems larger than 10 kW. For example, the system could be expanded to 30 kW (the peak load of the typical NEXRAD radar site) by extrapolating the current existing 10-kW design. Of course, this approach would incur additional engineering costs, unlike simply replicating the design. But from that point on, the 30-kW design could be considered off-the-shelf and applicable to any site that could accommodate it.

The CEC rebate program vastly enhanced the feasibility of the Miramar pilot project and could be applicable to other PV systems installed in California. Focusing implementation efforts on areas with high electricity costs and rebate programs like the CEC's can target the most near-term cost-effective projects for federal applications. Although renewable energy systems such as PV can provide a host of ancillary benefits beyond just electricity cost reductions, it may be difficult for federal agencies to quantify the value of those benefits. Economics should not be the sole determinant for installing renewable energy systems. However, agencies that can place dollar figures on the reliability or emissions reductions benefits of PV can better justify installing these systems on the basis of cost alone.

Case Study 2: A Combined Building-Integrated Photovoltaic System and Demand Response System at a U.S. Postal Service Facility

Overview

The U.S. Postal Service (USPS) recently implemented a technology demonstration project with the goals of reducing (1) peak demand on the grid, (2) the facility's energy costs, and (3) air pollutant emissions. To meet these objectives, the USPS worked with FEMP to install a PV array and an automated demand-response system (DRS) at the USPS Marina Processing and Distribution Center (P&DC) in Marina del Rey, California. This collaborative project involved Lawrence Berkeley National Laboratory, the Los Angeles Department of Water and Power (LADWP), and private-sector technology providers.

The resulting 127-kW rooftop PV system, the largest federal building-installed PV system in the nation at the time, generates electricity for the Marina P&DC directly from sunlight (Figure 6). The PV system was designed to shave up to 10% off the facility's 1.2-MW peak power demand and save approximately $25,000 per year in utility costs. The DRS was installed to further reduce the peak load for this facility. Implemented as part of a pilot program operated by CEC, it allows building managers to monitor the facility's electrical load in real time and curtail the load when requested to do so by utility system operators or at the discretion of the facility energy managers.

In the first installation of its kind, the PV array and DRS were linked together using a control system known as a solar load controller (SLC). This controller automatically monitors the PV electrical output to ensure that it exceeds a minimum desired threshold during critical periods (e.g., at times of day with high utility tariffs). This case study assesses the first-year performance of the USPS Marina's new PV and DRS.

Background

The Marina P&DC is a mail-handling facility covering 409,390 ft^2 of floor area in west Los Angeles in the LADWP service territory. The facility is highly

Figure 6. USPS Marina Processing & Distribution Center PV Array (G. Marsh, PIX 11015).

automated, operating 24 hours per day, 365 days per year. Historically, this site's daily electricity consumption has been relatively constant. The more than 200,000 ft^2 of flat roof made this site an ideal candidate for a building-installed PV system. The activities in the facility are primarily industrial. Two centrifugal chillers provide space cooling. Economic incentives available at the time of the installation made this project particularly attractive. The CEC funded the entire cost of the DRS. The installed cost of the PV system was approximately $1.03 million. Of this amount, approximately $680,000 was covered by a rebate from LADWP. In addition, FEMP provided a grant to the USPS to cover the remainder of the cost of the project, through the FEMP Distributed Energy Resources call for projects.

Table 2. Marina P&DC PV array characteristics.

Rated Array Capacity[a]	
—Nameplate (DC)	127 kW
—PTC-CEC (DC)	114 kW
—PVUSA simulation (AC)98 kW	
Estimated annual output	154,000 kWh
Surface area	
—Panels only	11,441 ft^2
—Panels plus curbs and walkways	13,618 ft^2
Completion date	**November 2001**
Start of data collection	**May 2002**

[a] Detailed in source report, Monitored Performance of a Building-Integrated Photovoltaic System at a U.S. Postal Service Facility, Appendix A, Lawrence Berkeley National Laboratory (LBL-52687), W. Golove et al.

System Description

PV system. The Marina P&DC PV system is a lightweight building-installed PV roofing assembly installed over an existing roof membrane (Figure 6). Because the roof is flat, the array has a horizontal orientation. The PV panels are bonded to foam insulation board, which provides additional thermal insulation to reduce building heating and cooling loads. A 100-kVA inverter converts the dc output from the PV modules to ac power. Table 2 shows additional system specifications. The estimated annual output is based on simulations performed by PowerLight Corporation, described in more detail below.

DRS. The P&DC DRS was installed as part of a project involving several USPS sites in response to concerns about peak power demand in California. The DRS is a web-based energy-consumption tracking system that collects the facility's energy-consumption data and reports those data over the Internet. In addition, the system allows the facility's electrical load to be reduced in response to a signal sent over the Internet. Technically, the load curtailment signal can be initiated at the site or at a regional USPS office. However, the USPS has a policy that all curtailments will be initiated on site.

Figure 7 shows the DRS network configuration. The DRS hardware consists of a network gateway that integrates load data from the facility's chillers and main meter. A pulse initiator was installed on the existing main utility meter so demand reductions could be verified when requested by the grid operators. Data collected by the gateway are uploaded to a central server daily for quality control and further analysis. The gateway is also able to send control signals to cycle the chillers off when a curtailment is requested. The total price was $1.2 million for 24 sites, or approximately $50,000 per site, paid entirely through a CEC grant.

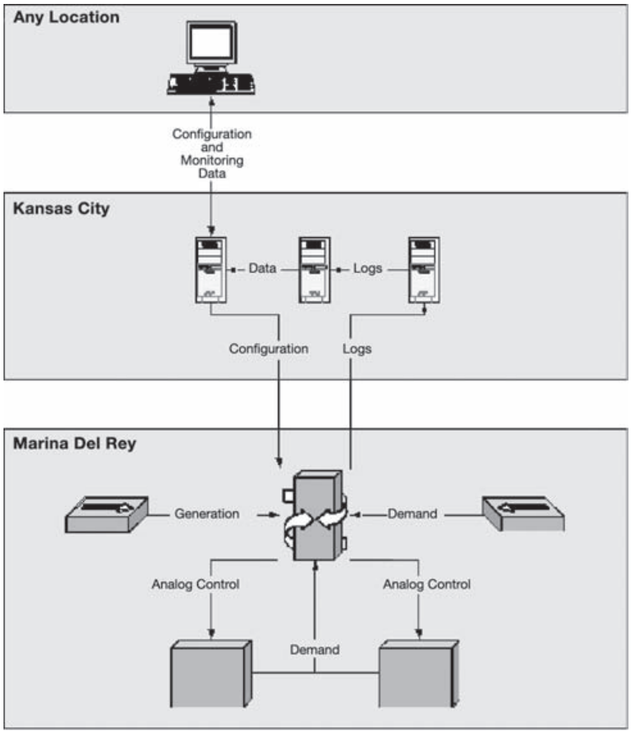

Figure 7. Marina Demand-Response System network configuration.

SLC. The PV array and DRS are linked together using an SLC, which monitors the PV electrical output to ensure that it meets or exceeds a minimum desired threshold during critical periods (e.g., at times of day with high utility tariffs). If the PV system power falls below this threshold, for instance, as a result of cloud cover, the SLC will call upon the DRS to curtail the building load and compensate for the reduced PV output. In this way, the SLC permits the PV to work in tandem with the DRS to provide an "assured" level of load reduction for the local utility grid. Because the power rate paid by the Marina P&DC includes a demand charge, the SLC will also serve to reduce the building's peak load and resulting demand charges.

The SLC is a software application that runs on the metering gateway installed as part of the DRS at the Marina facility (Figure 7). The cost of the DRS includes the SLC cost. The application receives several data inputs, including a utility rate schedule, real-time demand on the controlled devices, and real-time generation of the PV array. The SLC output is the desired demand reduction in kilowatts and a call to the DRS for a load curtailment.

The SLC is divided into two modules: demand reduction and curtailment. The demand reduction module is responsible for determining the appropriate demand reduction in kilowatts if one is needed to compensate for lower PV output. The curtailment module is responsible for achieving the desired demand reduction by selecting an appropriate level of curtailment for the facility's equipment. After obtaining the necessary operating parameters from the configuration files specified by the building's manager, the SLC then executes, once per minute, the control logic shown in Figure 8.

Once the SLC specifies the desired demand reduction, it is then translated into discrete curtailment steps corresponding to the curtailment levels implemented at the facility. The translation uses a simple look-up table. At the USPS Marina facility, there are five steps of curtailment, each corresponding to a percentage of load on the chillers. Table 3 shows the distribution of steps. After the SLC's curtailment module calculates the appropriate curtailment level, it sends an analog (0-20 mA) signal to the chiller's device controllers to implement the curtailment.

Curtailment recovery occurs when the intended curtailment level is less than the one currently implemented. To avoid spikes, the SLC maintains curtailment levels for a specified minimum duration; these can be specified separately for each curtailment level.

As of August 2003, the DRS has been in a monitoring mode, in which facility managers receive alerts from the system and manually curtail load if needed. The SLC was expected to be activated sometime during the fall of 2003 to allow automated curtailments. The USPS hopes to monitor the SLC's performance during its first year of operation to assess it against the agency's technical and financial goals.

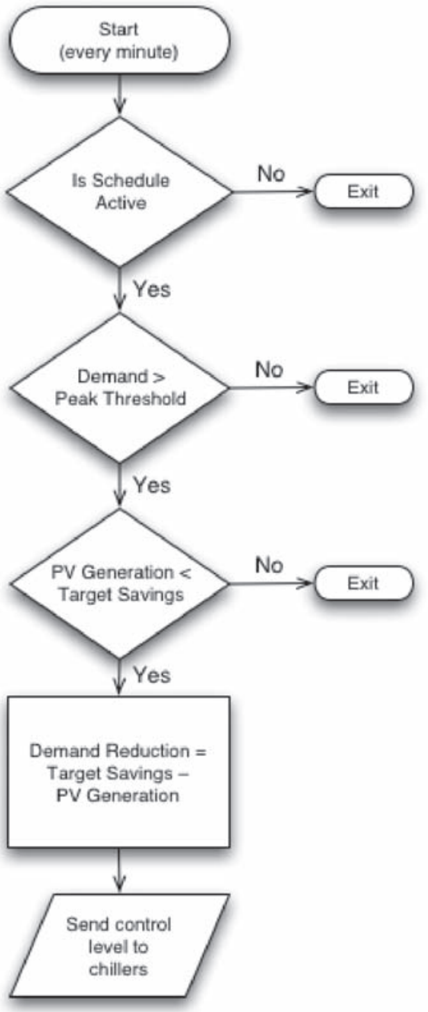

Figure 8. SLC control logic.

Table 3. Chiller curtailment levels.

Curtailment Step	Percentage Chiller Load
0	100%—no curtailment
1	80%
2	65%
3	50%
4	35%
5	0%—full curtailment; chillers shut down

PV System Performance

Two performance benchmarks were used to assess PV system performance: energy generation and peak power production. Data collected by the site's data acquisition system (DAS) were used to determine the level of these energy and demand savings and assess them with respect to actual weather conditions.

Data collection methodology. As part of the PV system installation, PowerLight installed a DAS, consisting of a Campbell Scientific data logger that records ac power (kW), ambient temperature (°C), solar irradiance (W/m^2), and wind speed (m/s). These four parameters allow for the most efficient and accurate benchmarking and evaluation of the system's performance. The data logger is fully programmable, with nonvolatile memory and a battery-backed clock, mounted in a small, rugged, sealed module. The sampling rate is 1 sample per second; average values are recorded every 15 minutes. Data for the 15-minute averaging periods are uploaded nightly to a central server and are available on the web for quality assurance and further analysis. Data on the building load are also logged by the demand management system.

Energy. One of the stated goals for the Marina PV installation was to reduce the facility's energy consumption. To assess how well this goal has been achieved, data for PV electricity production were collected and examined from May 2002 through March 2003 (at the time of publication, a full year's data were not available). The PV array produced 149,000 kWh during this period, shown by month in

Figure 9. When designed, it was estimated that the PV array would produce 154,000 kWh per year or 140,000 kWh during the May–March period. Thus the actual production exceeded estimates by 6%, during a time when the solar insolation [amount of electromagnetic energy (solar radiation) incident on the surface of the earth] was actually 7% lower than the long-term average (upon which the estimates are based). Based on this analysis, it appears that the Marina PV installation is performing very well in terms of energy production.

PV production and facility load. One purpose of this project was to reduce the Marina facility's demand, as seen by the utility, through the use of distributed generation. To assess how well the PV installation achieved this goal, we examined the facility's load profile on the day it registered its maximum peak load on September 6, 2002.

During the period of maximum building load, the PV system reduced the load by approximately 5% (80 kW out of 1730 kW). As mentioned earlier, the PV system was designed to meet about 10% of the facility's peak load. Two factors led to the actual contribution's being lower than originally designed. First, the actual output of the PV array at the time of the facility's peak demand is less than the rated output (because of meteorological conditions at the time of the facility peak, as well as system losses not included in the original system rating). Second, since the installation of the PV system, another building has been added to the Marina P&DC, increasing the facility's peak load by more than 40% (1700 vs. 1200 kW). At its peak output (at noon on July 20, 2002), the PV system met approximately 7% of the facility's original 1200-kW demand.

Another important consideration in reducing peak loads is how well the PV output coincides with both the building's and the utility's load profile. Figure 10 compares the normalized PV output with the building load and the system demand for the California Independent System Operator (CAISO) control area. The values shown have been normalized to the peak daily value for each data series (i.e., PV output is expressed as a percentage of peak PV output for that day). It appears that the peak output of the PV array coincides with the early portion of both the facility and the utility system peak.

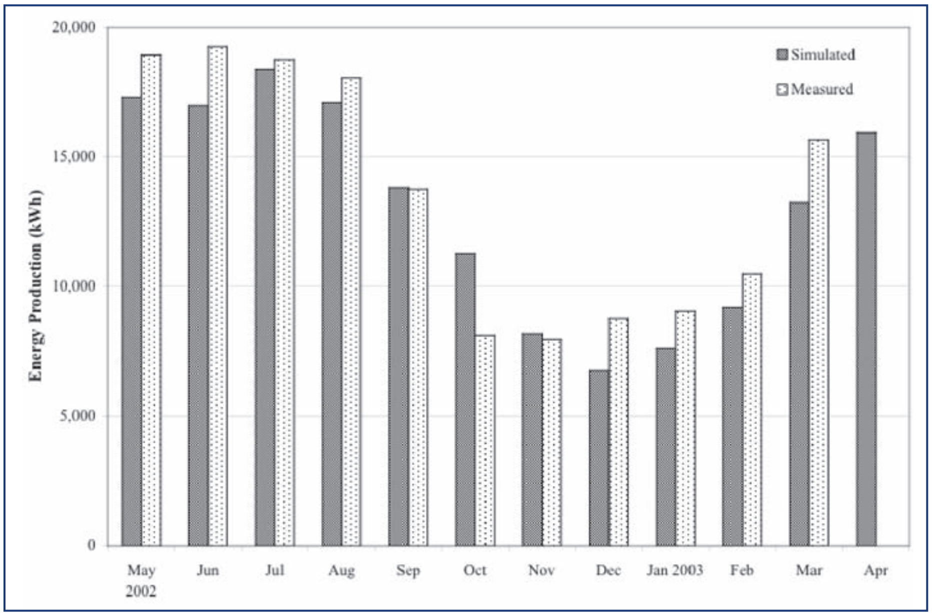

Figure 9. Comparison of estimated and measured energy production at USPS Marina Postal Processing Center. Measurements for April 2003 were not available yet. Actual production exceeded estimated amount by 6% for May–March. Actual production values for October–November may be under-represented because of measurement error (still under investigation).

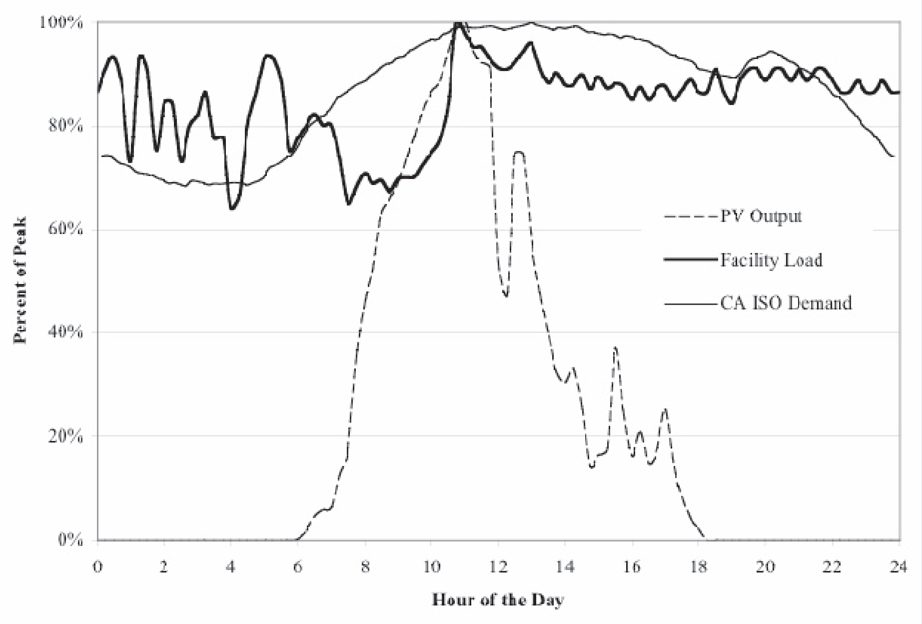

Figure 10. Relative PV performance on facility peak day. Generation and load profiles for Marina PV array, Marina facility load, and CA ISO system demand. Values have been normalized to the daily peak value for each data series. Data shown are for the day with the highest load for the facility, September 6, 2002. Facility load is the end-use load, excluding the effect of PV generation.

To assess how well this PV installation serves to meet the utility system peak, we also made this same comparison for the day with peak demand for the CAISO control area (Figure 11). Again, the PV production appears to peak during the hours when the building load and system demand are at peak values. The figures also show periods of reduced PV output during these peak demand periods, suggesting that the SLC has the potential for significant demand reduction benefits.

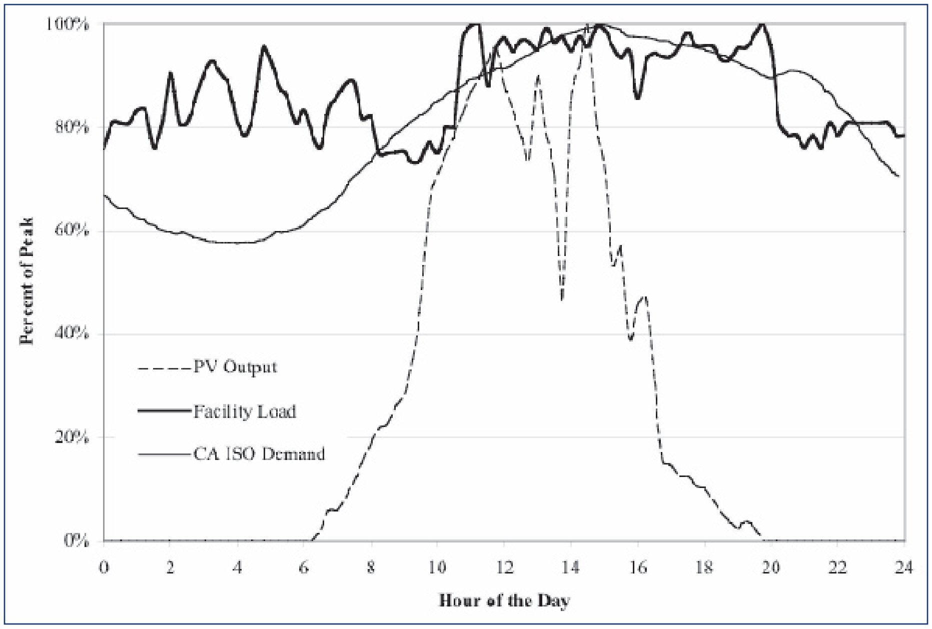

Figure 11. Relative PV performance on utility system peak day. Generation and load profiles for Marina PV array, Marina facility load, and CAISO system demand. Values have been normalized to the daily peak value for each data series. Data shown are for the day with the highest demand for the CAISO control area, July 10, 2002. Facility load is the end-use load, excluding the effect of PV generation.

Conclusion

Based on approximately one year of measured data, the PV system installed on the USPS Marina P&DC seems to be functioning as planned. In terms of energy production, the system produced about 6% more than expected, while its power output during peak solar periods has met or exceeded expectations. During periods of peak demand for the facility, the PV system has met a smaller share of the load than expected, mainly because the facility (and its load) has expanded since the system was originally designed. The PV system's peak output coincides fairly closely with peak demand for the facility and the CAISO utility system.

PV systems are often touted as having the ability to reduce peak loads, because the peak output of the PV system often coincides with the peak demand of the facility on which it is installed. Unfortunately, peak reductions from PV systems are difficult to guarantee because they are so dependent on the weather. Historically, the solution to this problem involved incorporating energy storage into the system to ride through periods of lower solar output. The system design for the Marina P&DC facility, using the DRS and the SLC, has the ability to ensure peak demand savings as a result of the PV installation by controlling building loads based on the PV system's output. To ensure more reliable and predictable energy savings, systems like this may be the wave of the future for PV.

Case Study 3: Offset-Mounted PV for Low-Slope Commercial Roofs

Overview

To research the potential of PV to reduce cooling loads, FEMP, Oak Ridge National Laboratory (ORNL), and other partners established a PV-distributed energy resource (DER) demonstration system at ORNL's Buildings Technology Center (BTC). Performance and energy production of the off-set mounted PV system is continuously monitored and it generates 8.5 kW of peak power. The setup also is being used to study whether the shade that roof-mounted PV systems cast on the roofs of commercial buildings can help reduce the cooling load.

Background

The higher the exterior temperature of a roof, the greater the potential for heat transfer into the building, which in turn increase the burden on the cooling system during warm months. In the winter, the opposite is true: the energy used for heating increases as heat is lost through the roof. By converting solar energy into electricity rather than absorbing it, roof-mounted PV systems have the potential to reduce cooling loads in commercial buildings as they generate power. Data describing the benefit derived from the effect of PV on mitigating cooling loads have been sparse. The objective of this effort is to provide utilities, state and federal agencies, the roofing industry, the solar industry, and the public with field data regarding the benefits of incorporating PV into commercial buildings.

Experimental Facility

The PV system is mounted on the low-slope roof of the Envelope Systems

Research Apparatus (ESRA), an air-conditioned test building at ORNL that is east-west oriented to expose large areas of roof products (Figure 12). The ESRA is used to conduct side-by-side testing of single-ply membrane roofs under the same solar irradiance and climatic conditions. It is sloped at 1/4 in. of rise for every 1/2 in. of run (i.e., 1.2 degrees). Approximately half of the ESRA roof (35 ft by 40 ft) is subdivided into ten sections, each consisting of a metal deck topped by a 1-in.-thick piece of wood fiberboard, a 1/2-in.-thick piece of wood fiberboard, and a mechanically attached membrane. The metal deck is 22-gage, 0.030-in.-thick galvanized steel. The center module of each test lane is instrumented with copper-constantan thermocouples and heat-flux transducers to measure temperature gradients across the roof insulation.

In March 2002, 72 solar panels were offset-mounted atop the membrane-covered test roofs. A second 72-panel array was mounted as an awning shading the south-facing wall of the ESRA (Figure 13). The PV array was oriented facing south for full solar exposure, and the slope from the horizontal was fixed at 30 degrees. The panels are BP Solar model BP MSX120 with dimensions of 39 by 43.6 in. and a rated power of 120 W. The conversion efficiency of the MSX120 rated at ASTM standard test conditions (STC) is 13.5%, based on the active solar cell surface area (ASTM 1996).

The PV system is connected to three ac-dc Sunny Boy SWR 2500U inverters to convert the dc power generated to 3-phase ac. The inverters have a rated peak efficiency of 94.1% and use maximum power-point tracking to feed the maximum power from the PV array to the electric utility grid. Islanding protection is designed into the inverters to detect a utility outage and automatically disconnect the inverters from the grid, thereby protecting line workers troubleshooting the grid. The temperature of the PV panels, the dc current, dc voltage, and dc power are monitored to determine the solid-state conversion efficiency of the PV array. The ac power output and conversion efficiency of the PV array are also used to document the seasonal performance of the system. The BTC's weather station also measures incident solar flux, the air temperature, wind speed, and wind direction for estimating the effects of weather.

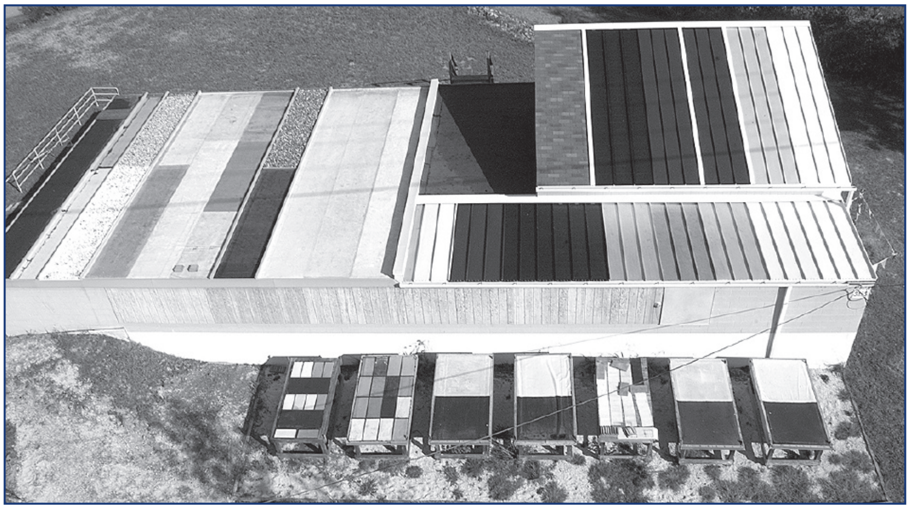

Figure 12. The Envelope Systems Research Apparatus used for testing painted and unpainted metal roofing.

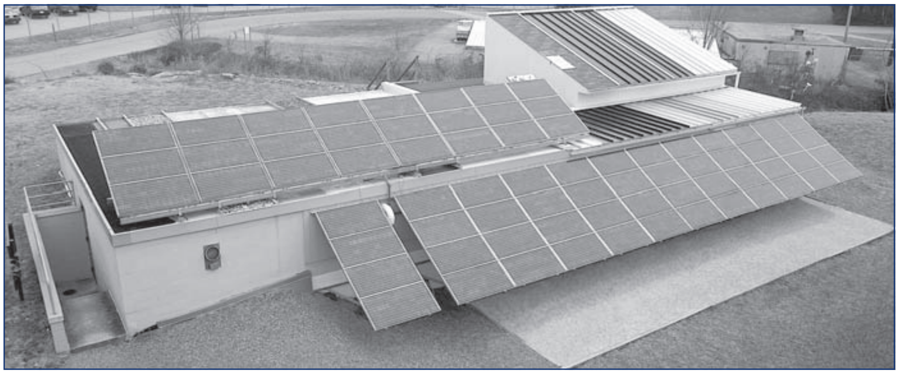

Figure 13. Building-integrated photovoltaic (BIPV)(offset-mounted) installed on the low-slope membrane roof systems and the south-facing wall of the ESRA.

PV Performance

The annual average array efficiency of the PV DER system, calculated by comparing the electrical output with the solar input incident on the panels, was found to be 8.8%. The best conversion efficiency for the ORNL system, about 9.5%, was observed in March through July. Those months have the highest solar irradiance, peaking in June and July.

However, during June and July, the PV panel temperature reaches about 106°F. The temperature of solar cells strongly impacts system efficiency: the output of commonly used panels drops about 4% per 18°F increase in solar cell temperature above 77°F STC (Hendriks and van de Pol 2000). Although April and May had about 15% fewer hours of solar irradiance, the lower panel temperature of 88°F in April and May was more conducive to conversion efficiency. The rated conversion efficiency of the solar panels (13.5% based on the STC) does not consider efficiency losses as the cell temperature exceeds 77°F, dc-to-ac conversion losses, and other balance-of-system losses. For the BTC system, efficiency losses were measured at 8.4% on average for the year. The inverters have an advertised peak efficiency rating of 94.1%. However, on average, about 91.6% of the dc energy produced by the PV was found to be converted to ac energy.

Peak Load Shaving

The PV system was coupled to an existing natural-gas-fired microturbine to demonstrate the interaction of multiple DER equipment items in a microgrid; in this case, the potential to shave the electrical loads for the BTC headquarters was demonstrated. Summer loading for the building peaks at about 50 kW around mid-afternoon. The PV and microturbine supplied roughly 78% of the overall electrical energy used by the building from 8 a.m. to 4 p.m. on August 4, 1999 (Figure 14). The power supplied by the PV and microturbine also shaved 70% off the building's instantaneous peak demand (which occurred at 3 p.m.), reducing demand on the grid and saving the building owner money.

The microturbine consumes about 417,000 Btu/h of natural gas to produce a steady output of 28 kW. The renewable energy generated by the 8.5-kWp PV array and the microturbine is about 64 MWh per year, assuming 2000 hours of turbine operation. The annual load for the BTC headquarters is 184 MWh. Given these inputs, the energy savings delivered by the microgrid (PV with microturbine) is 64,050 kWh/year or 34.7%. ORNL pays only about $0.048 per kWh for electricity. The price of natural gas has fluctuated but at the time of this writing was about $4.50 per decatherm. The cost of natural gas consumed by the microturbine for 2000 hours of operation is roughly $3753. The 64-MWh electrical savings costs only $3075, which includes the renewable energy supplied by the PV system. Therefore, there was no cost benefit compared with utility-supplied electrical energy. However, the system provided electricity during the peak demand period when grid power was most limited and most expensive. It also provided power at mission-critical periods.

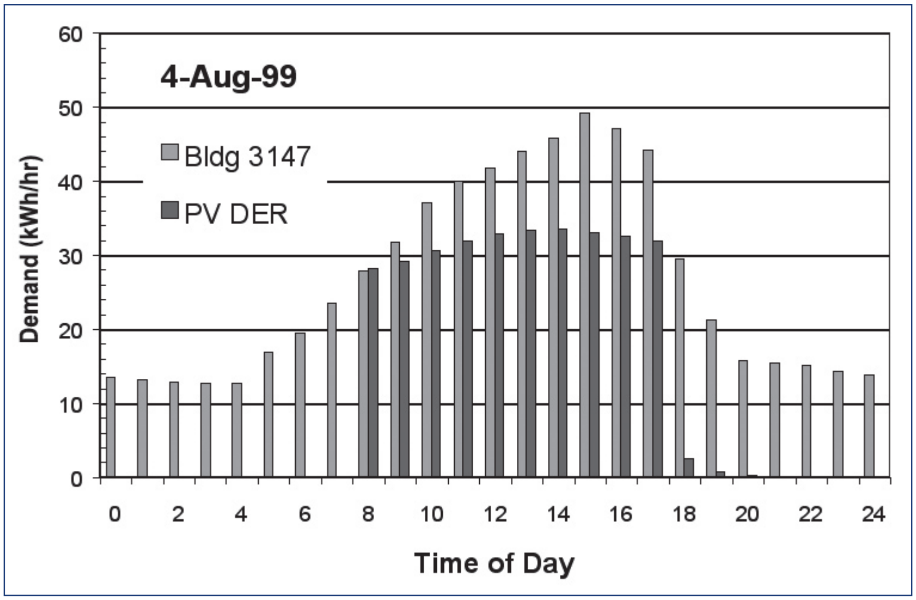

Figure. 14. The PV and microturbine supplied roughly 78% of the overall electrical energy used by the BTC headquarters from 8 a.m. to 4 p.m. on August 4, 1999.

Thermal Performance of Roofs with Offset-Mounted PV

The heat-flux transducers placed in the test roofs helped quantify the indirect shading benefit from the offset-mounted PV system. The ESRA field data for the test built-up roof (BUR) with R-5 insulation shows a significant drop in membrane temperature. Two different summer weeks of data, one with the ESRA fully exposed to solar irradiance and the other with it shaded by the PV, are displayed in Figure 15. Both data sets had clear skies and similar outdoor ambient air temperatures. Shading the dark absorptive BUR reduced the surface temperature by about 60°F at around solar noon (Figure 15), reducing the solar

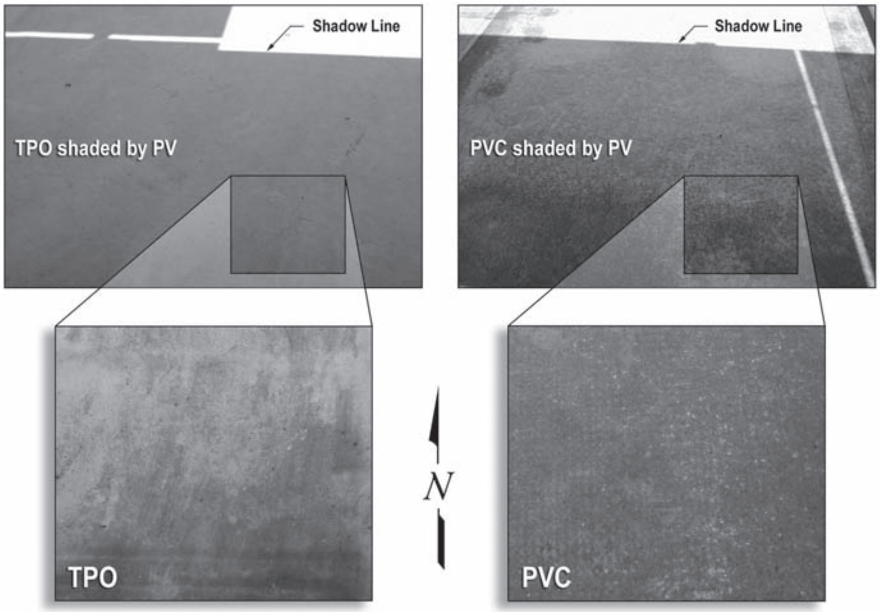

Figure 15. Biomass growth in shaded and fully exposed sections of thermoplastic membranes.

heat gain by a factor of four. The heat flux to the building interior dropped from 20 to about 5 Btu/h•ft^2. The reduction may significantly reduce the building's cooling load. However, the results must be generalized into a rating procedure that accounts for the ranges of roof insulation, of reflectance and emittance typically found on low-slope roofing, and of climates to which commercial roofing is exposed.

Shading Increases Roof Soiling

Exposed thermoplastic membranes in some U.S. climates tend to lose 30-50% of their reflectance over several years because biomass accumulates and attracts airborne contaminants that soil the roofs. The shading provided by the PV array on the ESRA apparently helped the biomass thrive on the roof membranes (Figure 15), as portions of the membranes fully exposed to sunlight did not show the accelerated growth observed on the shaded areas (see inserts in Figure 16). The TPO and PVC membranes had lost 31% and 40% of their initial reflectance, respectively, while fully exposed for 4 years. However, the sections shaded by the PV array lost more than 65% of their reflectance. The accelerated biomass growth does not necessarily affect the thermal performance of the membranes; however, it may pose a health hazard and affect the durability of the materials.

Offset-Mounted PV Computer Simulations

The Simplified Transient Analysis of Roofs (STAR) computer code was used to compare the thermal efficiency of a roof with PV to that of a conventional insulated roof for various U.S. climates. The code models transient one-dimensional heat flow through the exterior roof cover, through multiple layers of roof insulation, and through the supporting subframe. Simulations generated the heat flux entering or leaving the conditioned space for a range of roof radiation properties, insulation levels, and deck constructions. Roof insulation levels ranged from R-5 through R-30 with and without PV for the climates of Phoenix; Long Beach, California; Knoxville, Tennessee; Seattle; and Minneapolis.

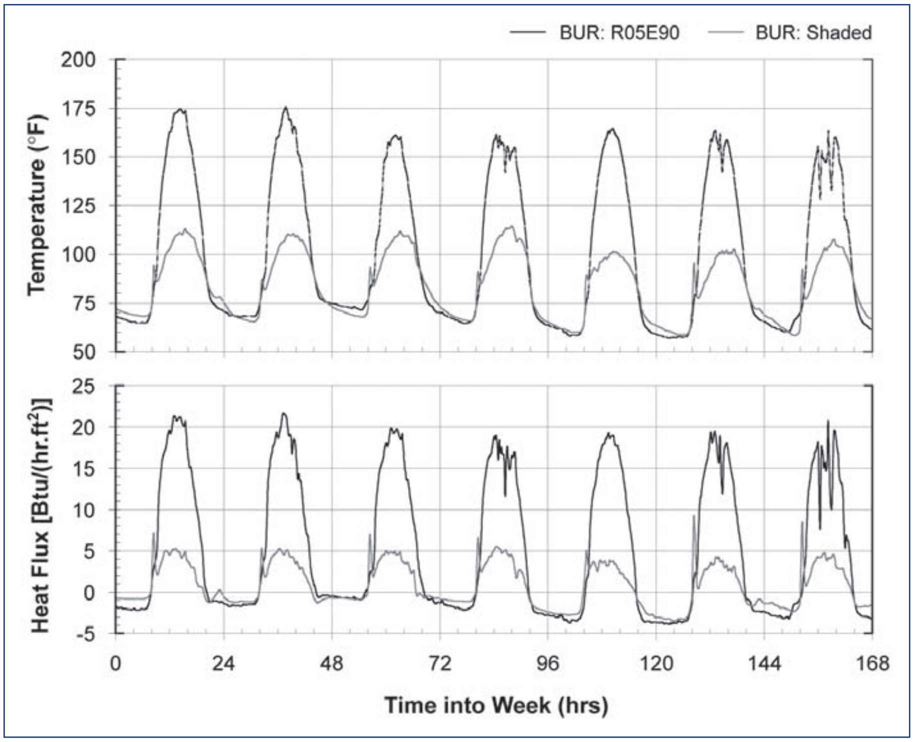

Figure 16. ESRA field data for a fully exposed BUR and the same BUR shaded by BIPV.

Simulations were run for TPO (R87E93)[1] and PVC (R81E94) thermoplastic membranes, a white painted PVDF metal (R64E83), and a dark BUR (R05E90). Modeled cooling load savings are shown for Phoenix in relation to the level of roof insulation (Figure 17). Savings are based on the difference in cooling load between a roof with PV and the same roof fully exposed to the elements. The ancillary shading is greatest for a dark, absorptive BUR. The trends were similar for a white painted metal roof with PV, but the benefit was less because the more reflective painted metal performs better thermally than an exposed dark BUR. Offset-mounted PV on a BUR with R-5 insulation saves about 16,000 Btu/ft^2 because the shading drops the surface temperature to just above the outdoor ambient temperature. Based on ASHRAE Standard 90.1 (1999), the minimum insulation level for nonresidential, low-slope roofing in Phoenix is R-15, and the annual savings for an R-15 BUR with PV is about 4000 Btu/ft^2 of shaded roof. Therefore, realistic cooling savings range from 4000 to 8000 Btu/ft^2 of shaded roof (R-15 and R-10 roofs, respectively) in Phoenix.

For the TPO and PVC membranes, offset-mounted PV actually increased the heat penetrating into an Arizona roof. Increasing the insulation lessened the penalty (Figure 17); however, the results indicate that placing PV on an existing highly reflective roof increases the cooling load because of heat transfer between the PV panels and the roof.

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[1] Each roof is described generically using an RxxEyy designation. Rxx states the solar reflectance of a new sample, 1.0 being a perfect reflector. Eyy defines the infrared emittance of the new sample, 1.0 being blackbody radiation. For example, the built-up roof is labeled R05E90. Its surface properties are therefore 0.05-reflectance and 0.90-emittance.

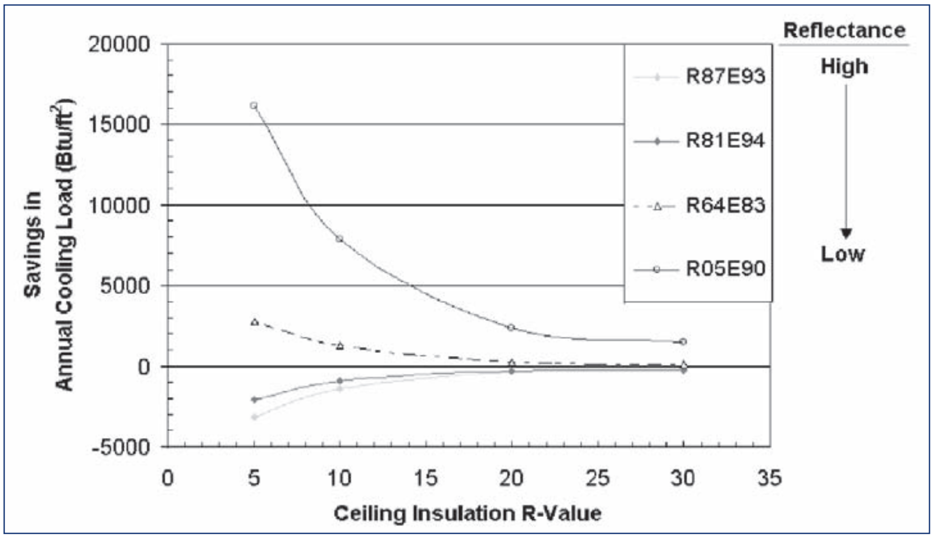

Figure. 17. Annual cooling load savings with offset-mounted PV array, Phoenix, Arizona.

At solar noon for August in Knoxville, the PV panels would reach an underside temperature of about 155°F. An exposed thermoplastic membrane would reflect roughly 80% of the incident solar irradiance and much of the infrared heat back to the sky. The heat gain resulting from the PV panels exceeds their shading benefit. The results imply that a roof designed according to new energy-efficient building codes would deliver less benefit from PV than existing building stock with less insulation and lower reflectance.

Attaching laminated PV (R26E90) directly to a reflective membrane caused an even greater penalty. The membranes are about 85% reflective; the laminate PV, only about 26%. The lower reflectance increased solar absorptance, and the 5% conversion efficiency for the PV laminate did not compensate for the increased solar flux. Placing the laminate on a thermoplastic membrane roof in Phoenix would cause the energy transfer from the roof to increase by 5000 Btu/ft^2 for insulation levels above R-20.[2]

In mostly heating climates, reflective membranes are not preferred because they reflect solar energy that would help heat the building during the winter, causing an energy penalty that exceeds cooling savings in the summer. However, according to the simulation results, PV placed on an existing reflective roof cover in a cold climate would reduce the heating burden because of the radiosity exchange between the PV and the roof and because the panels limit nighttime radiation losses from the roof.

In the predominantly heating climate of Minneapolis, the shading effect from placing offset-mounted PV onto a BUR increased the building's heating demand compared with a fully exposed BUR (Figure 18). Therefore, in heating climates, laminate PV should be used instead of a PV array offset from the roof. Simulations conducted for a PV laminate (R26E90) showed no annual net penalty in building load; hence, direct laminate is well suited to PV installations in heating climates.

The model predicts significant net annual savings for offset-mounted PV in Phoenix, Knoxville, and Long Beach (Figure 19) and energy penalties for the climates of Minneapolis and Seattle. Energy savings are predicted to drop exponentially as the roof insulation increases from R-5 through R-30 (Figure 19). Natural gas prices are roughly $6.70 per decatherm, and electricity costs about $0.08 per kWh in Phoenix. For these fuel prices and the energy savings of Figure 19, the predicted annual cost savings per square foot of low-slope roof using roof-mounted, offset PV arrays could be as high as $0.18 in that city. For the more moderate climate of Knoxville, Tennessee, the savings would be about $0.06 per square foot per year.

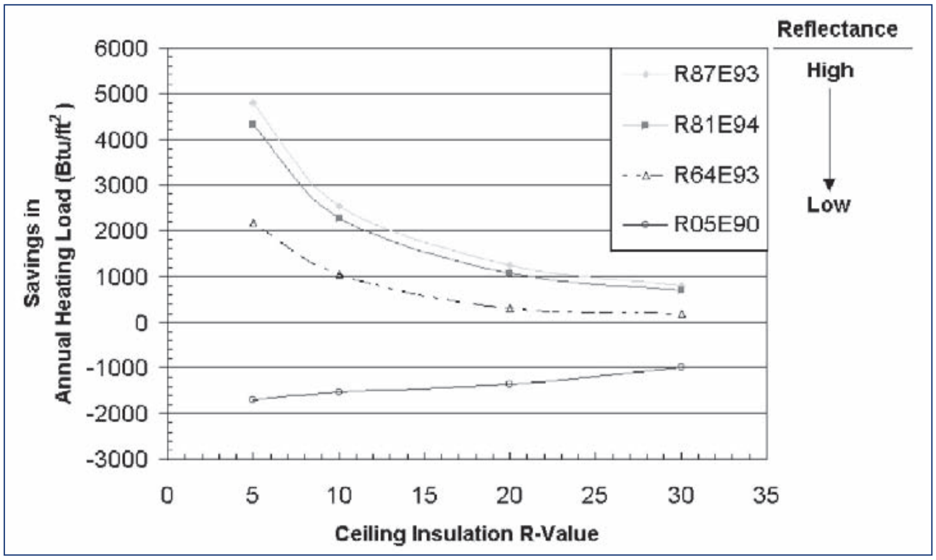

Figure. 18. Annual heating load savings with offset-mounted PV.

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[2] R-20 represents about 5 in. of expanded polystyrene insulation.

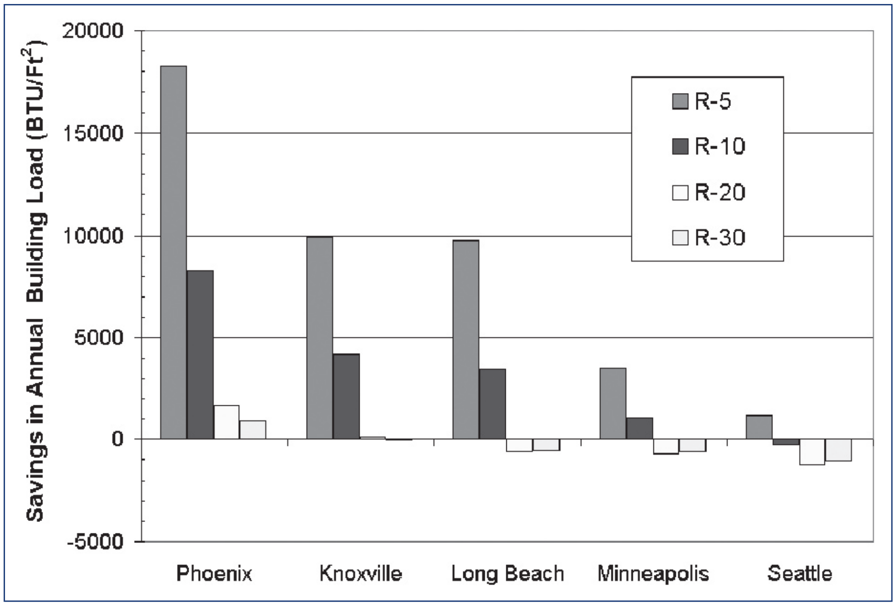

Figure 19. Annual building load savings with offset-mounted PV on a BUR (R05E90).

Summary

Data from this study show that shading from an offset-mounted PV system drops roof temperature to only about 5°F warmer than the outdoor air temperature. Based on these results, a PV system installed on a built-up low-slope roof system in Phoenix can provide space-cooling savings as high as $0.18 per square foot of roof area per year. Almost 70% of new and existing low-slope commercial roofing in the western United States is finished in dark roofing. Placing offset-mounted PV on such a roof in a mostly cooling climate can significantly reduce roof energy loss. However, a similar system on a highly reflective thermoplastic membrane results in an energy penalty in cooling climates. Adding laminate PV, which is less reflective, exacerbates the penalty; even with R-20 insulation, the net energy load increases by 5000 Btu/ft^2 per year compared with exposed reflective membranes.

In predominantly heating climates, offset-mounted PV on a BUR increases the energy load for insulation levels from R-5 through R-30. In Minneapolis, laminate PV would supply renewable energy without an energy penalty on an annual basis because the heating-load penalty matches the cooling-load benefit of the 26% reflective laminate.

Conclusion

Effective use of PV technology can help the federal sector meet its goals of reducing energy consumption and expanding the use of renewable energy in the federal sector. PV systems like those discussed in this report may help federal facilities integrate PV into their energy mix.

This review examined some of the costs and benefits of PV systems and associated technologies for federal facilities. Potential benefits of installing PV systems at federal facilities include these:

- Reliability—they operate for long periods with little maintenance.
- Low operating costs—the fuel is free, and there are few, if any, moving parts.
- Low environmental impact—they are quiet and nonpolluting (no greenhouse gas emissions) and require no air permitting.
- Standalone capability—they can operate in remote areas far from power lines.
- Modularity—power output can be increased by adding more panels.
- Safety—they are not flammable and meet National Electric Code requirements.
- Versatility—they operate well in almost any climate.
- Ease of installation—no heavy construction equipment is required.
- Grid support—they provide energy security in areas where electricity shortages are anticipated.

In addition, as is discussed in the case studies, roof-mounted PV systems provide shade for roofs and so may reduce solar heat gain and the resulting extra cooling required during the summer. At facilities where electricity demand is increasing, installing PV to handle the growth may be less costly than expanding existing electrical distribution equipment. In most of the country, peak electrical demand occurs during the sunniest times of the day, which is when PV energy production is at its peak. PV can be used to offset demand during those hours, reducing the stress on the utility grid and avoiding extra cost for power purchased during peak demand periods.

Although most cost-effective PV installations in the past were for remote, off-grid power applications, current installations include high-value grid-connected applications that provide reliable power, reduce energy consumption and costs, and reduce harmful emissions. The systems included in the case studies for this technology focus are all grid-connected. The economic analyses conducted for these projects indicate that grid-connected PV systems are not likely to meet traditional cost-effectiveness criteria (e.g., brief payback periods) if only energy cost savings are considered. For example, a life-cycle cost analysis of the PV system at the NEXRAD facility in Miramar indicated that even with a substantial rebate from the local utility and above-average electricity rates, the project was marginally cost-effective in traditional economic terms. The simple payback period for the project is 18 years.

However, economics is not the only factor to consider in determining whether to implement renewable energy systems such as PV. Besides reducing energy costs, PV may provide significant security, operational, and environmental benefits such as reducing harmful emissions from power plants, reducing demand on the electrical grid, enhancing energy reliability and security, and aiding the development of renewable sources of energy. Agencies that can place a dollar value on benefits such as those will be better able to justify installing these systems on the basis of cost.

Still, capital cost remains a major challenge to widespread implementation. Although the cost of PV panels has dropped to less than $6 per watt (compared with $100 per watt 30 years ago), making use of rebate programs and identifying ancillary benefits from PV systems are crucial to finding cost-effective applications. Some ways to improve the economics of PV systems include

- Recognizing and valuing the ancillary benefits of PV installations, such as reduced emissions or more reliable power
- Integrating PV into the building itself, for example, installing a PV system during a regular roof replacement or considering a PV carport when new covered parking is needed so building material costs are offset
- Obtaining rebates for PV systems (available only in some parts of the country) to reduce the capital costs
- Using federal financing mechanisms such as energy savings performance contracts to reduce the initial cost of grid-connected PV systems

As PV costs continue to decrease, utility costs continue to increase, and it becomes easier to procure and install PV systems, PV should become more accessible and more economically feasible for federal facilities.

Two existing grid-connected PV installations that supply power to federal facilities—a 10-kW ground-mounted system for the NEXRAD radar system at the NWS Miramar facility and a 127-kW rooftop system at the USPS Marina Processing and Distribution Center—were described, as well as a grid-connected PV system at ORNL that was installed for research purposes.

Results from the case studies show that all three systems met or exceeded performance expectations in terms of operating efficiency and power output. Data collected for the USPS system comparing PV output with the facility's load profile showed that PV production peaks during the hours when the facility's power requirements and demand on the utility system are also at a peak, indicating that PV can be useful in helping facilities alleviate stress on the utility grid and avoid extra costs that many utilities charge for power purchased during peak periods.

One of the purposes of the system installed at ORNL was to assess whether the shading on a roof from offset-mounted PV panels reduces heat gain from the roof and thus trims cooling energy use during hot weather. The results show that the benefit depends upon the type of roof covering, the amount of roof insulation installed, and the climate of the area. The shading benefit is greatest for dark built-up roofs that absorb large amounts of heat. The less insulation the roof has, the greater the energy savings due to the shading. For highly reflective membranes that reflect most solar energy back to the sky, however, offset-mounted PV actually increases energy consumption because the energy penalty from heat transfer between the panels and the roof exceeds the shading benefit. In colder climates, the shading effect of offset-mounted PV panels generally resulted in higher demand for heating in the winter that exceeded cooling savings in the summer. Overall, modeling results indicate that the shading provided by offset-mounted PV offers significant energy savings in predominantly cooling regions and energy penalties in predominantly heating climates.

Beyond simply describing the PV and related technologies involved in these installations, the case studies provided insight into the potential sources of benefits associated with them. The first and most obvious benefit is the financial savings from reduced utility charges. Generally, it can be broken down into two components, reduced energy charges and reduced demand charges. The future value of the lower energy charges is relatively easy to forecast. However, reduced demand charges, although potentially of greater magnitude, are less predictable and currently less manageable. PV system output cannot be reliably controlled and can vary from minute to minute; therefore, although particular PV systems have been shown to reduce peak demand, the reductions are not dependable. The USPS case study describes one approach, the use of a solar load controller that is being used to increase the manageability and predictability of reduced demand charges. If successful, this type of system could be used in future PV installations to help ensure the reliability of peak demand reductions.

As described in the ORNL case study, recent research indicates potential additional savings associated with rooftop PV systems in particular—utility cost reductions resulting from the shading provided by the PV systems.

In addition to the energy and cost saving benefits, these case studies highlight ancillary benefits associated with PV systems, such as reducing the air pollution associated with conventional electricity generation, and preserving natural resources. These are all of tremendous social significance and are consistent with the goals and objectives of the federal government. PV systems can also make important contributions to reducing peak energy demand across local and regional grids. Given the cost of peak power and the value of electricity reliability in many parts of the country, this benefit is significant. And simply diversifying the mix of energy generation at federal facilities can enhance homeland security.

There are, however, limits to the benefits of PV systems that should be recognized. All the systems described in this document benefited greatly from subsidies from outside organizations; without the subsidies, the costs of these systems would have outweighed their economic benefits. In most parts of the country, no subsidies are available; without them, the life-cycle cost of these systems may not be attractive. Further, utility rates in California, where the NWS and USPS systems are located, are among the highest in the country, which further contributed to the economic attractiveness of these systems. PV remains expensive, and locations with high utility rates and subsidies are good geographic targets that can result in the most cost-effective systems. Agencies that can place dollar figures on the reliability or emissions reductions benefits of PV can also better justify installing these systems based on economics. Finally, uncertainty surrounding demand reduction benefits can further reduce PV's appeal. Those limitations notwithstanding, the case studies presented in this document clearly illustrate instances where PV installations have proved beneficial to federal agencies. As the price of PV systems goes down and as better control over the peak reduction benefits is achieved, PV technologies will continue to increase their contribution to our national energy systems.

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