Building-Integrated Photovoltaic Designs for Commercial and Institutional Structures

A Sourcebook for Architects

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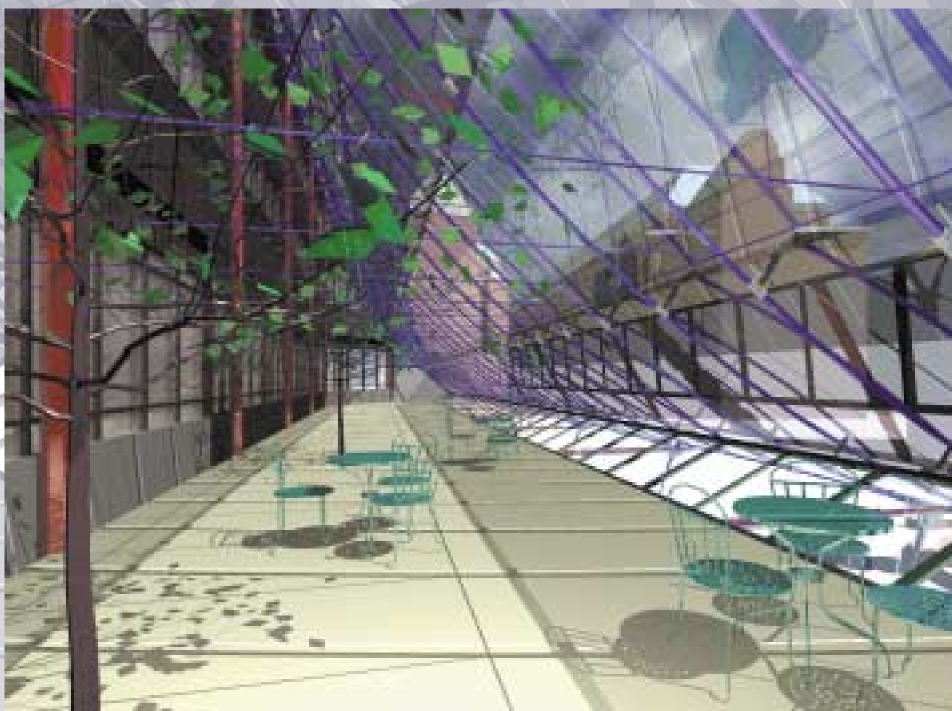

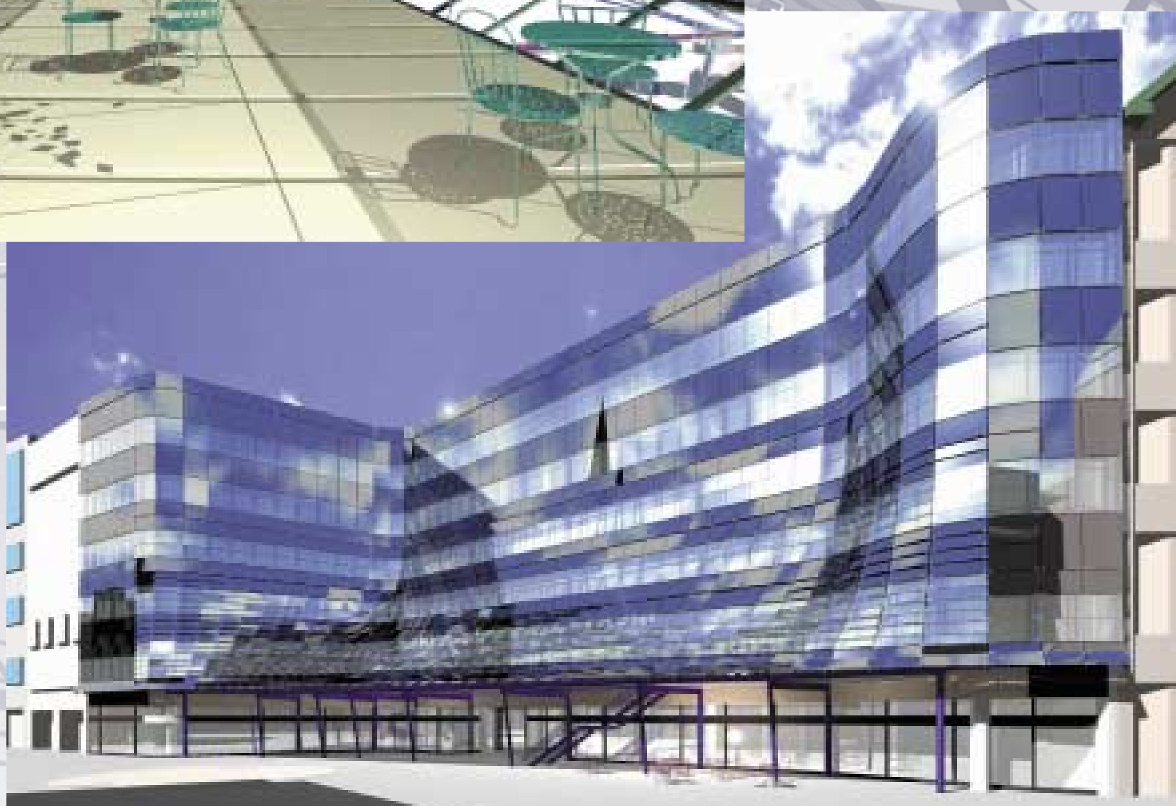

Acknowledgements

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On the cover: Architect's rendering of the HEW Customer Center in Hamburg, Germany, showing how a new skin of photovoltaic panels is to be draped over its facade and forecourt (architects: Kiss + Carthcart, New York, and Sommer & Partner, Berlin).

Contents

Introduction

Building-integrated photovoltaic (BIPV) electric power systems not only produce electricity, they are also part of the building. For example, a BIPV skylight is an integral component of the building envelope as well as a solar electric energy system that generates electricity for the building. These solar systems are thus multifunctional construction materials.

The standard element of a BIPV system is the PV module. Individual solar cells are interconnected and encapsulated on various materials to form a module. Modules are strung together in an electrical series with cables and wires to form a PV array. Direct or diffuse light (usually sunlight) shining on the solar cells induces the photovoltaic effect, generating unregulated DC electric power. This DC power can be used, stored in a battery system, or fed into an inverter that transforms and synchronizes the power into AC electricity. The electricity can be used in the building or exported to a utility company through a grid interconnection.

A wide variety of BIPV systems are available in today's markets. Most of them can be grouped into two main categories: facade systems and roofing systems. Facade systems include curtain wall products, spandrel panels, and glazings. Roofing systems include tiles, shingles, standing seam products, and skylights. This sourcebook illustrates how PV modules can be designed as aesthetically integrated building components (such as awnings) and as entire structures (such as bus shelters). BIPV is sometimes the optimal method of installing renewable energy systems in urban, built-up areas where undeveloped land is both scarce and expensive.

The fundamental first step in any BIPV application is to maximize energy efficiency within the building's energy demand or load. This way, the entire energy system can be optimized. Holistically designed BIPV systems will reduce a building's energy demand from the electric utility grid while generating electricity on site and performing as the weathering skin of the building. Roof and wall systems can provide R-value to diminish undesired thermal transference. Windows, skylights, and facade shelves can be designed to increase daylighting opportunities in interior spaces. PV awnings can be designed to reduce unwanted glare and heat gain. This integrated approach, which brings together energy conservation, energy efficiency, building envelope design, and PV technology and placement, maximizes energy savings and makes the most of opportunities to use BIPV systems.

It is noteworthy that half the BIPV systems described in this book are on Federal buildings. This is not surprising, however, when we consider these factors: (1) the U.S. government, with more than half a million facilities, is the largest energy consumer in the world, and (2) the U.S. Department of Energy (DOE) has been directed to lead Federal agencies in an aggressive effort to meet the government's energy-efficiency goals. DOE does this by helping Federal energy managers identify and purchase the best energy-saving products available, by working to increase the number and quality of energy projects, and by facilitating effective project partnerships among agencies, utilities, the private sector, and the states.

Because it owns or operates so many facilities, the U.S. government has an enormous number of opportunities to save energy and reduce energy costs. Therefore, the Federal Energy Management Program (FEMP) in DOE has been directed to help agencies reduce energy costs, increase their energy efficiency, use more renewable energy, and conserve water. FEMP's three major work areas are (1) project financing; (2) technical guidance and assistance; and (3) planning, reporting, and evaluation.

To help agencies reach their energy-reduction goals, FEMP's SAVEnergy Audit Program identifies cost-effective energy efficiency, renewable energy, and water conservation measures that can be obtained either through Federal agency appropriations or alternative financing. FEMP's national, technology-specific performance contracts help implement cutting-edge solar and other renewable energy technologies. In addition, FEMP trains facility managers and showcases cost-effective applications. FEMP staff also identify Federal market opportunities and work with procurement organizations to help them aggregate purchases, reduce costs, and expand markets.

All these activities ultimately benefit the nation by reducing building energy costs, saving taxpayers money, and leveraging program funding. FEMP's activities also serve to expand the marketplace for new energy-efficiency and renewable energy technologies, reduce pollution, promote environmentally sound building design and operation, and set a good example for state and local governments and the private sector.

This sourcebook presents several design briefs that illustrate how BIPV products can be integrated successfully into a number of structures. It also contains some basic information about BIPV and related product development in the United States, descriptions of some of the major software design tools, an overview of international activities related to BIPV, and a bibliography of pertinent literature.

The primary intent of this sourcebook is to provide architects and designers with useful information on BIPV systems in the enclosed design briefs. Each brief provides specific technical data about the BIPV system used, including the system's size, weight, and efficiency as well as number of inverters required for it. This is followed by photographs and drawings of the systems along with general system descriptions, special design considerations, and mounting attachment details.

As more and more architects and designers gain experience in integrating photovoltaic systems into the built environment, this relatively new technology will begin to blend almost invisibly into the nation's urban and rural landscapes. This will happen as BIPV continues to demonstrate a commercially preferable, environmentally benign, aesthetically pleasing way of generating electricity for commercial, institutional, and many other kinds of buildings.

4 Times Square

Location:	Broadway and 42nd Street, New York City, New York
Owner:	Durst Corporation
Date Completed:	September 1999
Architect & Designer:	Fox & Fowle Architects, building architects; Kiss + Cathcart Architects, PV system designers
PV Structural Engineers:	FTL/Happold
Electrical Engineers:	Engineers NY
Tradesmen Required:	PV glazing done by shop labor at curtain wall fabricator
Applicable Building Codes:	New York City Building Code
Applicable Electric Codes:	New York City Electrical Code and National Electric Code
PV Product:	Custom-sized BIPV glass laminate
Size:	14 kWp
Projected System Electrical Output:	13,800 kWh/yr
Gross PV Surface Area:	3,095 ft^2
PV Weight:	13.5 lb/ft^2
PV Cell Type:	Amorphous silicon
PV Module Efficiency:	6%
PV Module Manufacturer:	Energy Photovotaics, Inc.
Inverter Number and Size:	Three inverters; two 6 kW (Omnion Corp.), one 4 kW (Trace Engineering)
Inverter Manufacturers:	Omnion Corp. and Trace Engineering
Interconnection:	Utility-Grid-Connected

Kiss + Cathcart, Architects/PIX08458

Close-up view of curtain wall illustrates that BIPV panels (dark panels) can be mounted in exactly the same way as conventional glazing (lighter panels).

Description

The tallest skyscraper built in New York City in the 1990s, this 48-story office tower at Broadway and 42nd Street is a somewhat unusual but impressive way to demonstrate "green" technologies. Its developers, the Durst Organization, want to show that a wide range of healthy building and energy efficiency strategies can and should be incorporated into real estate practices.

Kiss + Cathcart, Architects, are consultants for the building tower's state-of-the-art, thin-film BIPV system. Working in collaboration with Fox and Fowle, architects for the base building, Kiss + Cathcart have designed the BIPV system to function as an integral part of the tower's curtain wall. This dual use makes it one of the most economical solar arrays ever installed in an urban area. Energy Photovoltaics of Princeton, New Jersey, developed the custom PV modules to meet rigorous aesthetic, structural, and electrical criteria.

Traditionally, solar technologies have been considered economical only in remote areas far from power grids or in areas with an unusually high amount of sunlight. Advances in PV efficiency are overturning these assumptions, allowing solar electricity to be generated cost-effectively even in the heart of the city. In fact, PV is the most practical means of generating renewable electricity in an urban environment. Further, BIPV can be directly substituted for other cladding materials, at a lower material cost than the stone and metal it replaces. As the first major commercial application of BIPV in the United States, 4 Times Square points the way to large-scale production of solar electricity at the point of greatest use. The next major market for PV may well be cities like New York that have both high electricity costs and high-quality buildings.

Special Design Considerations

The south and east facades of the 37th through the 43rd floor were designated as the sites for the photovoltaic "skin." BIPV was incorporated into the design after the tower's general appearance had already been decided upon, so the

Kiss + Cathcart, Architects/PIX06457

BIPV panels have been integrated into the curtain wall instead of conventional glass spandrel panels on the 37th through the 43rd floor.

Kiss + Cathcart, Architects/PIX08460

The custom-made BIPV panels are visible in this sidewalk view from Broadway.

installation was made to harmonize with the established design concept.

PV System Configuration

The PV modules replace conventional spandrel glass in the south and east facades. There are four different sizes of modules, and they correspond to the spandrel sizes established earlier in the design process.

PV Module Mounting and Attachment Details

The PV modules are attached to the building structure in exactly the same way that standard glass is attached. The glass units are attached with structural silicone adhesive around the back edge to an aluminum frame. An additional silicone bead is inserted between the edges of adjacent panels as a water seal.

There is a separate electrical system for each facade. Each system consists of two subsystems, feeding two 6-kW inverters and one 4-kW inverter. The larger inverters serve the two large-sized PV modules, which have electrical characteristics that are different from those of the smaller ones. Using multiple inverters enables the system to perform more efficiently. The inverters are located in a single electrical closet at the core of the building. The AC output of the inverters is transformed from 120 V to 480 V before being fed into the main electrical riser.

Kiss + Cathcart, Architects/PIX06458

4 Times Square during construction

Thoreau Center for Sustainability

Presidio National Park, Building 1016

Location:	Presidio National Park, Building 1016, San Francisco, California
Owner:	U.S. Department of Interior, National Park Service
Date Completed:	May 1996
Architect & Designer:	Tanner, Leddy, Maytum, Stacy
Structural and Electrical Engineers:	Equity Builders
Tradesmen Required:	Glaziers
Applicable Building Codes:	California structural and seismic codes
Applicable Electric Codes:	National Electric Code
PV Product:	Roof-integrated, translucent glass-laminate skylight
Size:	1.25 kWp
Projected System Electrical Output:	716.4 kWh/yr/AC
Gross PV Surface Area:	215 ft^2
PV Weight:	8 lb/ft^2
PV Cell Type:	Polycrystalline silicon
PV Efficiency:	11% cell, 7% module
PV Module Manufacturer:	Solar Building Systems, Atlantis Energy
Inverter Size:	4 kW
Inverter Manufacturer and Model:	Trace Engineering Model 4048
Interconnection:	Utility-Grid-Connected

The first application for integrating photovoltaics into a Federal building is the skylighted entryway of the Thoreau Center in Presidio National Park.

Atlantis Energy, Inc./PIX04779

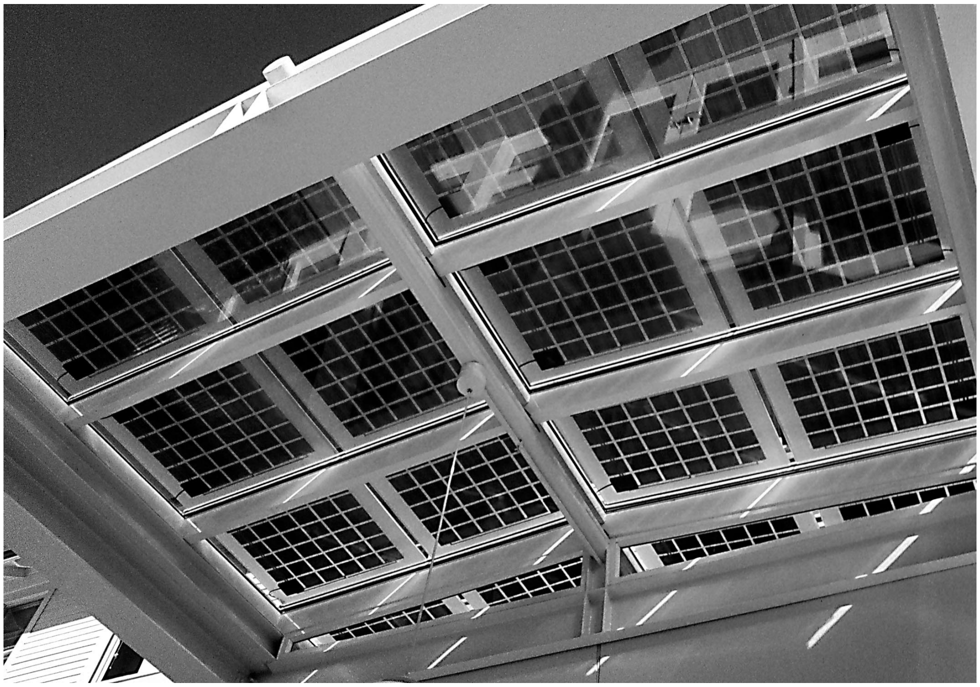
Description

The *Greening of the Presidio* demonstrates the impact of successful partnerships between the private and public sector. The Thoreau Center for Sustainability is a historic building, located in the National Historic Landmark District of the Presidio in San Francisco, California. The goal of transforming this historic building into an environmentally responsive structure produced an opportunity to apply principles of sustainable design and architecture and educate the public about them. Within this building rehabilitation project, materials selected for the renovation included recycled textile materials, recycled aluminum, recycled newsprint, recycled glass, and wood grown and harvested sustainably.

The environmentally friendly strategy included reducing energy consumption through a Demand Side Management (DSM) Program with the local utility company, PG&E. The building has a highly efficient direct/indirect lighting system with translucent office panels to allow inner zones to borrow daylight from the perimeter. The building is heated by an efficient modular boiler and is cooled by natural ventilation. The BIPV system is a highly visible sustainable building feature. The demonstration of this power system by DOE FEMP, the National Renewable Energy Laboratory (NREL), and numerous private-sector partners illustrates that BIPV is a technically and economically valuable architectural element for designers.

The skylit entryway of the Thoreau Center for Sustainability at Presidio National Park was the first demonstration in the United States of the integration of photovoltaics into a federal building. Laminated to the skylight glass are photovoltaic cells that produce electricity and also serve as a shading and daylighting design element. Atlantis Energy provided custom-manufactured PV panels and the system design and integration for this project. The firm was joined by construction specialists who made it possible to transform this historic building into an environmentally responsive structure.

The solar electricity generated in the PV system in the skylight offsets power provided by the utility, thereby conserving fossil fuels and reducing pollution. Converting the DC electricity to AC, the system can produce about 1300 watts during periods of full sun. The system is fully automatic and requires virtually no maintenance. Like other PV systems, it has no moving parts, so this solar generating system provides clean, quiet, dependable electricity.



Lawrence Berkeley Laboratory/PIX01052

The PV arrays produce electricity and serve as a daylighting design element.

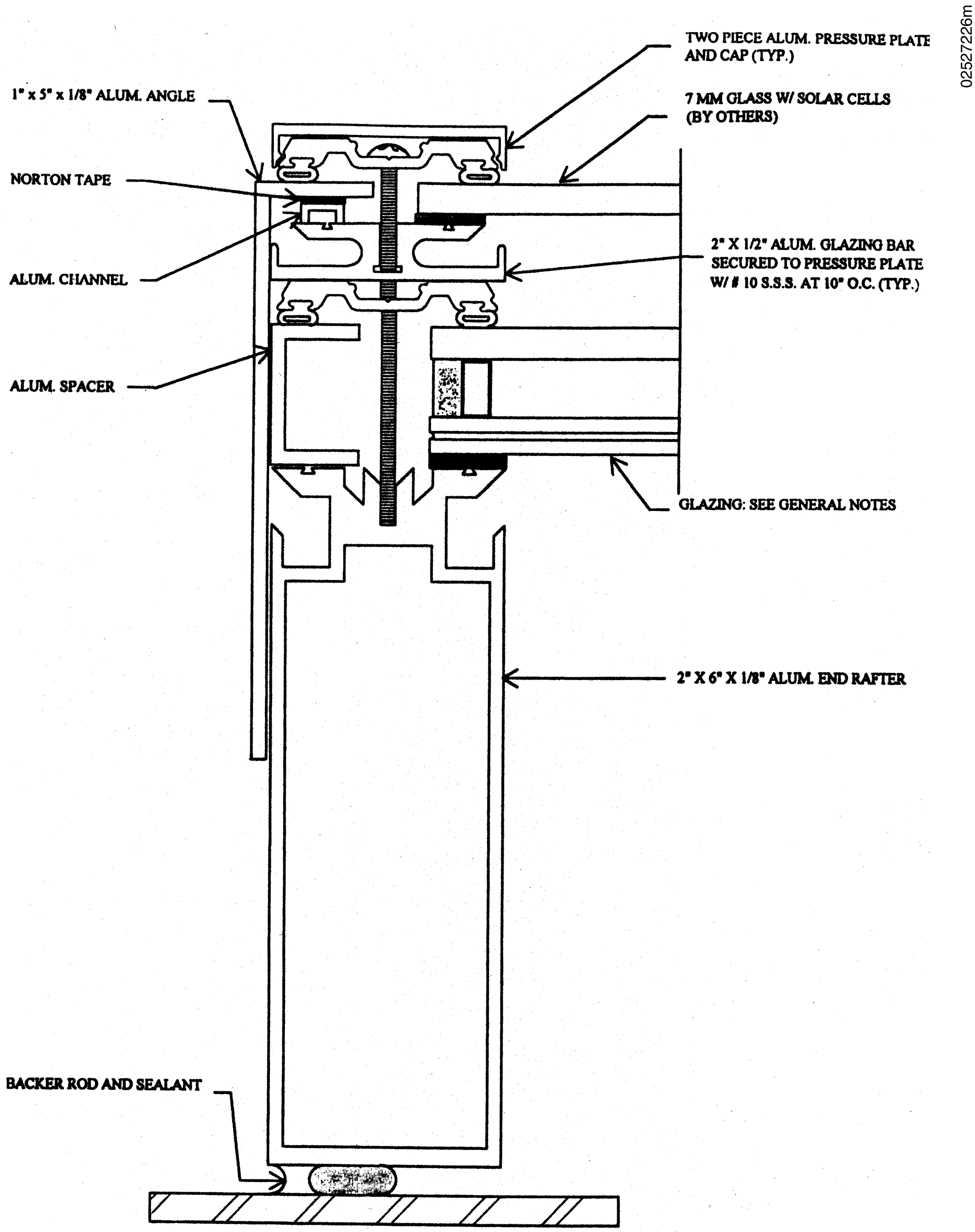
The entry area into the Thoreau Center is a rectangular space with a roof sloping slightly to the east and west. The roof is constructed entirely of overhead glazing, similar to a large skylight. PV cells are laminated onto the 200 square feet of available overhead glazing to produce approximately 1.25 kW of electricity under standard operating conditions. The PV-produced DC electric power is converted to high-quality AC by a power-conditioning unit (inverter). After it is converted, the power enters the building to be consumed by the building's electrical loads.

Special Design Considerations

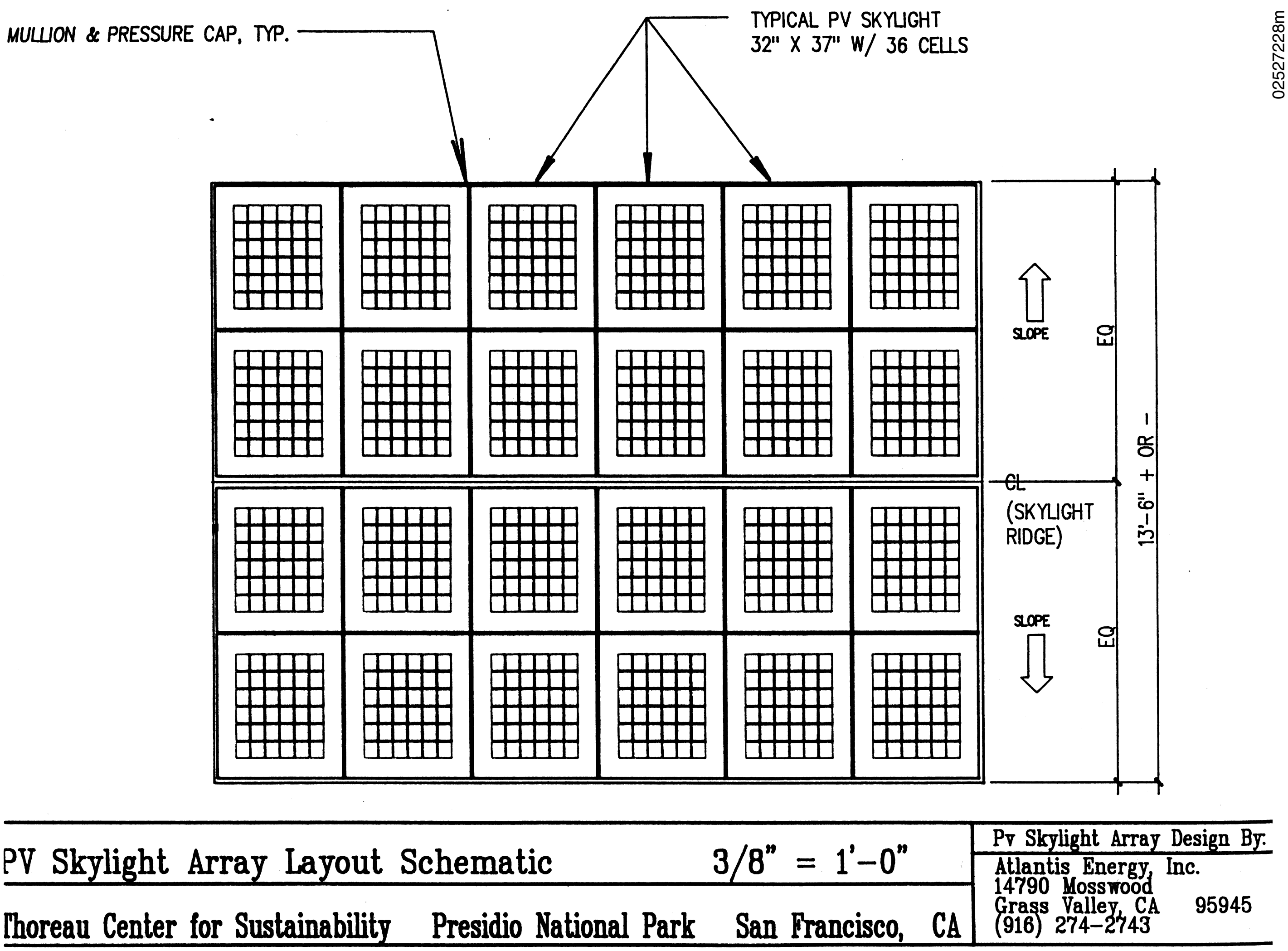
Design and construction issues for the relatively small Thoreau Center system were similar in many ways to issues involved with designing and constructing much larger systems. The panels for this project were custom-manufactured by Atlantis Energy to meet the esthetic requirements of the architect. The square, polycrystalline PV cells are spaced far enough apart from one another to permit daylighting and provide pleasant shadows that fall within the space. The amount of daylight and heat transfer through these panels was considered in determining the lighting and HVAC requirements for the space. The panels themselves were constructed to be installed in a standard overhead glazing system framework.

The system is installed above seismic-code-approved skylight glazing. The daylighting and solar gains through the PV modules mounted above the skylight system do affect the building lighting and HVAC loads, but the modules do not also serve as the weathering skin of this building envelope. Originally, the design called for the PV modules to replace the skylight units. But during design approval, local building code authorities were uncertain whether the modules could meet seismic code requirements. So the alternative design, stacking the skylights and the modules, was used instead.

To ensure that the glazing used in manufacturing the PV panels was acceptable according to Uniform Building Codes



This schematic drawing shows how the PV modules were attached above the conventional skylight glazing.



This drawing shows how the photovoltaic skylight array was arranged. The total array area is 20.6 square meters.

(UBC), building code issues were addressed. Special arrangements were made with the local electrical utility to ensure that the grid-tied system would meet safety requirements. Finally, installing the system required coordination between the panel supplier, electrician, glass installer, and Presidio facilities personnel.

PV System Configuration

The BIPV glazing system consists of 24 PV glass laminates. The spacing of the cells within the modules allows approximately 17% of the sunlight into the entryway, reducing the need for electric lights. The modules consist of 6-mm Solarphire glass, 36 polycrystalline silicon PV cells, an ethylene-vinyl acetate coating, a translucent Tedlar-coated polyester backsheet, and two sealed and potted junction boxes with a double pole plug connector. The PV cells are laminated in a 6-cell x 6-cell matrix. The minimum spacing between cells is 1.25 cm (1/2 in.). The dimension of each module is 81 cm x 94 cm (32 in. x 37 in). The gross area of the entire structure is 18.8 m^2 (200 ft^2).

The power produced by the system is converted to high-quality AC electricity and supplements power supplied to the building by the utility. The system is rated at 1.25 kW. Each of the 24 PV modules generates 8.5 V of DC power at approximately 5.5 amps. Six modules per sub-array are connected in series to feed the sine-wave inverter, which is configured to 48 V and rated at 4,000 W capacity.

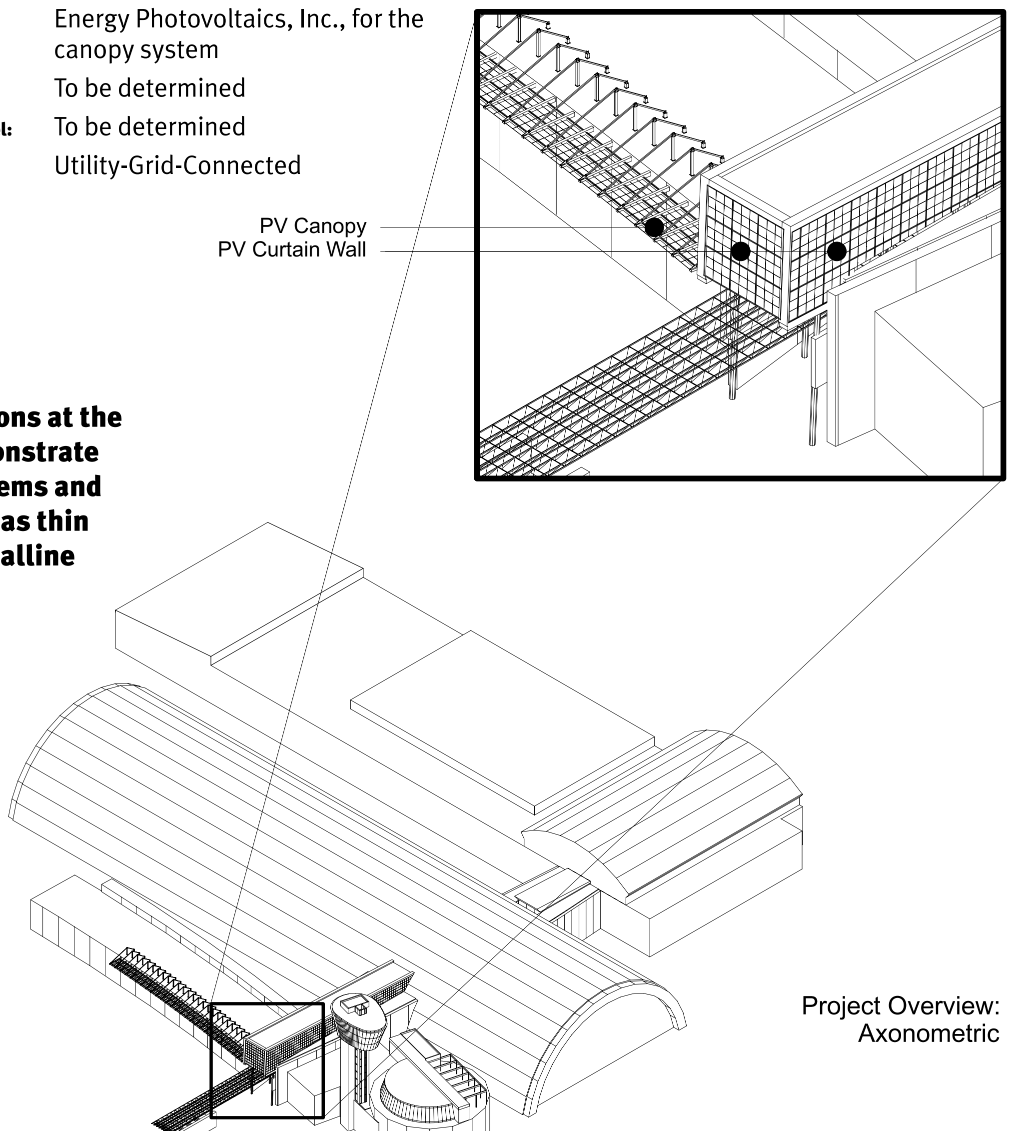
PV Module Mounting and Attachment Details

Structural upgrades were made to accommodate the additional weight of the PV system. These added about $900 to the total cost, for structural components.

National Air and Space Museum

Location:	Dulles Center, Washington, DC
Owner:	Smithsonian Institution
Date Completed:	Construction begun in 2000, scheduled for completion in 2003
Architect & Designer:	HOK, Building Architects; Kiss + Cathcart Architects, PV System Designers; Satish Shah, Speigel, Zamel, & Shah, Inc.
Structural Engineers:	N/A
Electrical Engineers:	N/A
Tradesmen Required:	Building tradesmen
Applicable Building Codes:	BOCA, Metropolitan Washington Airport Authority
Applicable Electric Codes:	National Electric Code
PV Product:	Various BIPV systems
Size:	To be determined for BIPV curtain wall, facades, and canopy
Projected System Electrical Output:	15.12 kWh for the canopy system
Gross PV Surface Area:	223 m² for the canopy system
PV Weight:	5 lb/ft² for the canopy system
PV Cell Type:	Polycrystalline cells, amorphous silicon film for various systems
PV Efficiency:	Systems will range from 5% to 12%
PV Module Manufacturer:	Energy Photovoltaics, Inc., for the canopy system
Inverter Number and Size:	To be determined
Inverter Manufacturer & Model:	To be determined
Interconnection:	Utility-Grid-Connected

The BIPV installations at the entryway will demonstrate different BIPV systems and technologies, such as thin films and polycrystalline solar cells.



Project Overview: Axonometric

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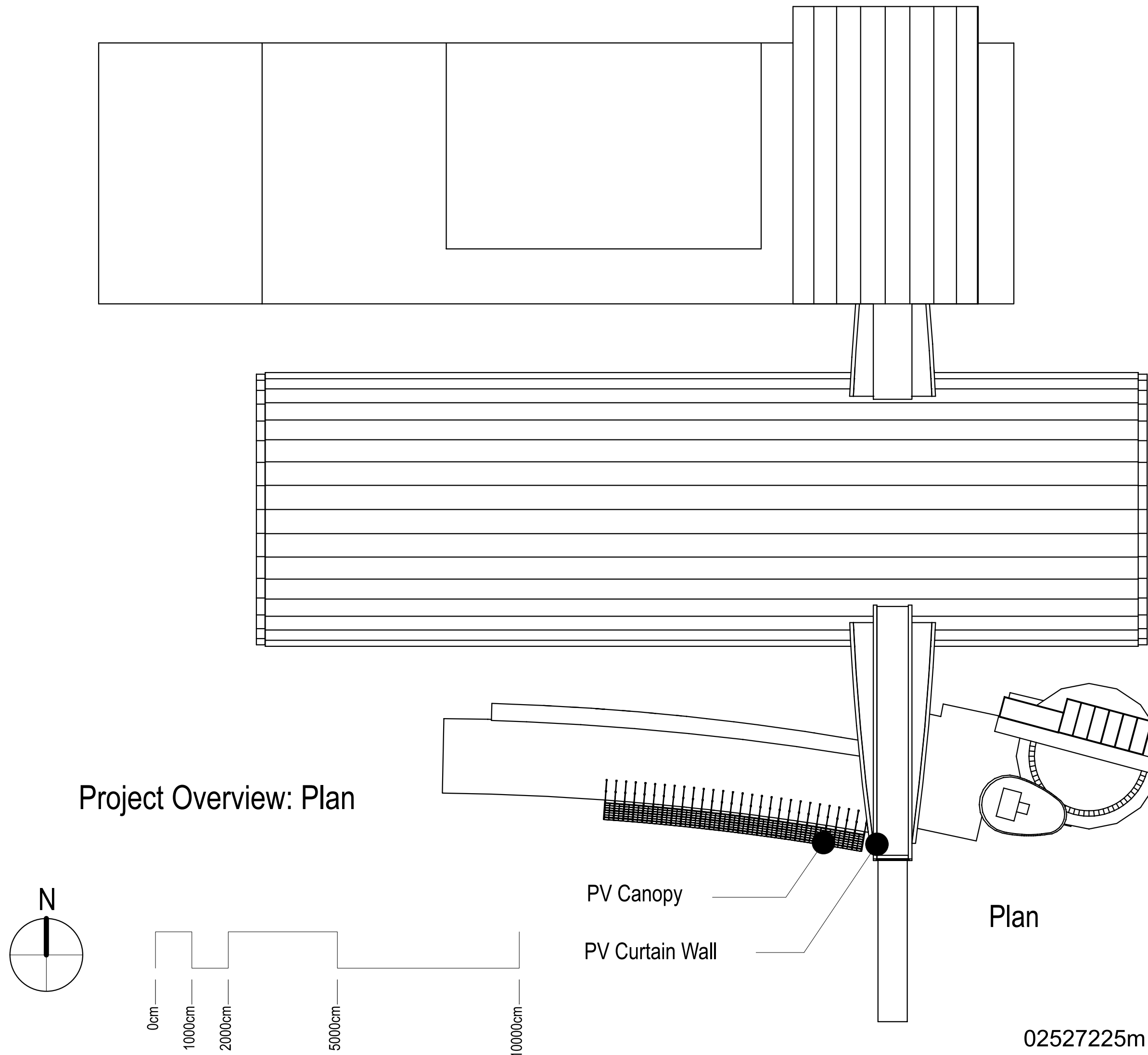


Plan view of BIPV installation at entry areas

Description

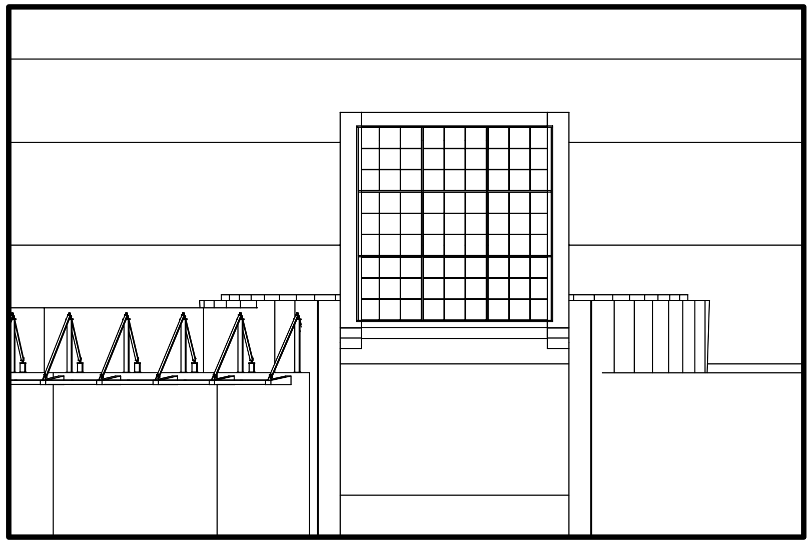
The National Air & Space Museum (NASM) of the Smithsonian Institution is one of the most-visited museums in the world. However, its current building on the Mall in Washington, D.C., can accommodate only a fraction of NASM's collection of historical air- and spacecraft. Therefore, a much larger expansion facility is planned for a site adjacent to Dulles Airport. Since the new facility will exhibit technologies derived from space exploration, the use of solar energy, which has powered satellites and space stations since the 1950s, is especially fitting for this new building.

Kiss + Cathcart, Architects, are under contract to the National Renewable Energy Laboratory as architectural-photovoltaic consultants to the Smithsonian Institution. Working with the Smithsonian and HOK Architects, Kiss + Cathcart is identifying suitable areas for BIPV, selecting appropriate technologies, and designing the BIPV systems. For DOE FEMP, a partner in the project, a primary goal is to demonstrate the widest possible range of BIPV applications and technologies in one building. Construction should begin in 2000.

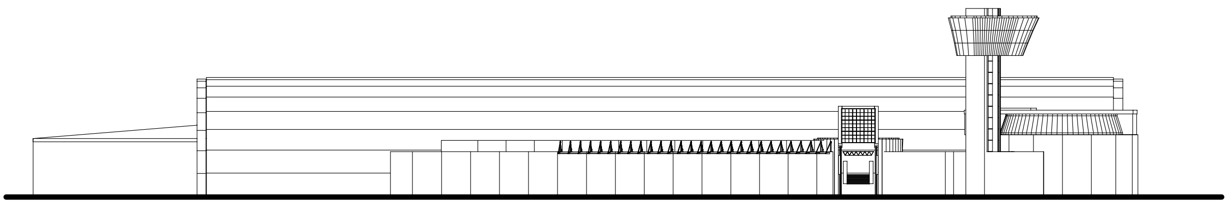
The NASM Dulles Center will serve as an exhibit and education facility. Its core mission is to protect the nation's collection of aviation and space-flight-related artifacts. It will also house the preservation and restoration workshops of the Air and Space Museum.

The center's design includes a large, hangar-style main exhibition space that will allow visitors to view the collections from two mezzanines as well as from ground level. It is estimated that more than 3 million people will visit the center annually to view aircraft, spacecraft, and related objects of historic significance, many of which are too large to display at the National Air and Space Museum in Washington, D.C. The facility will set new

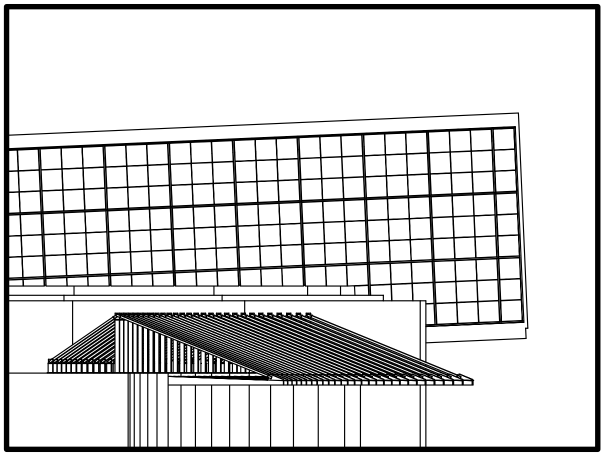
Project Overview: Elevations



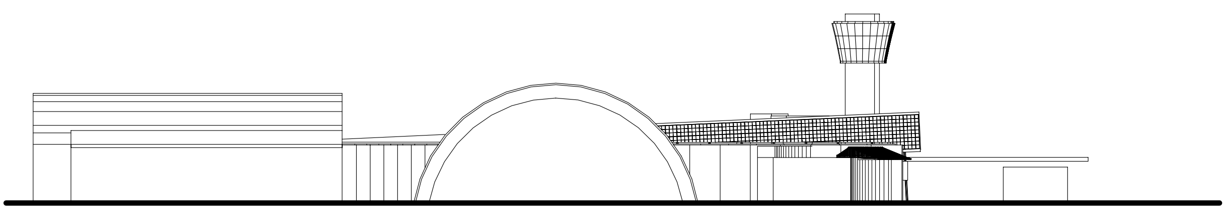
South Detail 1:350



South Elevation 1:1500

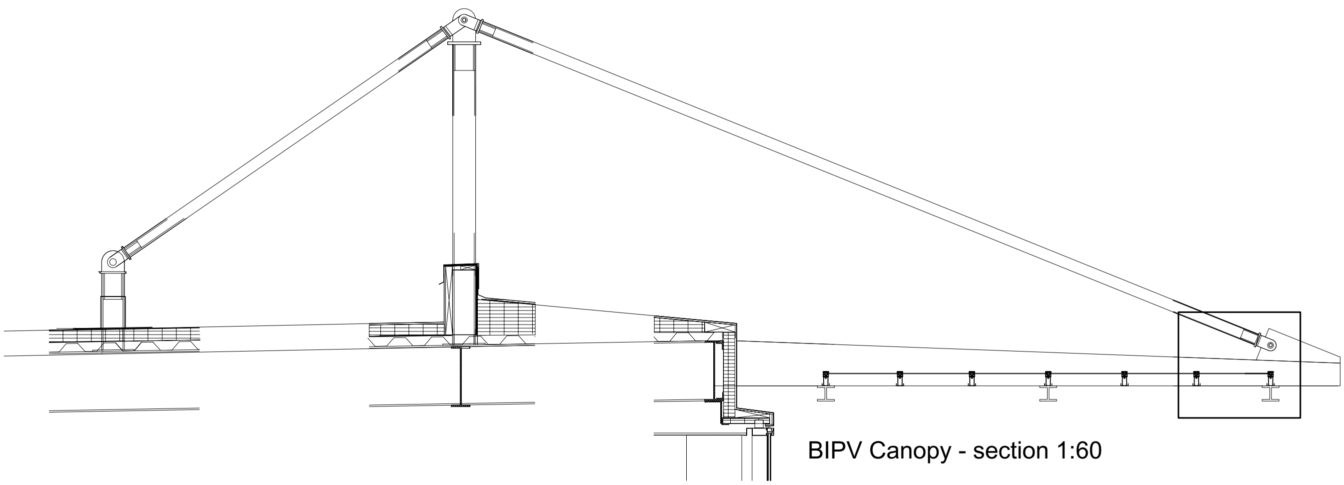


West Detail 1:350

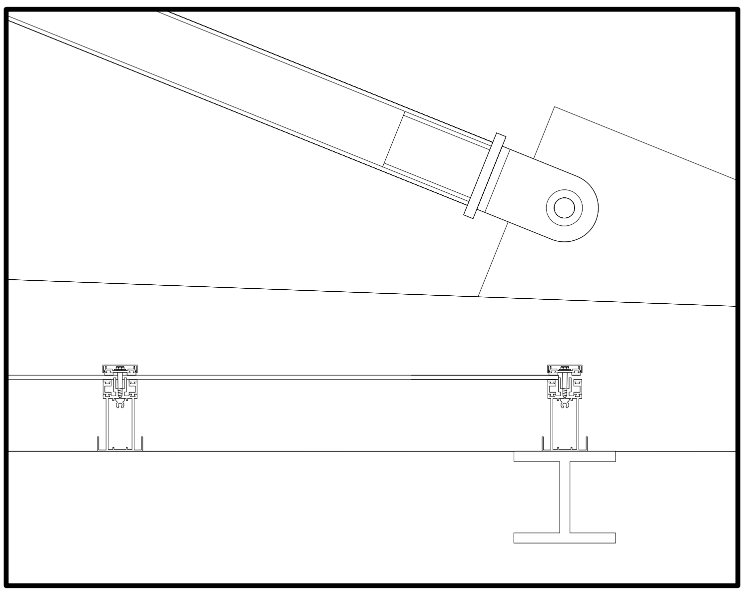


West Elevation 1:1500

The south- and west-facing facades of the entry hall will be glazed with polycrystalline glass laminates.



BIPV Canopy - section 1:60



Canopy:
Structural Details

BIPV Canopy detail 1:10

02527219m

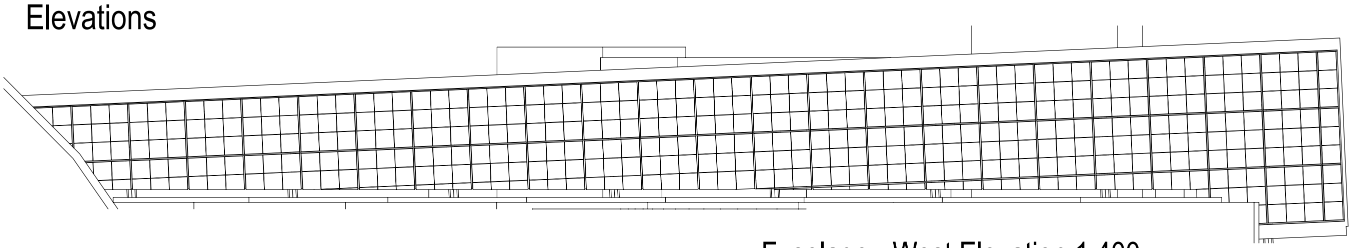
Thin-film BIPV glass laminates will function as the canopy.

standards for collections management and the display of large, 20th-century functional objects.

Smithsonian staff are evaluating the integration of a number of grid-connected BIPV systems into the building. The NASM Dulles Center will be a very large structure (740,000 ft²), with commensurate energy and water requirements. As part of its educational mission, the museum plans to exhibit hardware that points to the historic use of photovoltaic (PV) power systems in space; the museum would also like to demonstrate how that technology can be used today in terrestrial applications such as BIPV. To this end, the Smithsonian is evaluating the highly visible application of BIPV at this facility to meet a portion of its energy requirements. In this way, two objectives will be met: (1) reduce the amount of energy required from the power grid, especially during peak times, and thus conserve energy and save operational funds, and (2) demonstrate the use of PV in a highly visible context in a much-visited Federal facility.

Five BIPV subsystems could be demonstrated at the new NASM facility, including the south wall and skylight of the entry "fuselage," the roof of the restoration hangar and space shuttle hangar, the facade of the observation tower, and awning canopies. The entry fuselage figure clerestory windows will be a highly visible way of demonstrating PV to visitors approaching the center. Once in the entryway, visitors would also see the patterns of shadow and light the fritted glass creates on the floor, thus focusing visitors attention on the PV. Labels, exhibit material, and museum tour staff could further highlight the PV arrays and call attention to the energy savings being realized. PV would also be used to power some exhibit material exclusively. The related exhibit materials could highlight the many connections between PV and the field of space exploration and utilization, as well as today's construction and building industry.

Fuselage-PV Curtain Wall Elevations

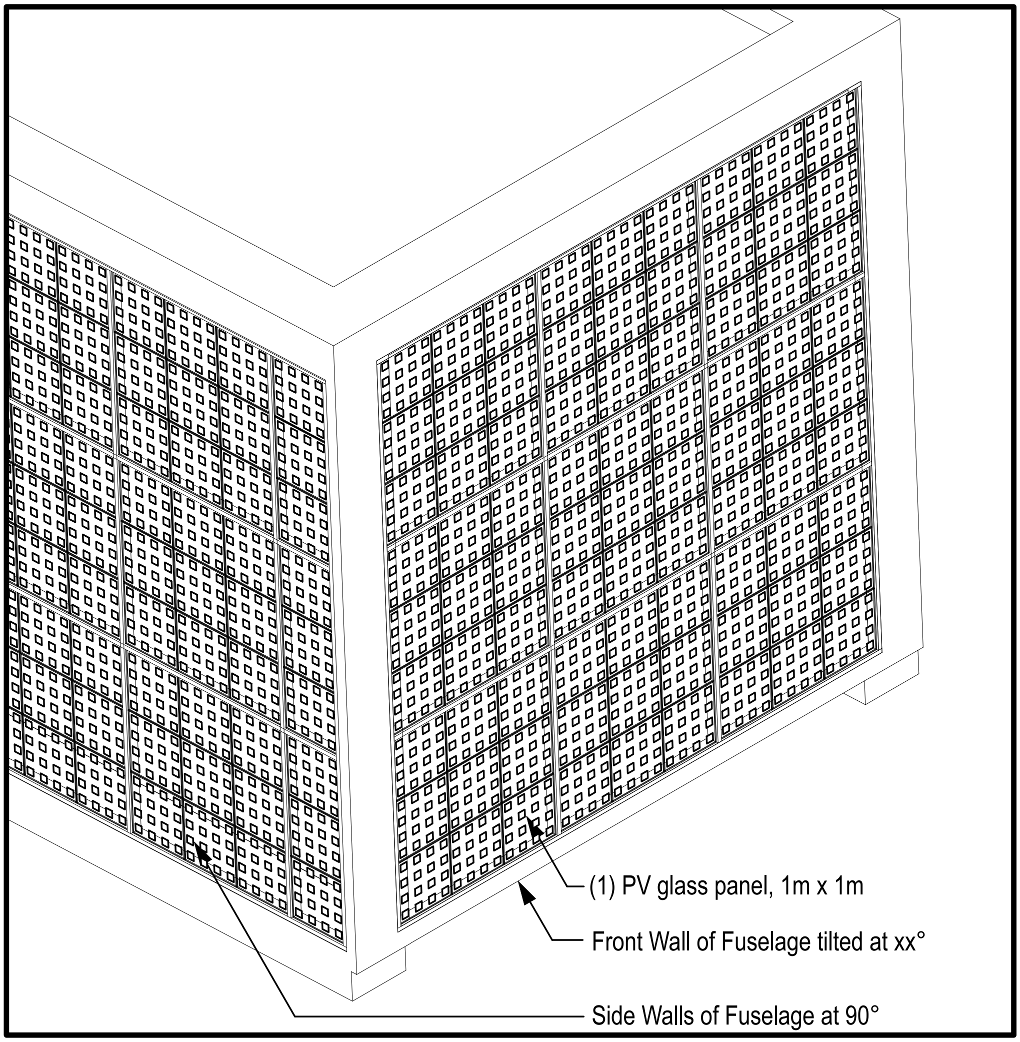


Fuselage - West Elevation 1:400

Watts/panel	27	
		W/facade
# panel sections/east	356	9,612
# panel sections/west	356	9,612
# panel sections/south	81	2,187
TOTAL facades (W)		21,411
TOTAL kW		21.41

Fuselage - PV output summary

Fuselage - SW Corner Axo



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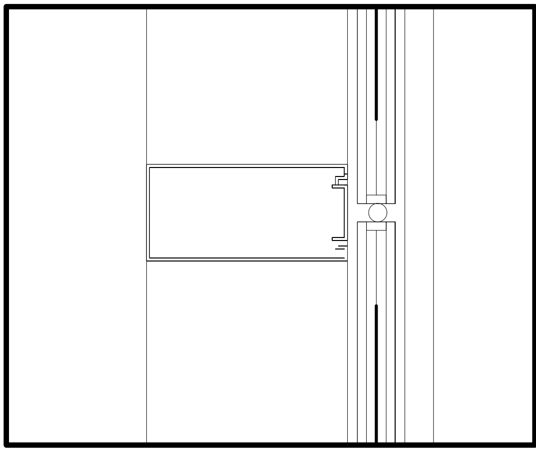
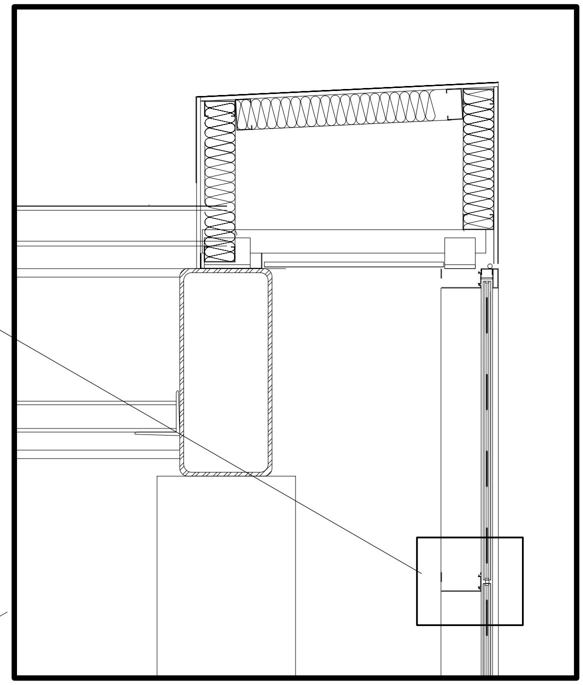
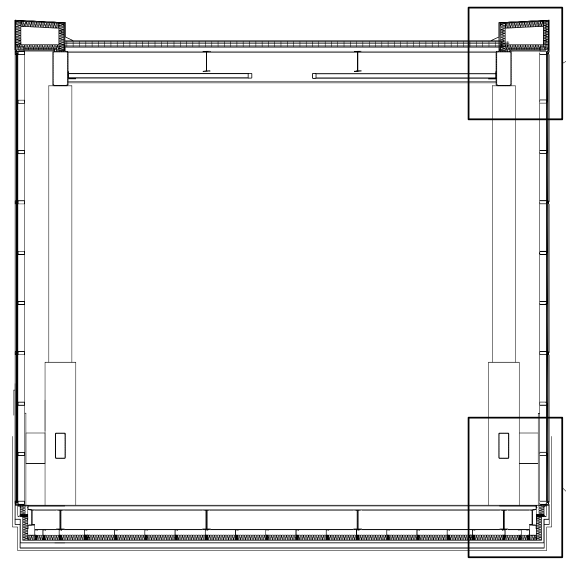
Fuselage detail illustrates patterns of polycrystalline glazing.



Detail at mullion 1:5

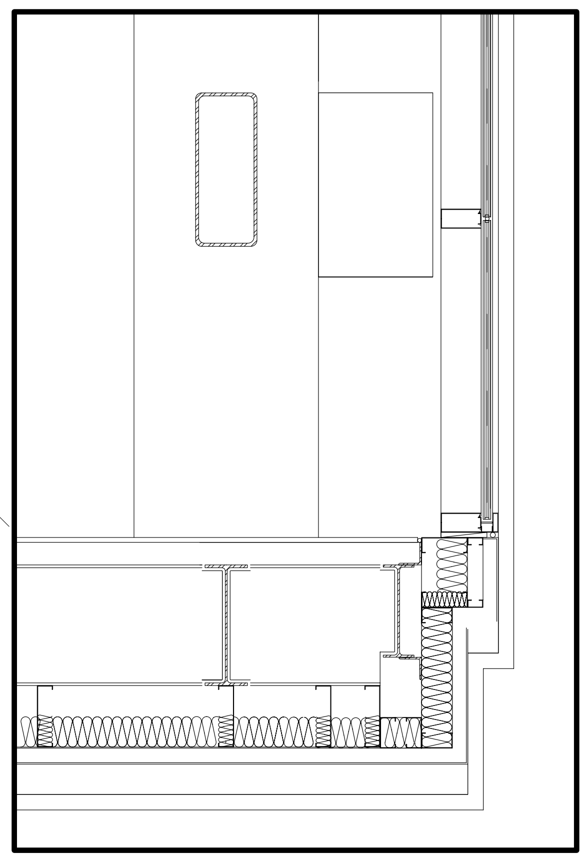


Detail at top of CW 1:25



East/West Section 1:150

Fuselage-PV Curtain Wall
Structural Details



Detail at bottom of CW 1:25

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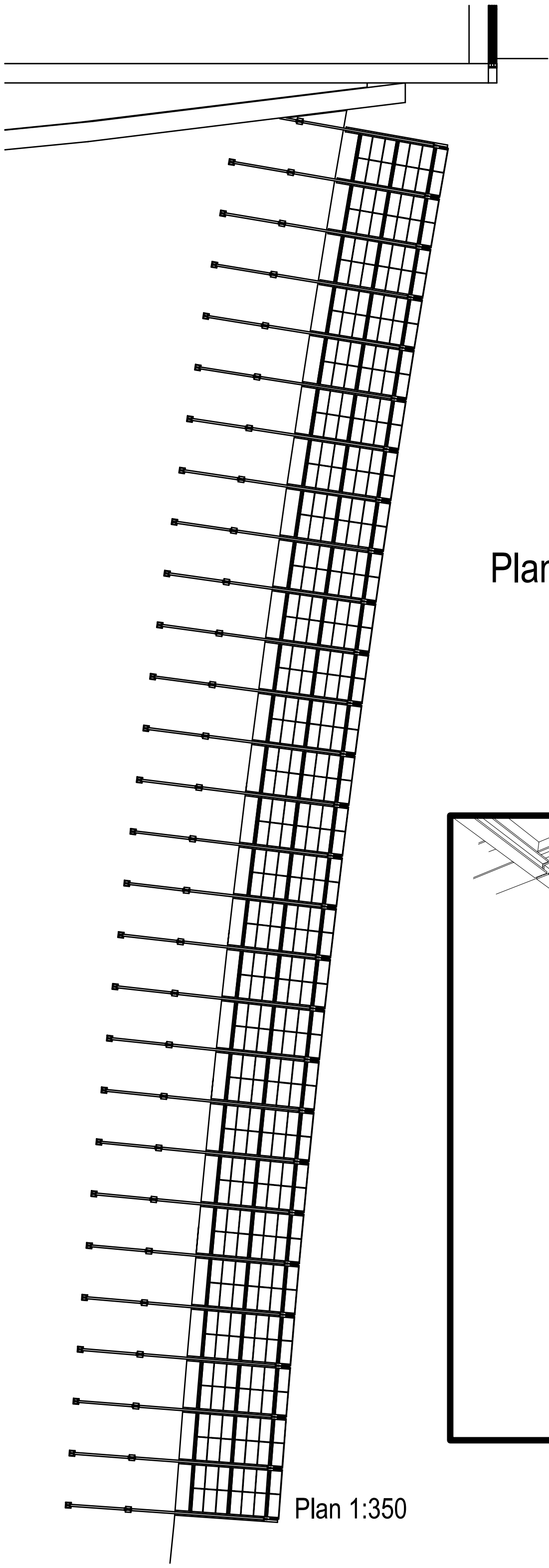
Curtain wall details indicate how mullion channels will act as electrical conduits.

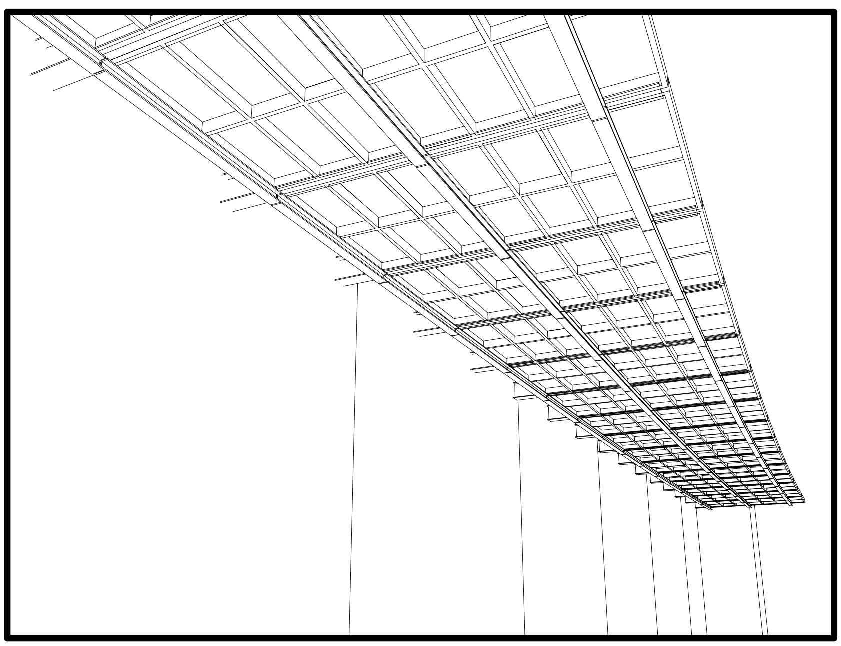


Plan 1:350

Canopy: Plan and Summary

Watts/panel	40	
# panel sections/bay	14	
# bays	27	15,120
TOTAL canopy (W)		15,120
TOTAL kW		15.12

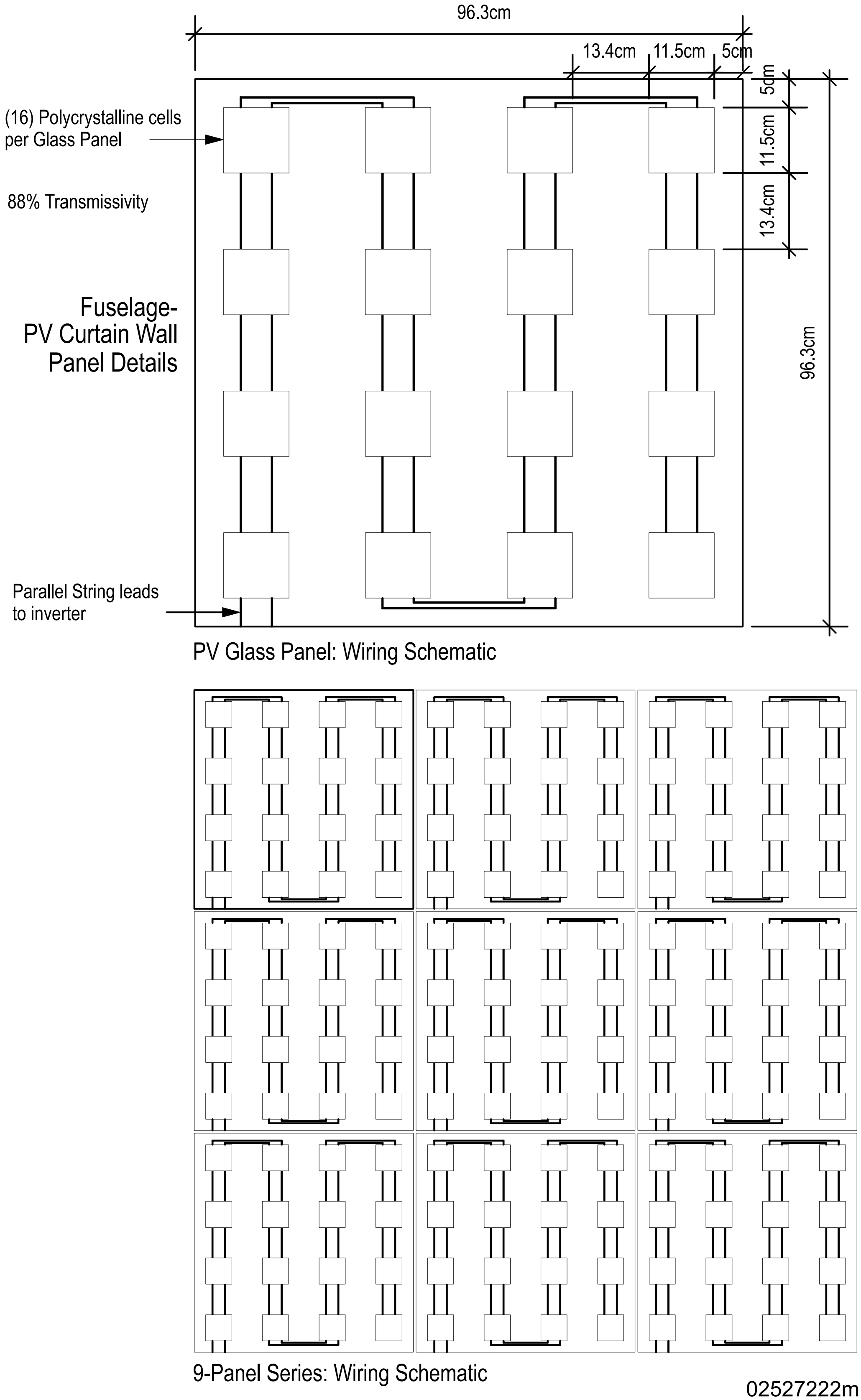
Fuselage - PV output summary



Perspective below canopy

02527220m

The canopy plan and perspective demonstrate how shading and power output are combined in one architectural expression.

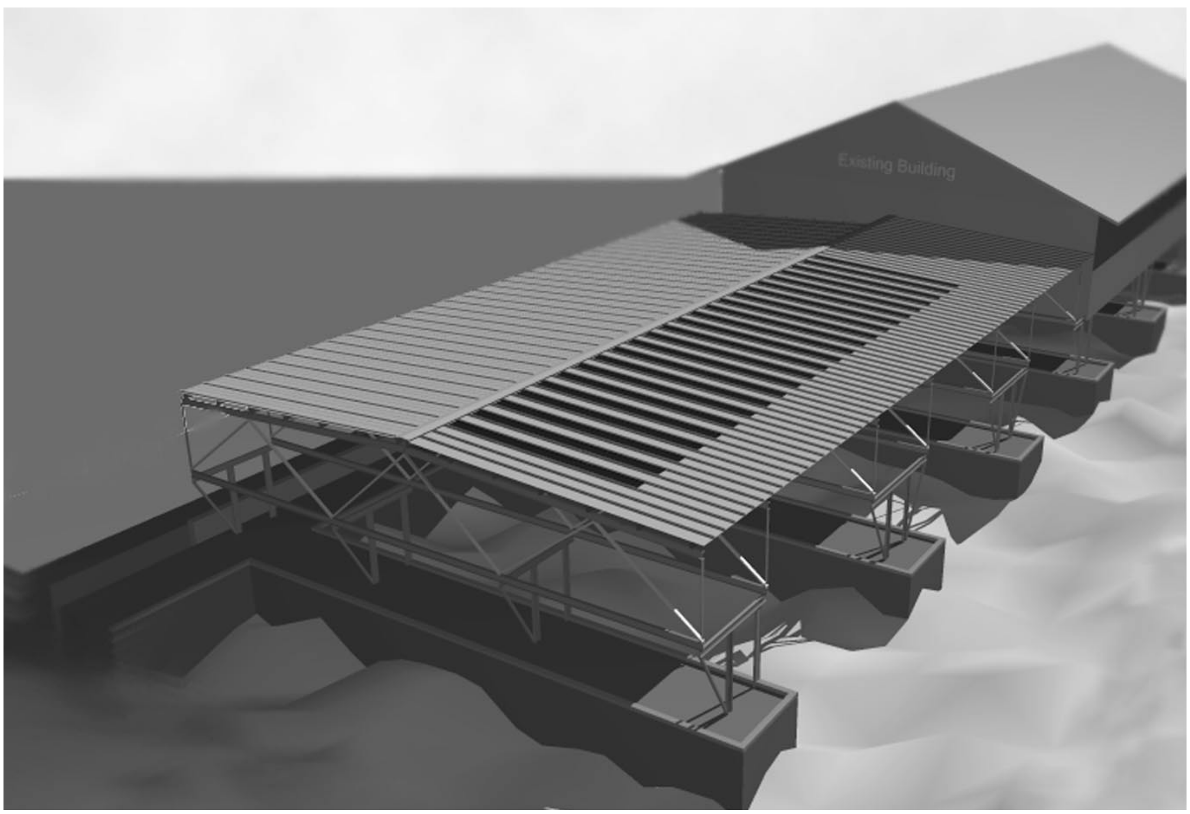


Curtain walls typically will be 16 polycrystalline solar cells per panel, laminated between two clear glass panes.

Ford Island

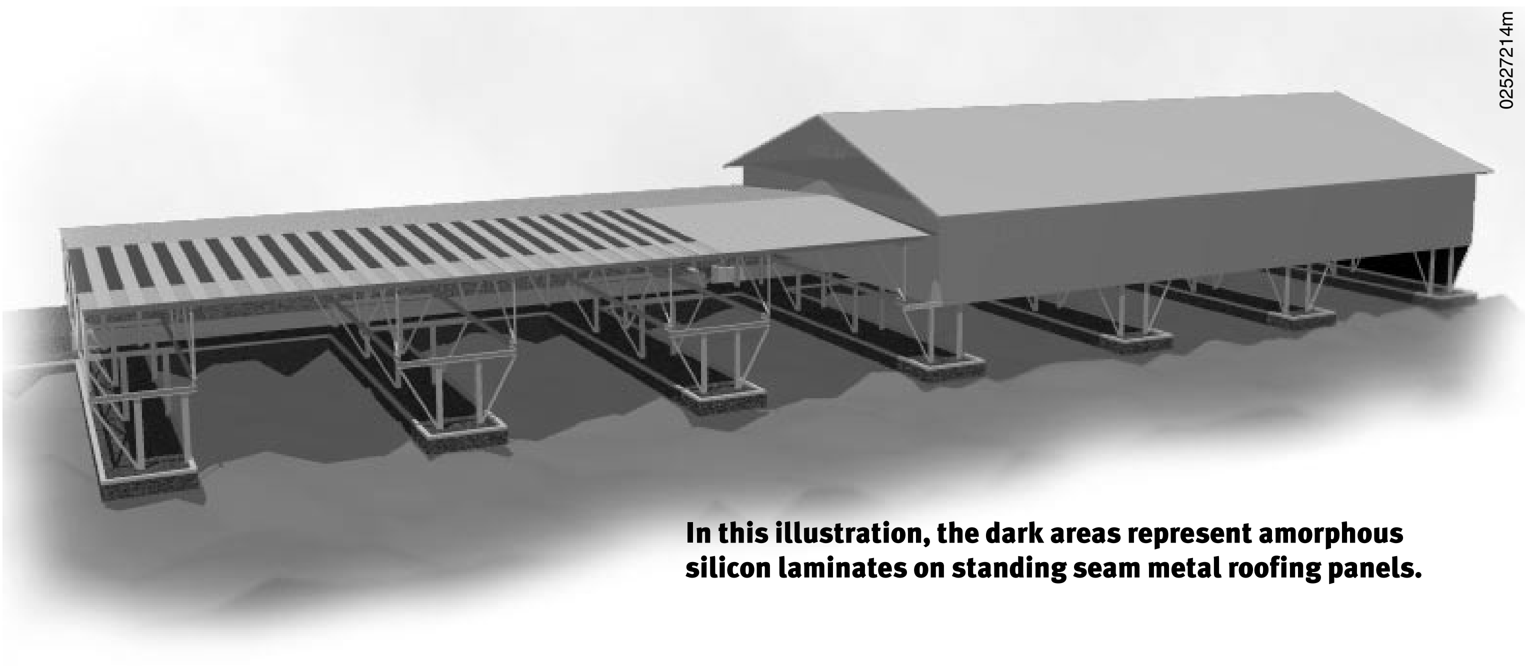
Building 44, Pearl Harbor Naval Station

Location:	Honolulu, Hawaii
Owner:	U.S. Navy, Department of Defense, and Hawaiian Electric Company
Date Completed:	September 1999
Architect & Designer:	Victor Olgyay, Fred Creager, and Stephen Meder, University of Hawaii, School of Architecture
Structural Engineers:	Hawaiian Electric Co.
Electrical Engineers:	Hawaiian Electric Co.; Peter Shackelford, Renewable Energy Services, Inc., system integrator
Tradesmen Required:	Roofers, electrical contractors
Applicable Building Codes:	Uniform Building Code
Applicable Electric Codes:	National Electric Code
PV Product:	Integrated standing seam metal roof
Size:	2.8 kW DC
Projected System Electrical Output:	9,720 kWh per month
Gross PV Surface Area:	571 ft^2
PV Weight:	4 lb/ft^2, with the roof
PV Cell Type:	Multijunction amorphous silicon
PV Module Efficiency:	5%-6%
PV Module Manufacturer:	Uni-Solar
Inverter Number and Size:	One, 4-kW
Inverter Manufacturer and Model:	Trace SW 4048PV
Interconnection:	Utility-Grid-Connected



02527213m

This illustration is a view of the building from the southwest corner; the dark areas represent the photovoltaic standing-seam metal roofing material.



In this illustration, the dark areas represent amorphous silicon laminates on standing seam metal roofing panels.

Description

A partnership consisting of the U.S. Navy, Hawaiian Electric Co. (HECO), the University of Hawaii, the U.S. DOE Federal Energy Management Program (FEMP), and the Utility PhotoVoltaic Group (UPVG) was created in order to design and install a 2-kW, grid-intertied, BIPV retrofit system using the Uni-Solar standing seam metal roofing product and to monitor its performance for one year. The University of Hawaii School of Architecture designed and administered the project and a local utility, HECO, funded it. Additional construction cost support was supplied by FEMP, NREL, and the Navy. The utility and the Navy determined the site, and the installation date was scheduled for the third quarter of 1998 (Figure 1). HECO was designated to be the client for the first year, after which the Navy will assume ownership of the system.

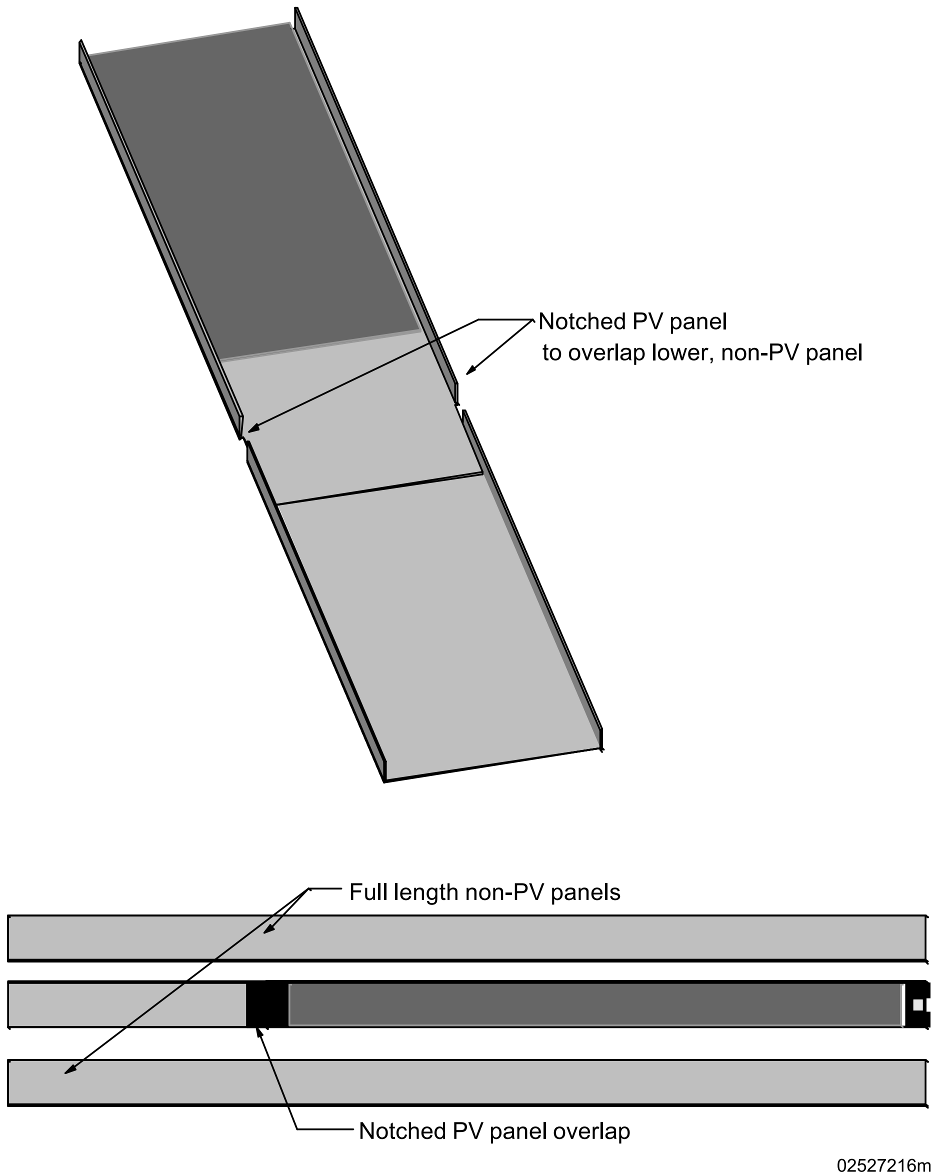
The tropical location (21° North) and the site's microclimate make it an ideal location for PV installations. Project planners expected an annual daily average of 5.4 peak sun hours and 20 to 25 in. (57 cm) of annual rainfall. This project, at this particular site, will also be testing the limits of the products used in the installation. Monitoring the performance of the PV system, the McElroy metal substrate, and the Trace inverter in a tropical marine environment will provide valuable performance information to guide the future development and use of these products.

The total cost of this project was $92,000. This included design, procurement, roof removal and BIPV installation, and a year of monitoring.

Special Design Considerations

The context of this project is the naval industrial site at Pearl Harbor Naval Base.The site contained a 90 ft x 52 ft (27.4 m x 15.8 m) open-wall boathouse structure. The existing roof of the structure was made of box rib metal on trusses (Figure 2) in gable form, divided longitudinally on its east-west axis. The south

The array in mid-installation is shaded only by cloud cover.



This illustration shows how the notched BIPV standing-seam components overlap the regular roofing panels.

slope provides a 90 ft x 26 ft (27.4 m x 7.9 m) surface at a 5° incline. This half of the roof measured approximately 2,340 ft^2 (217 m^2). The box rib roofing was removed from the entire south-facing slope, and new standing seam pans, including 24 of the Uni-Solar SSR 120 photovoltaic standing seam panels, replaced the original roofing.

Integrating the new metal roofing with the existing roof posed several design and construction challenges. In addition, the longest panel that Uni-Solar could provide is 20 ft (6.09 m) and the required run is 26+ ft (8 m). This shortfall required overlapped joints to be used on the ends of the panels and additional purlines to be welded for support. Full-length, standing-seam panels and non-PV panels were set in an alternating pattern with the PV modules. This arrangement allowed the full-length pans to add strength over the required lap joint of the shorter PV units.

The length limitation of the Uni-Solar panels was a design deficiency of the Uni-Solar product; unless new PV-to-metal laminating processes are developed, this product will be substantially limited in metal roofing applications. Joining the panels to extend their length not only increases material and labor costs, it also provides opportunities for water penetration and corrosion. The "galvalum" coating is cut away everywhere the panel is modified. This exposes the steel of the standing seam panel to the marine environment. Therefore, McElroy, Uni-Solar's metal roof supplier, will not warranty the product for marine applications.

In addition, to match the paint of the existing structure, McElroy required a minimum order to custom-paint the new roof panels. Therefore, about one-third more roofing panels had to be purchased than were needed, and this increased the overall project cost. The extra panels turned out to be useful, however, since many were damaged during transport to Hawaii.

The part of the roof to be retrofitted spans a dock area below. This presented staging challenges for the roofing and electrical contractors. Along with restricted access to the military base and the need to take a bridge to the site, the location of the roof added to the complexity and costs of the project. And the harsh marine environment could have a corrosive effect on the array and its components.

PV System Configuration

The system is rated at 2.175 kW AC (2.8 kW DC). The estimated system output is 9,720 kWh per month. The building is not independently metered. It is fed by the Pearl Harbor grid, to which HECO supplies power. The estimated demand of the building is about 12000 kWh per month. The energy generated by the PV system will feed but not meet the average loads of this building.

PV Module Mounting and Attachment Details

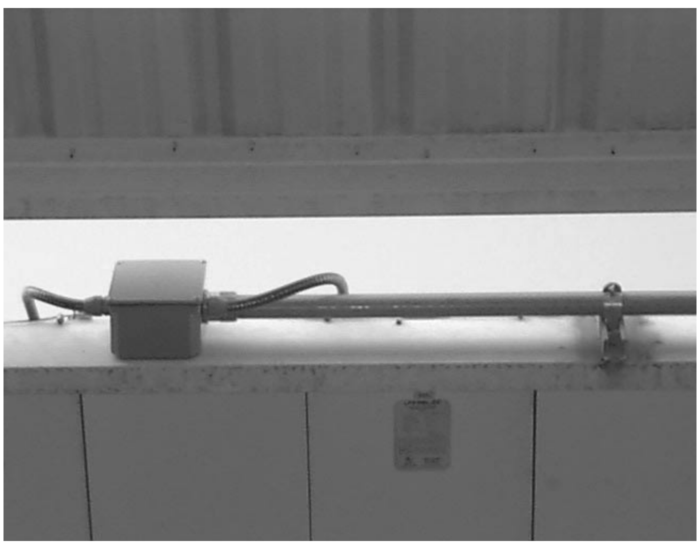
Integrated connection follows standard metal seam roof attachment process. Notched PV panels are secured to non-PV panels with metal fasteners.

PIX08476

Workers install short lapped roofing pans at BIPV module sections.

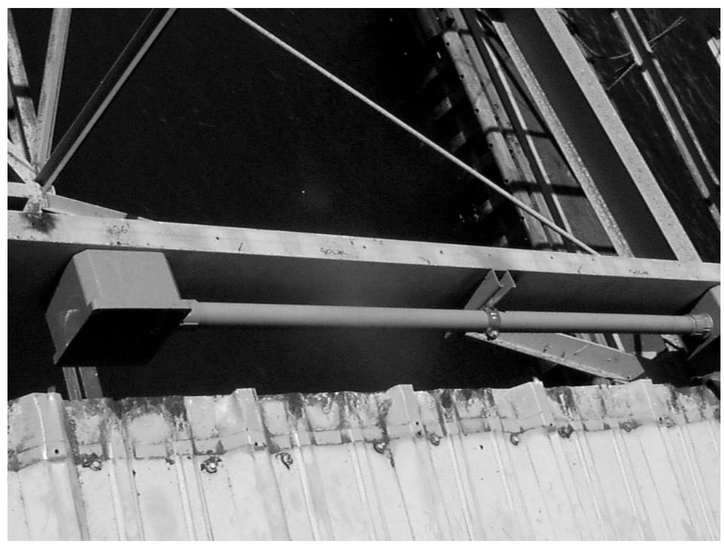
PIX08477

Additional electrical junction boxes were required over potted terminals and raceways at the ridge, before the ridge cap was installed.



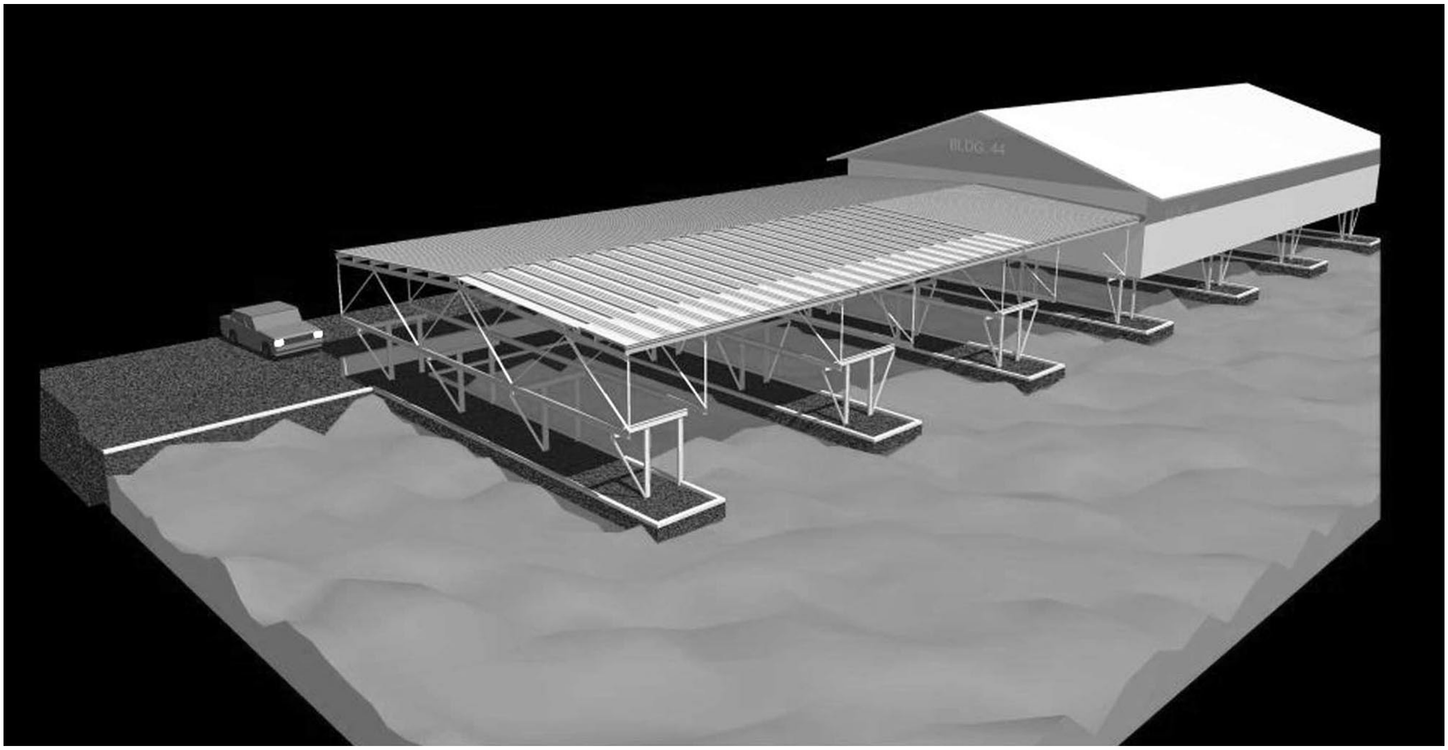
PIX08478

Junction box at ridge, viewed from below



PIX08480

Junction box at ridge, viewed from above



02527289m

The part of the roof containing BIPV spans a dock area, as shown in this illustration.

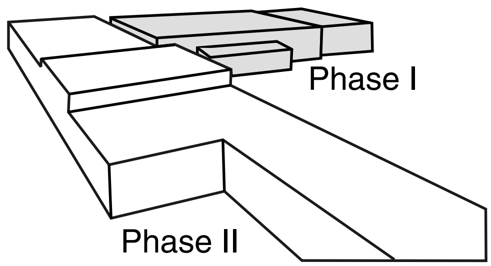
Western Area Power Administration

Elverta Maintenance Facility, Phases I and II

Phase I

Location:	Elverta, California
Owner:	U.S. Department of Energy (DOE) Western Area Power Administration
Date Completed:	May 1996
Architect & Designer:	DOE Western Area Power Administration, PowerLight Corporation
System Integrator:	PowerLight Corporation
Structural Engineers:	DOE Western Area Power Administration
Electrical Engineers:	DOE Western Area Power Administration
Tradesmen Required:	Roofers, electrical contractors
Applicable Building Codes:	Standard California building codes
Applicable Electric Codes:	National Electric Code
PV Product:	PowerGuard™ BIPV roof tiles
Size:	40 kW DC
Projected System Electrical Output:	70,000 kWh/year
Gross PV Surface Area:	5,400 ft^2
PV Weight:	4 lb/ft^2
PV Cell Type:	Polycrystalline silicon
PV Efficiency:	12%
PV Module Manufacturer:	Solarex
Inverter Number and Size:	8 inverters, 6 kW each
Inverter Manufacturer:	Omnion Corp.
Interconnection:	Utility-Grid-Connected

A 38-kW BIPV system supplements a 40-kW system installed in 1996.



PIX08451

Description

Staff in the Department of Energy's Western Area Power Administration Sierra Nevada Region (SNR) have had two main goals for SNR's photovoltaic (PV) program: (1) promote PV systems as a renewable energy resource, and (2) do so in a cost-effective manner. In support of these goals, SNR has incorporated PV panels into the roofs of buildings in Elverta and Folsom, California. The building-integrated systems will repay investments in them by extending roof lives, reducing maintenance costs, generating electric power, and reducing the buildings' cooling requirements.

In Phase I, a 40-kW building-integrated photovoltaic system was installed at SNR's Elverta Maintenance Facility. The Sacramento Municipal Utility District (SMUD) funded the PowerLight Corp. PowerGuard® system, while Western contributed funds equivalent to the cost of replacing the facility roof. Funding was also provided by the Utility Photovoltaic Group (UPVG) through TEAM-UP, with support from the U.S. Department of Energy.

With a power capacity of 40 kW peak DC and an annual energy output of more than 70,000 kWh/year, the PV systems have significant environmental benefits. Phase I prevents the emission of 2,300 tons of carbon dioxide, 8.7 tons of nitrogen oxides and 16.4 tons of sulfur dioxides; these emissions would be the result if fossil fuels were burned to generate the same amount of electricity. Because this system is designed to have a life expectancy of 20 years, the cumulative benefits for the environment are many.

PIX08450

A PowerLight rooftop PV system is installed on Western's facility in Elverta, California.

PIX08452

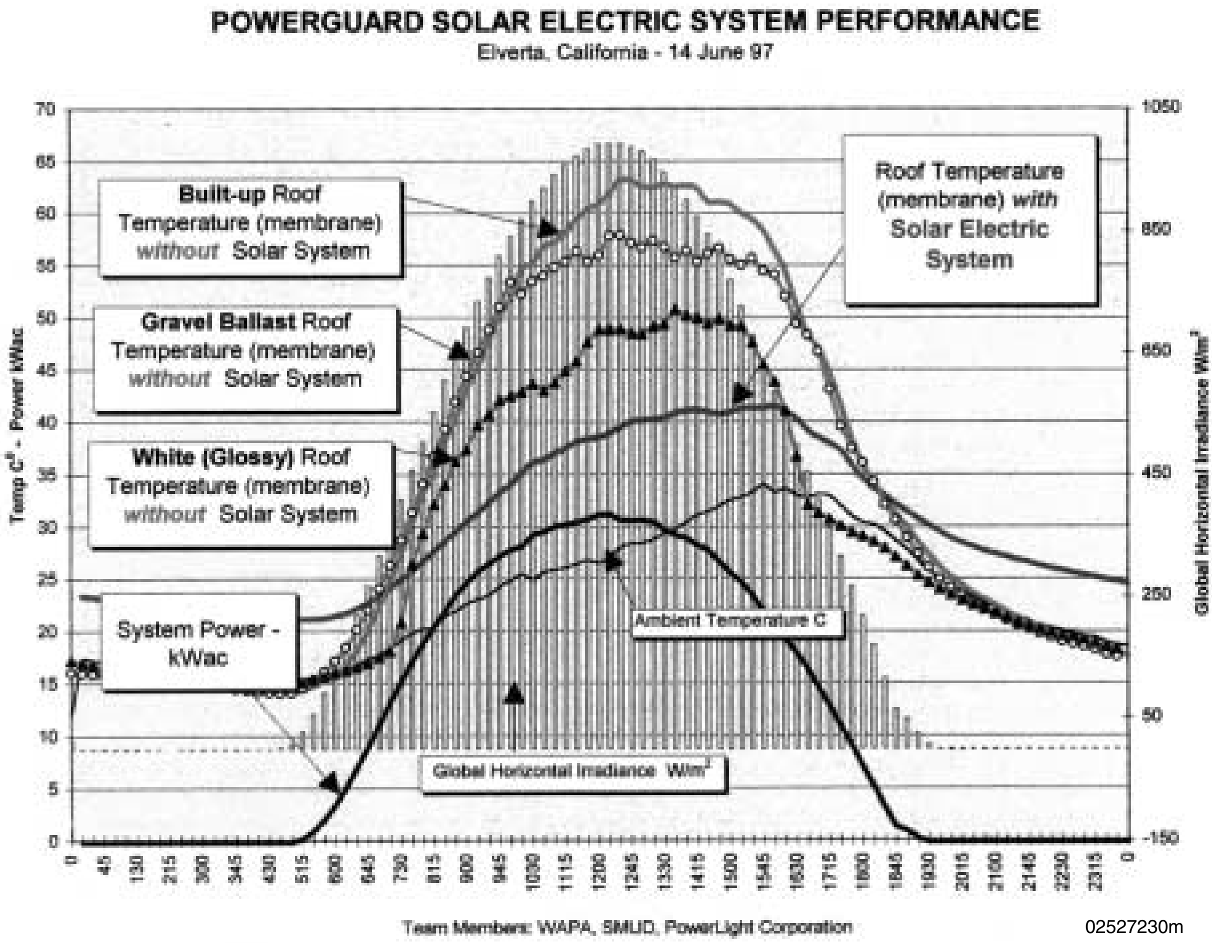
A view of the rooftop of the Elverta facility after the PV system installation.

Special Design Considerations

PowerGuard PV tiles were used to reroof the building, saving on the cost of conventional roofing material. The patented PowerGuard tiles incorporate high-efficiency polycrystalline silicon cells from Solarex. Site conditions were favorable for this sytem: 38° latitude; a dry, sunny climate throughout most of the year; and no shading. The system features horizontal tiles and tiles with an 8° southerly tilt for greater annual energy production. In addition to generating clean renewable energy, the lightweight system provides R10 roof insulation for improved building comfort and membrane protection for extended roof life. Installation took only 7 days to complete once the building's old roof was replaced with a new single-ply membrane roof.

PV System Configuration

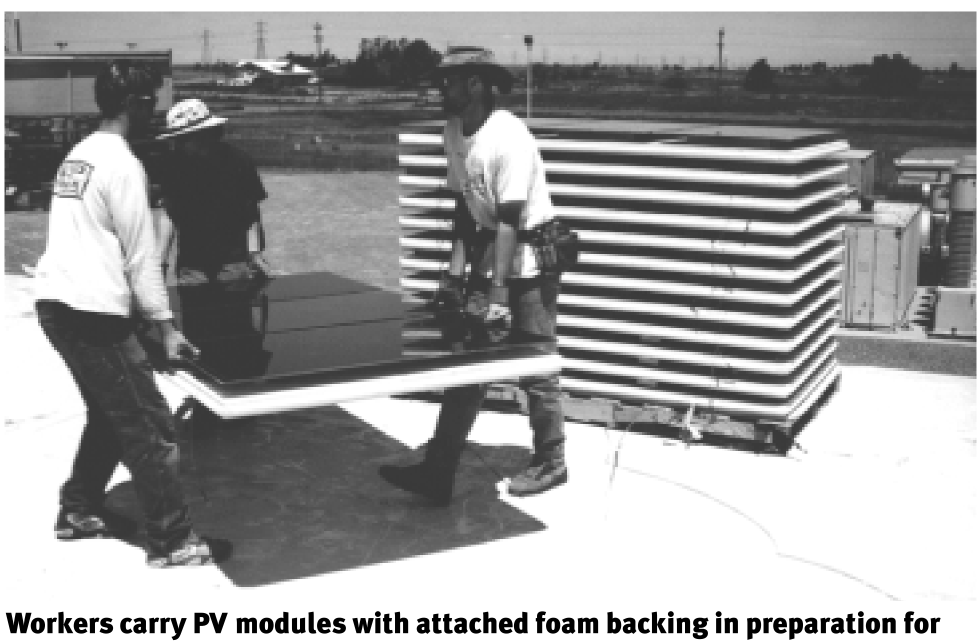
A 40-kW PowerGuard building-integrated PV system was installed at the Elverta Maintenance Facility in Western's Sierra Nevada Region to function as both a roof and solar electric photovoltaic (PV) power plant. Phase I modules were installed in parallel strings containing 56 modules per string (7 series, 8 parallel).



The temperature curves show how the PV-integrated roof compares with various roofs without solar electric systems. Roof-integrated PV with integral insulation reduces a building's heat load as much as 23°C. The measurements were derived from sensors placed in representative roof specimens.

PV Module Mounting and Attachment Details

The panels are designed to interlock using a tongue-and-groove assembly. Panels with 3/8-in. concrete topping, instead of PV modules, are set among the PV panels to allow working access throughout the roof. Along the edges of the PV array, a steel ribbon links the modules together, in order to connect everything structurally.

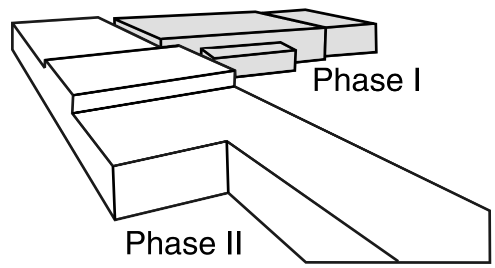


PIX08453

Workers carry PV modules with attached foam backing in preparation for rooftop mounting. Smaller panels with concrete topping were also installed as a walking surface.

Phase II

Location:	Elverta, California
Owner:	U.S. Department of Energy (DOE) Western Area Power Administration
Date Completed:	June 1998
Architect & Designer:	DOE Western Area Power Administration, PowerLight Corporation
System Integrator:	PowerLight Corporation
Structural Engineers:	DOE Western Area Power Administration
Electrical Engineers:	DOE Western Area Power Administration
Tradesmen Required:	Electrical and building contractors
Applicable Building Codes:	Standard California building codes
Applicable Electric Codes:	National Electric Code
PV Product:	PowerGuard™ BIPV roof tiles
Size (kWp):	38 kW DC
Projected System Electrical Output:	67,500 kWh/year
Gross PV Surface Area:	9,900 ft^2
PV Weight:	5 lb/ft^2
PV Cell Type:	Thin-film amorphous silicon
PV Efficiency:	4%-5%
PV Module Manufacturer:	Solarex (762 modules) and APS (264 modules)
Inverter Number and Size:	One 32-kW AC
Inverter Manufacturer and Model:	Trace Technologies
Interconnection:	Utility-Grid-Connected



Description

This 38-kW BIPV system supplements the Phase I system. Both systems completely cover the Elverta roof and are the largest PV application of its kind in the United States. Phase II is totally funded and owned by Western. The PV systems utilize thin-film amorphous silicon technology. The DC output from the PV modules is converted to 240 V AC by means of a custom-built 32-kW Trace inverter, and then stepped up to 480 V, three-phase AC by a 45-kVA transformer for direct connection to the building's service panel. Besides replacing grid power, the Powerlight system protects the roof membrane, which extends its life. The roof system also provides R10 insulation to reduce cooling and heating loads, thereby decreasing energy consumption.

Special Design Considerations

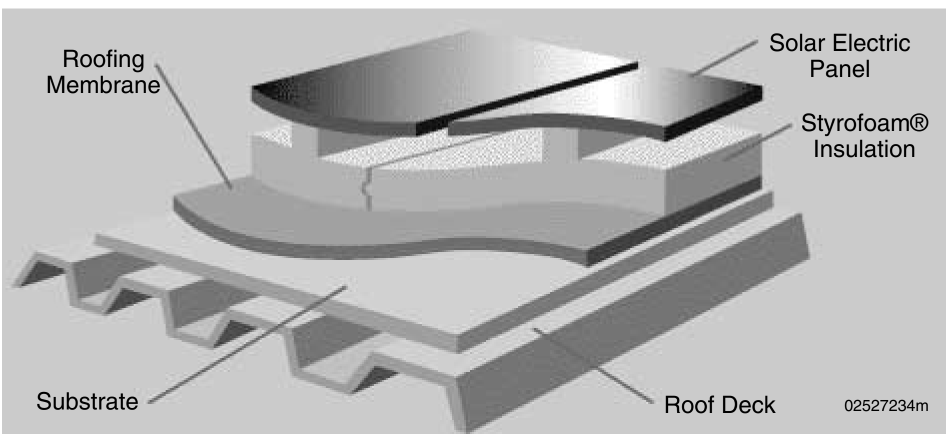
The flush roof design provides excellent insulation as well as electricity, as shown in the graph comparing roof temperature data.

PV System Configuration

The Solarex modules were installed in 254 parallel strings, with three Solarex modules in series per string. The modules produce 43 watts each. The APS modules were installed in 22 parallel strings with 12 modules in series per string. The APS modules produce 22 watts each.

PV Module Mounting and Attachment Details

Same as those for Phase I.



The illustration shows how the layers in the roofs provide above-average insulation as well as a good base for the PowerGuard PV system.

Photovoltaic Manufacturing Facility

Location:	Fairfield, California
Owner:	BP Solar
Date Completed:	1993
Architect & Designer:	Kiss Cathcart Anders, Architects
Structural Engineers:	Ove Arup & Partners
Electrical Engineers:	Ove Arup & Partners
Tradesmen Required:	Glaziers, electricians
Applicable Building Codes:	BOCA and California Title 24
Applicable Electric Codes:	National Electric Code
PV Product:	Glass laminates as curtain wall spandrel, skylight, and awning
Size:	9.5 kWp
Projected System Electrical Output:	7.9 kW
Gross PV Surface Area:	1,975 ft^2
PV Weight:	3 lb/ft^2
PV Cell Type:	Amorphous silicon
PV Efficiency:	5%
PV Module Manufacturer:	APS
Inverter Number and Size:	6 kW
Inverter Manufacturer:	Omnion Corporation
Interconnection:	Utility-Grid-Connected

Views looking north (top) and south show how BIPV is integrated into both the facade and the canopy that runs the length of the building.

PIX08446

PIX08449

PIX08447

Interior view shows how BIPV is used with vertical and sloped glazing.

Description

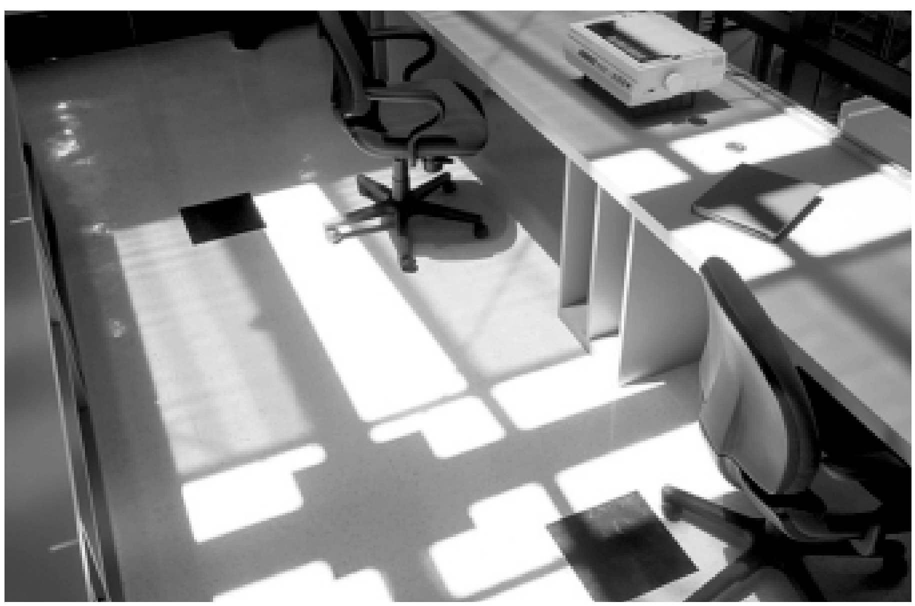
Completed in 1993, this 69,000-ft² manufacturing facility houses a new generation of production lines tailored to thin-film PV technology. The building also incorporates into its design several applications of thin-film solar modules that are prototypes of BIPV products.

The heart of the project is a 22.5-ft-high BIPV glass cube containing the factory's control center and visitor facilities. This cube is perched on the second floor, and half of it is outside of the manufacturing building, emphasizing its status as an independent element and a prototype that demonstrates BIPV in a typical commercial building. The cube's PV cladding, the solar entrance canopy, and the translucent BIPV skylight provide more than enough energy to power the control center's lighting and air-conditioning systems.

The production floor and warehouse space are housed in a tilted-up concrete shell with a steel intermediate structure and a timber roof. Glass blocks embedded as large-scale "aggregate" in the outside walls provide a pattern of light in the interior during the day and on the exterior at night. Mechanical service elements are contained in a low, steel-framed structure on the north side of the building. The entry court is paved in a pattern of tinted concrete and uplighting that represents an abstracted diagram of solar energy generation.

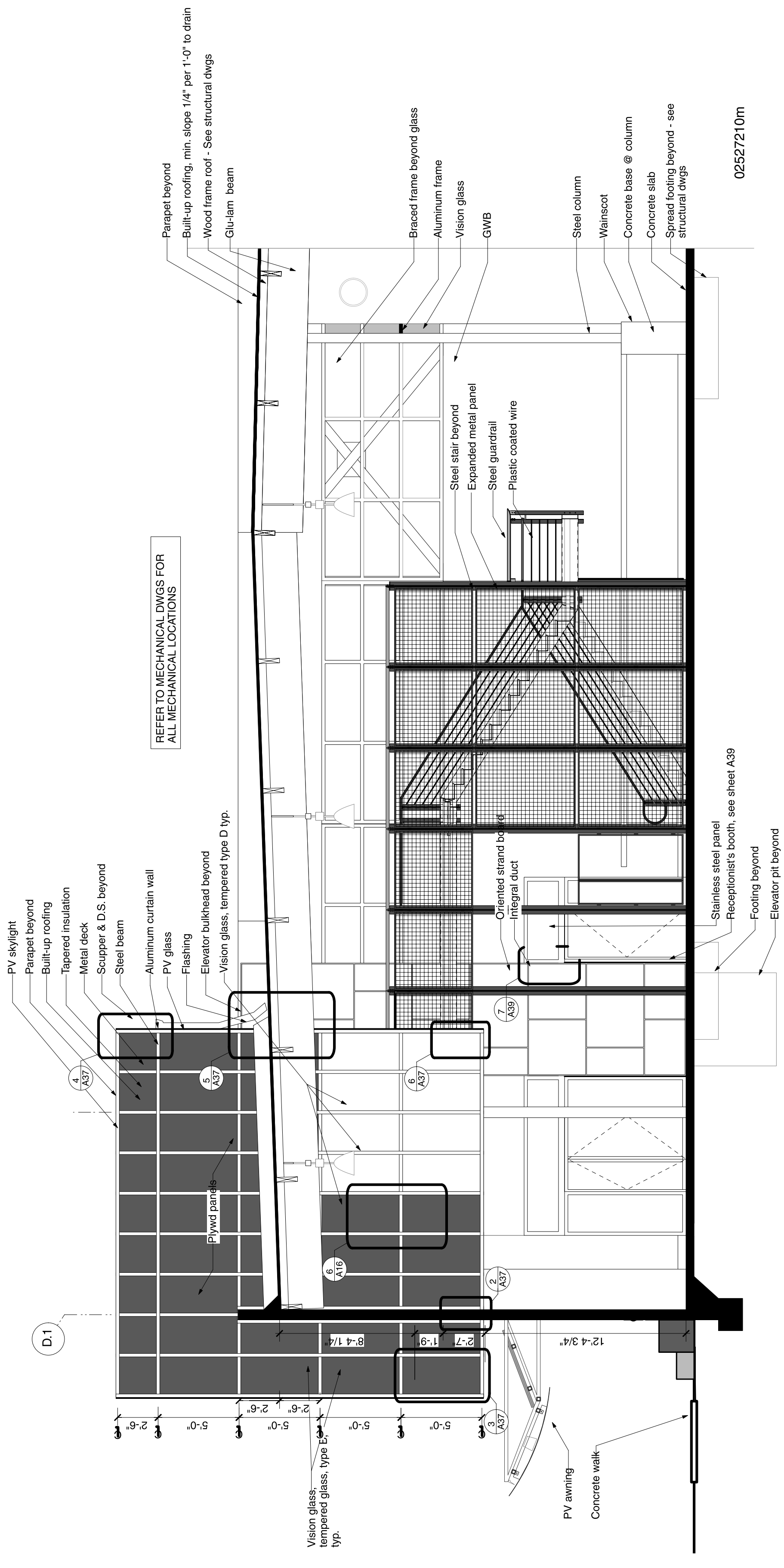
Special Design Considerations

In addition to providing a working product development test bed for BIPV systems, the project serves an educational function for public and private groups. The lobby/reception area provides display space for products and research. A pattern cast into the paving in front of the main entry combines a sun path diagram with a representation of the photovoltaic effect at the atomic level. The control room/cube also serves an educational

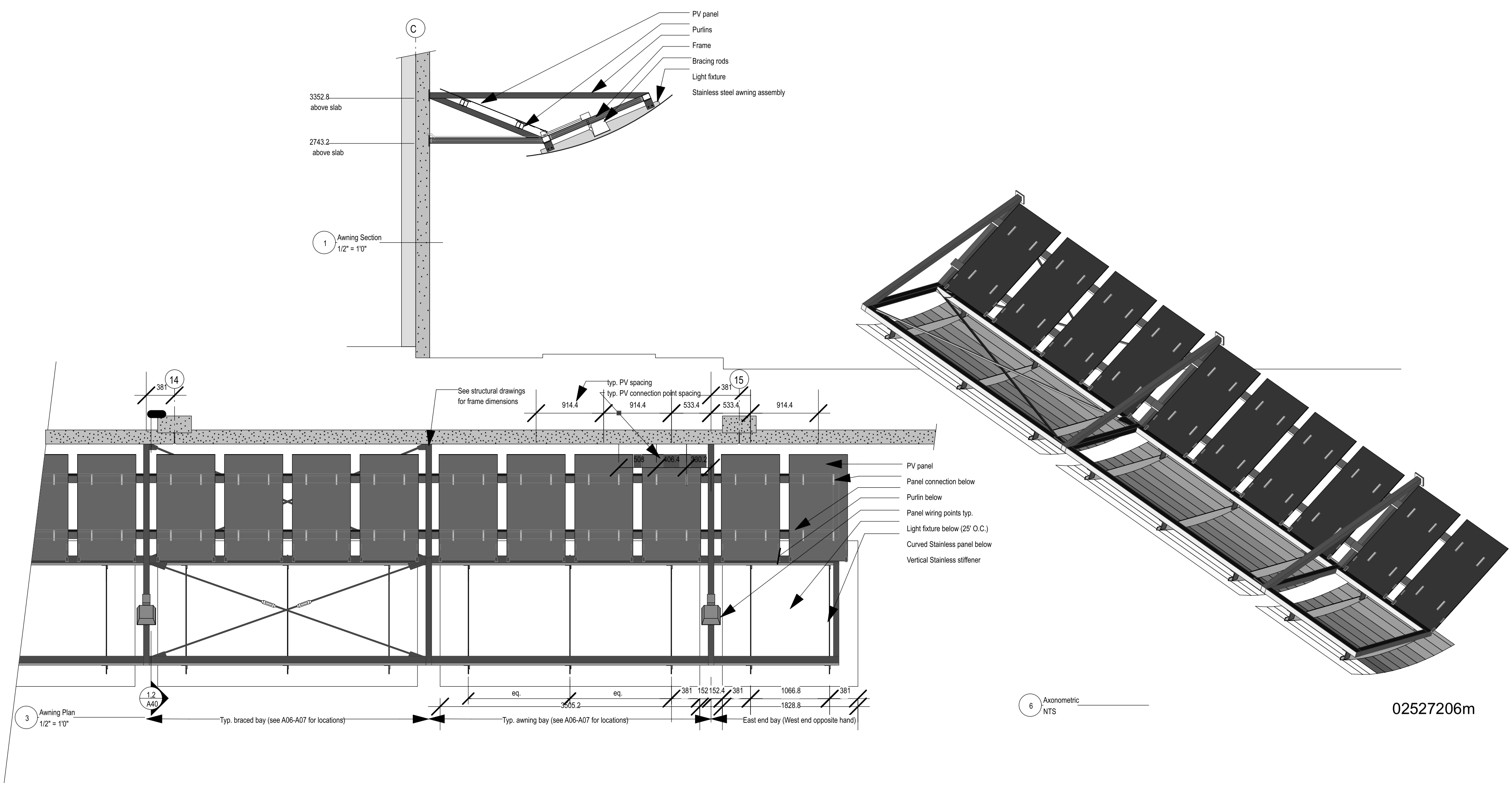


PIX08448

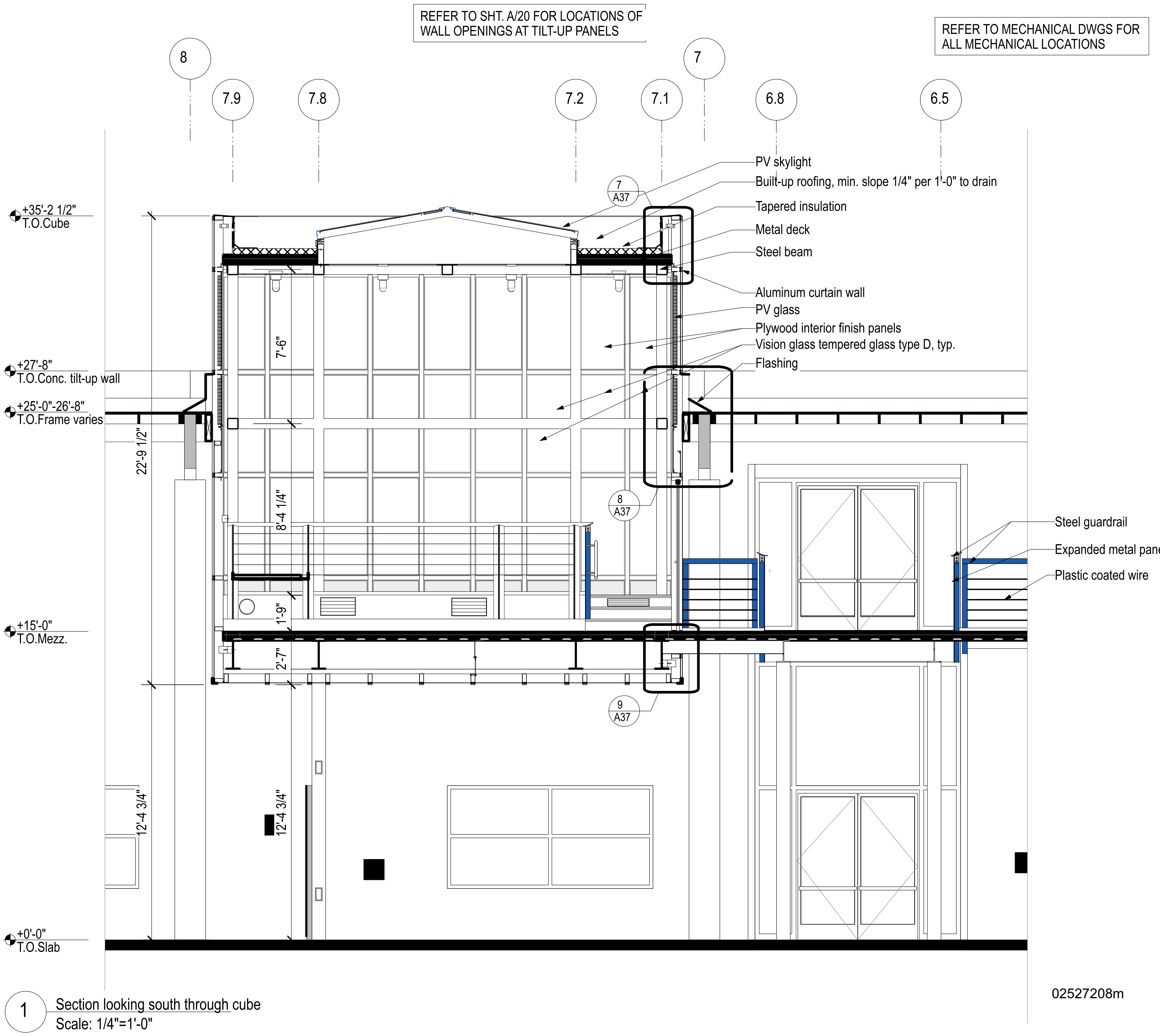
This office interior view demonstrates the quality of light transmitted by the approximately 5% translucent BIPV panel skylight.



Sectional view shows office "cube" and factory.



The PV awning provides a sunscreen.



Sectional view indicates skylight configuration and curtain-wall facade.

function; a raised platform allows groups of visitors to view the control equipment, and beyond it, the production line. Computerized monitoring equipment displays the status of the PV systems as well as information regarding building HVAC and lighting energy use, exterior ambient conditions, insolation, and other data.

Wherever possible, the PV systems are designed to do double duty in terms of energy management by reducing heat gain while providing power. The curtain wall and skylight are vented, eliminating radiant heat gain from the modules and enhancing natural ventilation in the cube. The awning is designed to shade the row of south-facing windows that open into the production area and employee lounge. The cube curtain wall integrates PV modules with vision glass in a standard pressure plate curtain wall framing system, modified to be self-ventilating. The system is intended to be economical and adaptable to new construction or retrofit.

PV System Configuration

The PV module is a nominal 2.5 ft x 5.0 ft, a-Si thin-film device rated at 50 Wp stabilized. The PV system contains 84 full-size modules mounted on the awning, 91 modules installed in the curtain wall, and 8 in a skylight. The curtain wall modules are installed in custom sizes as required by architectural conditions. The system has a total capacity of 7.9 kW; because of the varying orientations of the modules, the peak output is 5 kW. Despite the hot local climate, the power consumed by the cube for cooling and lighting never exceeds 3.5 kW, producing a surplus of PV power which is directed into the main building grid.

PV Module Mounting and Attachment Details

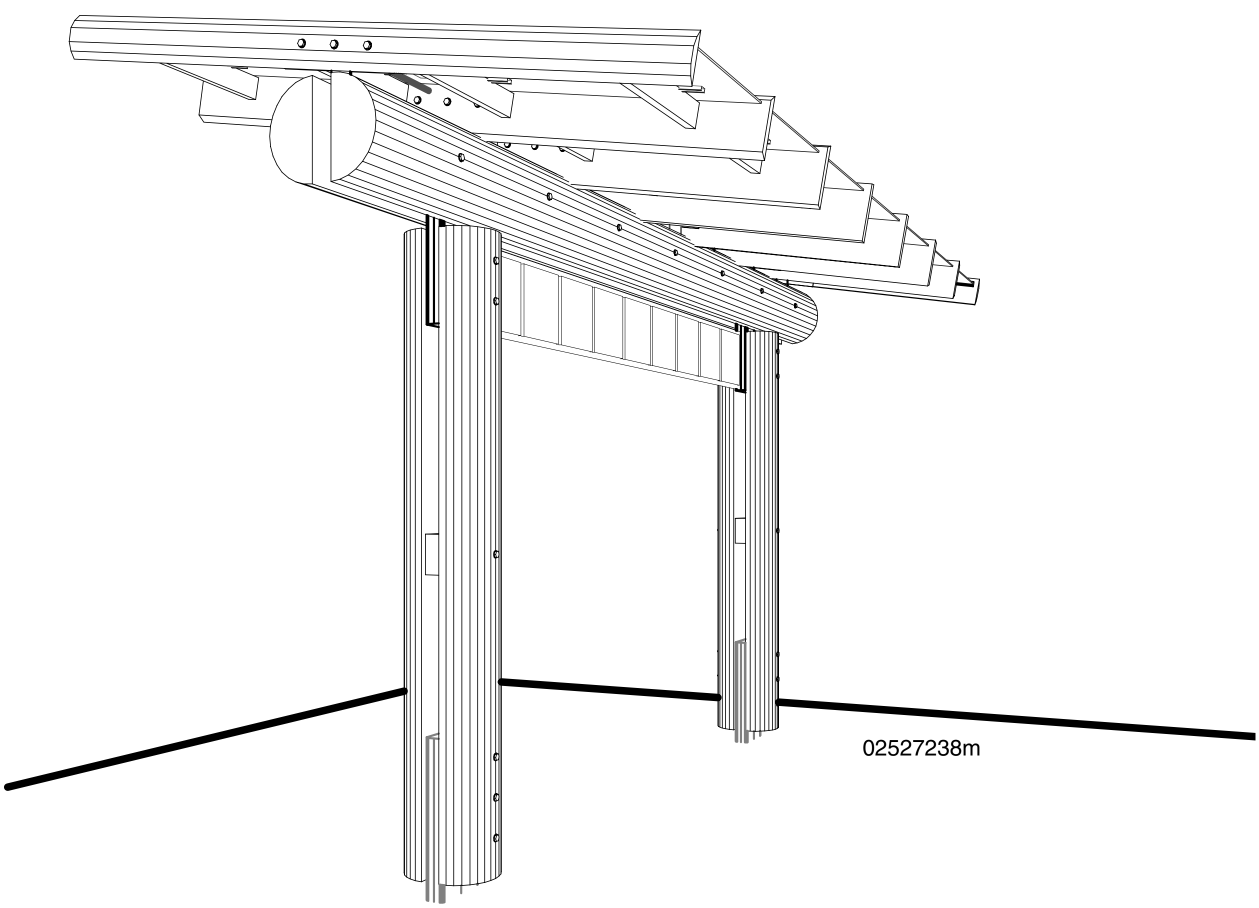
Standard PV modules are 31 in. x 61 in. but can be produced in custom sizes as required to fit the framing requirements of the curtain wall. One unique feature is that the modules are glass-to glass laminated products. The modules are installed with an insulated inner liner, which forms a plenum for ventilation. Heat radiated into the curtain wall plenum is vented to the outside by natural convection through holes drilled in the horizontal mullions. In some cases, the hollow vertical mullions are used as ducts to direct the warm air upward.

The skylight panels are standard modules that transmit approximately 5% of the sunlight through the laser scribe lines. The PV modules are supplemented by clear glazing units to increase light transmission. Another unique feature of this BIPV system is that the skylight is vented to remove heat gain from the modules.

The awning panels are bolted through the steel tube awning structure to aluminum channels epoxied to the encapsulating glass. This is the attachment used in typical field-mounted arrays.

Yosemite Transit Shelters

Location:	Yosemite National Park, California
Owner:	U.S. Department of Interior, National Park Service
Date Completed:	Scheduled for system completion in 2001
Architect & Designer:	Kiss + Cathcart, Architects
Structural Engineers:	Ove Arup & Partners, Structural Engineers
Electrical Engineers:	None; design overview provided by inverter manufacturer
Tradesmen Required:	Standard Contractor/Carpenter and Electrician
Applicable Building Codes:	National Park Service, self-regulating
Applicable Electrical Codes:	National Park Service, self-regulating
PV Product:	Amorphous silicon glass panels
Size:	560 Wp per transit shelter
Projected System Electrical Output:	1.15 MWh/yr
Gross PV Surface Area:	112 ft²
PV Weight:	3.375 lb/ft²
PV Cell Type:	Amorphous silicon
PV Efficiency:	6%
PV Module Manufacturer:	Energy Photovoltaics, Inc.
Inverter Numbers and Size:	1 kW
Inverter Manufacturer:	Advanced Energy Systems
Interconnection:	Optional—Grid-Connected or Stand-Alone



The transit shelter prototype makes use of both high-tech and low-tech materials, combining locally forested lumber with BIPV panels.

Description

Yosemite National Park is one of the most treasured environments in the United States – and also the site of serious vehicular traffic congestion. The National Park Service is working to reduce traffic and pollution in Yosemite by expanding the shuttle bus service and introducing electric shuttle buses. This necessitates an infrastructure of combined weather shelters and information boards at the new shuttle stops.

Funded by DOE FEMP, Kiss + Cathcart, Architects, is under contract to NREL to design a prototypical bus shelter incorporating BIPV panels. The park will begin installing the first of 19 new shuttle stops in the summer of 2000. The shelters that are near existing electrical lines will send the power they generate into the utility grid system serving Yosemite; the more remote shelters will have battery storage for self-sufficient night lighting.

Dave Parsons, NREL/PIX00923

Yosemite National Park

Special Design Considerations

The design mandate for this project is to balance a sense of the rustic historical building style of the Yosemite Valley with the frankly technological appearance of BIPV systems. The overall structure is a composite of heavy timber and steel plates that serves two purposes: accommodating heavy snow loads with minimum structural bulk and projecting an appearance that is rustic from a distance but clearly modern in a close-up view. The structural timbers (unmilled logs from locally harvested cedar) are split in half, and the space between them is used for steel connections, wiring, and mounting signage. The BIPV roof structure is made of a single log cut into eight separate boards.

A shallow (10°) tilt was chosen for the PV roof. A latitude tilt of approximately 37° would provide the maximum annual output in an unobstructed site; however, a shallower angle is better suited to Yosemite because of the considerable shading that occurs at low sun angles in the valleys, especially in winter. A steeper slope would also have made the shuttle stop much taller, significantly increasing structural loading and demanding a heavier structure. This was determined to be undesirable in terms of both appearance and material use.

PV System Configuration

Fourteen semitransparent, 40-W thin-film modules make up the PV system for each shelter. Power is fed to a single inverter. Some systems will be grid-connected and some will be stand-alone with batteries for backup.

PV Module Mounting and Attachment Details

The PV roof of the shelter is not designed to be watertight like the roof of an enclosed building. Instead, it is designed to be waterproof so that water does not drip through the roof in normal weather conditions. Therefore, the PV modules are overlapped (shingled) slightly along the center seam, and sheet metal gutters are inserted at the seam between the rough wood rafters and the modules.

Sun Microsystems Clock Tower

Location:	Burlington, Massachusetts
Owner:	Sun Microsystems
Date Completed:	October 1998
Architect & Designer:	HOK Architects and ASE Americas, Inc.
Structural Engineers:	Whiting-Turner Contracting Co.
Electrical Engineers:	Enertech Engineering
Tradesman Required:	Glaziers, electricians
Applicable Building Codes:	Uniform Building Code
Applicable Electrical Codes:	National Electric Code Section 620
PV Product:	BIPV curtain wall
Size:	2.5 kWp
Projected System Electrical Output:	2.5 kWp
Gross PV Surface Area:	827 ft^2
PV Weight:	8.3 lb/ft^2
PV Cell Type:	Polycrystalline silicon manufactured by ASE Americas, Inc.
PV Efficiency:	12.8%
PV Module Manufacturer:	Pilkington Solar International
Inverter Number and Size:	One 2.5 kWp inverter
Inverter Manufacturer and Model:	Omnion Power Corp.
Interconnection:	Utility-Grid-Connected

ASE Americas, Inc./PIX07044

North-facing view of the clock tower at Sun Microsystems facility.

ASE Americas, Inc./PIX07042

Pilkington Solar International's project leader, John Goldsmith, is shown with the integrated curtain wall on the south and west faces of the clock tower.

ASE Americas, Inc./PIX07045

East view of the clock tower shows BIPV installation.

Description

ASE Americas recently provided the design, PV panels, and electronic equipment needed to power an 85-ft high clock tower on Sun Microsystems' new 1 million ft^2 campus in Burlington, Massachusetts. The architects who designed the building included both electrically active and electrically inactive glass panels on four sides of the tower. The electrically active panels incorporating PV modules were used on the east and west sides. A diffuse light pattern washes around the edges of the solar cells in the inside of the tower to create a soft look in the interior. The clock tower load is primarily a nighttime load. Energy from the PV array goes into the building by day, and the clock tower draws power at night from the building's electrical grid. This could be the first use of dual-glazed, thermally insulated PV panels in a U.S. building structure.

Special Design Considerations

The PV panels were custom designed to match the dimensions of the Kawneer Series 1600 mullion system used on the four sides of the clock tower. They were fabricated as dual-glazed, thermally insulating panels with a glass-cell-glass laminate as the outer surface and a frosted glass sheet as the inner surface. Some of the panels were required to wrap around the clock, so three different basic shapes were designed with round cusps cut out of the corners to match the curvature of the round, 7.5-ft-diameter clock. Two rectangular shapes were required so the panels were vertically arranged to match the floor levels.

PV System Configuration

The PV modules are connected in series and feed electricity into an inverter that converts the 2.5 kW DC power to AC.

PV Module Mounting and Attachment Details

Eight electrically active panels were fuly wired and interconnected through an inverter and transformer into the building wiring as a utility-interactive system. These systems are the simplest and most economical way to install a PV power source. There are no batteries in this type of system, since the system draws power from the building's electrical grid.

State University of New York, Albany

Location:	Albany, New York
Owner:	State University of New York, Albany
Date Completed:	Summer 1996
Architect:	Cannon Architects
Electrical Engineer:	Cannon Architects
Solar Consultant:	Solar Design Associates, Inc.
Tradesmen Required:	Beacon Sales Corporation, roofing contractors
Applicable building codes:	New York State Building Code and ANSI Z97.1
Applicable electrical codes:	National Electric Code
PV product:	Kawneer 1600 PowerWall™
Size:	15 kWp
Project System Electrical Output:	19,710 kWh / yr.
Gross PV Surface Area:	1,500 ft^2
PV Weight:	1.93 lb / ft^2
PV Cell Type:	Polycrystalline silicon
PV Cell Efficiency:	12%
PV Module Manufacturer:	Solarex
Inverter Number and Size:	AES 250 watt
Inverter Manufacturer and Model:	Advanced Energy Systems Micro Inverter
Interconnection:	Utility-Grid Connected

Gordon Schenck/PIX084

Looking southeast at the Center for Environmental Sciences and Technology Management

Description

For the new Center for Environmental Sciences and Technology Management (CESTM) at the State University of New York in Albany, Cannon Architects developed an energy-conscious design strategy. This strategy included the integration of solar electric systems into both the building and the project site as landscape elements. The building incorporates 15 kWp of custom PV modules in building-integrated sunshades that support the PV modules while reducing cooling loads and glare on the south facade. The PV modules feature module-integrated inverters.

Special Design Considerations

This system was the first of its kind in the United States to tie together more than 2 kW of AC modules, and the first to use the AC module platform for a sunshade. AC modules proved to be far more effective than a typical single inverter, given the different light levels on the modules over the course of a day.

PV System Configuration

There are two different system configurations in the CESTM solar system. The sunshade portion consists of 59 pairs of framed Solarex MSX 120 modules. Each pair is connected to its own accessible AC micro-inverter. The inverters are installed inside the building for ease of service. The landscape portion consists of 18 pairs of Solarex MSX 240 modules. An AC micro-inverter is attached to the underside of each pair.

PV Mounting and Attachment Details

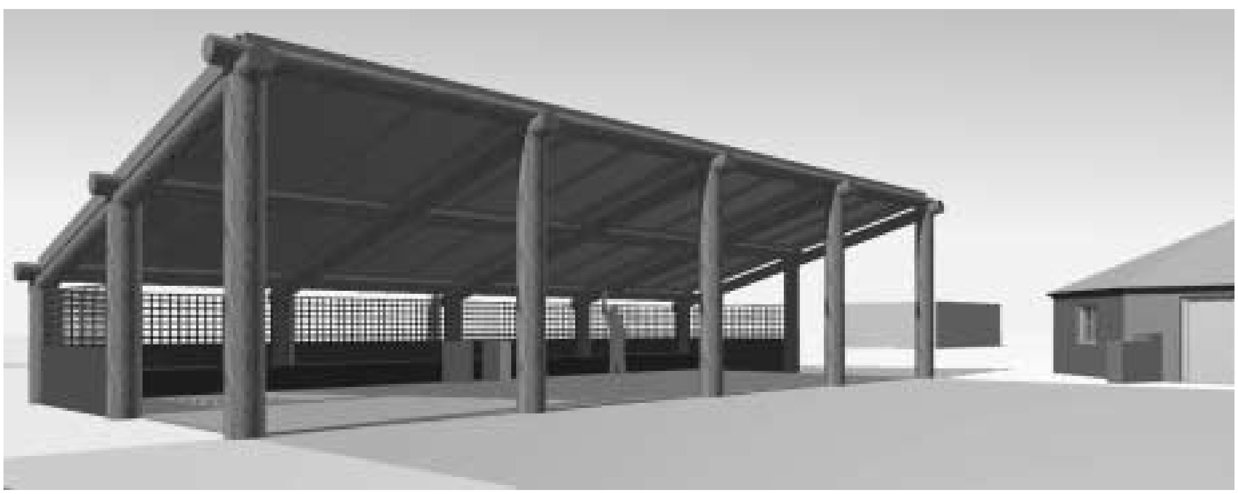
Solarex provided framed PV modules that were modified to incorporate the AES micro-inverters. Most of the modules were mounted in an aluminum strut, creating a solar sunshade. The rest of the modules were mounted above ground, along a curved pathway at the main approach to the building. The building's sunshades use standard extrusions from the Kawneer curtain wall system, the Kawneer 1600 PowerWall™. This custom configuration provided structural support to the modules.

Gordon Schenck/PIX08464

Close-up view of photovoltaic sunshade

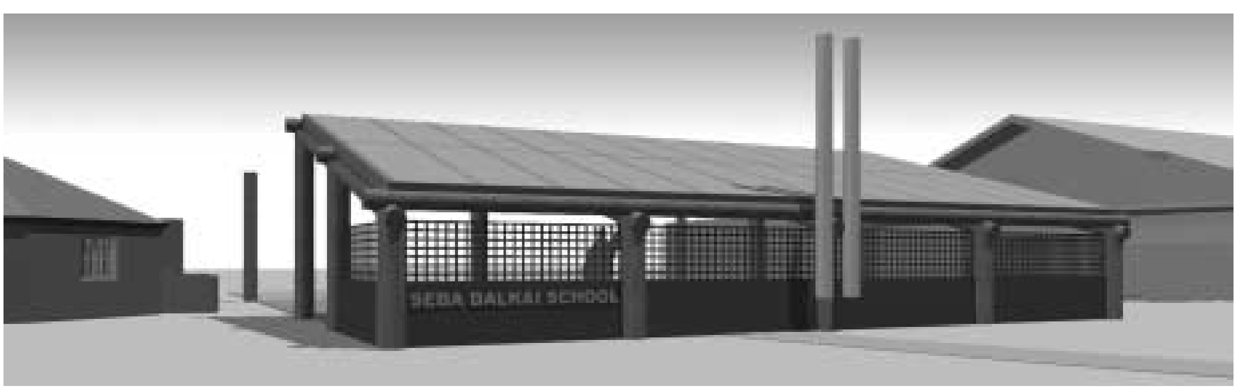
Navajo Nation Outdoor Solar Classroom

Location:	Seba Dalkai, Navajo Reservation, Arizona
Owner:	Seba Dalkai Boarding School
Scheduled Completion Date:	Fall 1999
Architect:	Kiss + Cathcart, Architects
Electrical Engineer:	Energy Photovoltaics, Inc.
Solar Consultant:	Kiss + Cathcart, Architects
Tradesmen Required:	Electricians, laborers
Applicable Building Codes:	Standard building codes
Applicable Electrical Codes:	National Electric Code
PV Product:	Energy Photovoltaics EPV-40 modules
Size:	4.0 kWp
Projected System Electrical Output:	5,818 kWh/yr
Gross PV Surface Area:	625 ft^2
PV Weight:	3.75 lb/ft^2
PV Type:	Amorphous silicon
PV Efficiency:	6%
PV Module Manufacturer:	Energy Photovoltaics, Inc.
Inverter Number and Size:	Four 2.5 kW inverters
Inverter Manufacturer:	Trace Engineering
Interonnection:	Stand-Alone System

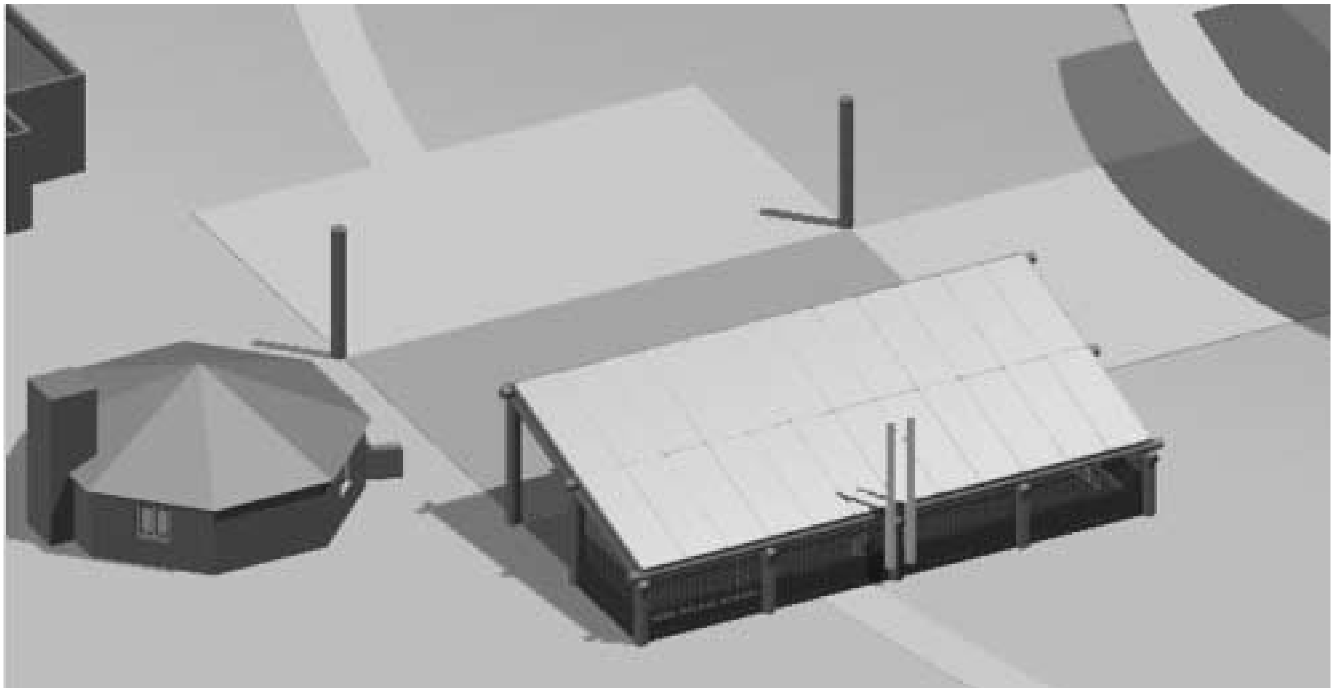


02527276m

Each new BIPV structure at the Seba Dalkai School will serve as an open-air classroom supported by timber columns in a concrete foundation.



02527274m



02527275m

The design attempts to establish a connection with Navajo building traditions.

Description

The Seba Dalkai Boarding School, a Bureau of Indian Affairs school on the Navajo Reservation in Arizona, is constructing a new K-8 facility to be completed in 2001. Funded by DOE FEMP, this facility will incorporate a BIPV system capable of producing approximately 4.0 kW of electricity.

The school is currently housed in a traditional hogan and in a stone facility built in the 1930s. These will remain and be juxtaposed with a new school facility. The photovoltaic component of this project will mediate between the old and the new, and it will add a structure that clearly expresses solar technology and BIPV principles. Funded by DOE FEMP, this structure will serve as an outdoor classroom and as part of the school's HVAC circulation system. It will also be a hands-on laboratory for educating people about BIPV systems and training them in system installation.

Special Design Considerations

The installation is designed to minimize the cost of the support structure while incorporating sustainable construction materials. Within an enforced simplicity, the design attempts to establish a connection with Navajo building traditions.

PV System Configuration

The design includes two 25-ft x 25-ft, open-sided, timber-framed structures. Each one supports 2.88 kW of semitransparent PV modules, and each one includes two Trace 2.5-kW inverters plus batteries for three days' worth of energy storage. Each structure will function as an open-air classroom.

PV Mounting and Attachment Details

The PV modules are attached with aluminum extrusions fixed with silicone to the back of the glass (four per module). Each aluminum channel is 12 ft long. The channels are supported on a grid of rough timber beams, which in turn are supported by timber columns on concrete foundations.

General Services Administration, Williams Building

Location:	408 Atlantic Avenue, Boston, Massachusetts
Owner:	U.S. General Services Administration
Date Completed:	September 30, 1999
Project Developers:	Enron Energy Services and U.S. General Services Administration
Electrical Engineer:	PowerLight Co.
Solar Consultant:	PowerLight Co.
Tradesmen Required:	Electricians and roofers
Applicable Building Codes:	Standard building codes
Applicable Electrical Codes:	National Electric Code, Boston Electric Interconnection Guidelines, and IEEE Specifications
PV Product:	PowerLight, using ASE Americas, Inc., solar panels
System Size:	37 kW DC, 28 kW AC
Projected System Electrical Output:	50,000 kWh/yr
Gross PV Surface Area:	Approx. 3,800 ft^2
PV Weight:	4 lb/ft^2
PV Cell Type:	Amorphous silicon
PV Efficiency:	12%
PV Module Manufacturer:	ASE Americas, Inc.
Inverter Number and Size:	1 30 kVa
Inverter Manufacturer:	Trace Engineering
Interconnection:	Utility-Grid-Connected

PIX08465

PIX08474

The nine-story Williams Building in Boston (at right in photo above) has a new BIPV roof (bottom, lower right photo) rather than a conventional one.

Description

In this project, a regularly scheduled roof replacement was upgraded to the installation of a building-integrated photovoltaic roof. The BIPV roof is installed on the Williams Building in downtown Boston. The U.S. Coast Guard is the leading tenant of this 160,000-ft² building, which sits on Rowe's Wharf at 408 Atlantic Avenue, near the city's financial district.

In addition to the new PV system for the roof, the building is also switching from district steam to on-site gas boilers. Two 75-kW Teco-gen co-generation units are also being added, as well as a high-efficiency chiller, more efficient lighting, and upgraded, more efficient motors.

Special Design Considerations

The building is located on a wharf, so the design must take into account not only the water but also 140-mile-per-hour wind conditions at the site.

After a site review, including a review of the wind conditions, the contractor decided to use a PowerLight RT photovoltaic system. The RT system was chosen for its cost-effectiveness when extreme roof penetrations are required (for example, with penthouses, skylights, and HVAC frames).

PV System Configuration

This system produces 37 kWp DC and 28 kW AC. Its 372 PV panels are connected in sets of 12. Each panel has a maximum output of 100 watts.

PV Mounting and Attachment Details

A metal raceway, ballast, and anchoring system is used. It was also necessary to add rigid insulation for thermal protection.

The PowerLight RT system is fastened to the roof along its perimeter using epoxy-embedded anchors set into the concrete deck. These use pitch pans and a raceway for moisture protection. The system allows water to flow under the PowerGuard to existing roof drains. It should not be necessary to add new drains.

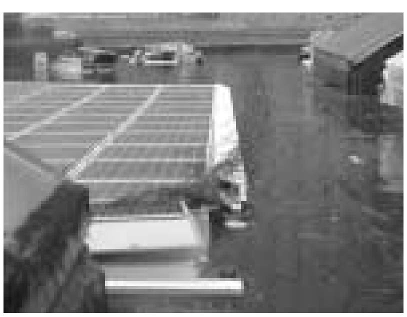
A harness from the panels goes through two conduits into attic space located above the eighth floor. Part of the attic needed additional metal decking.

Wiring for the rooftop installation

PIX08473

Paul King, DOE Boston Regional Office FEMP liaison, surveys the installation work.

PIX08470

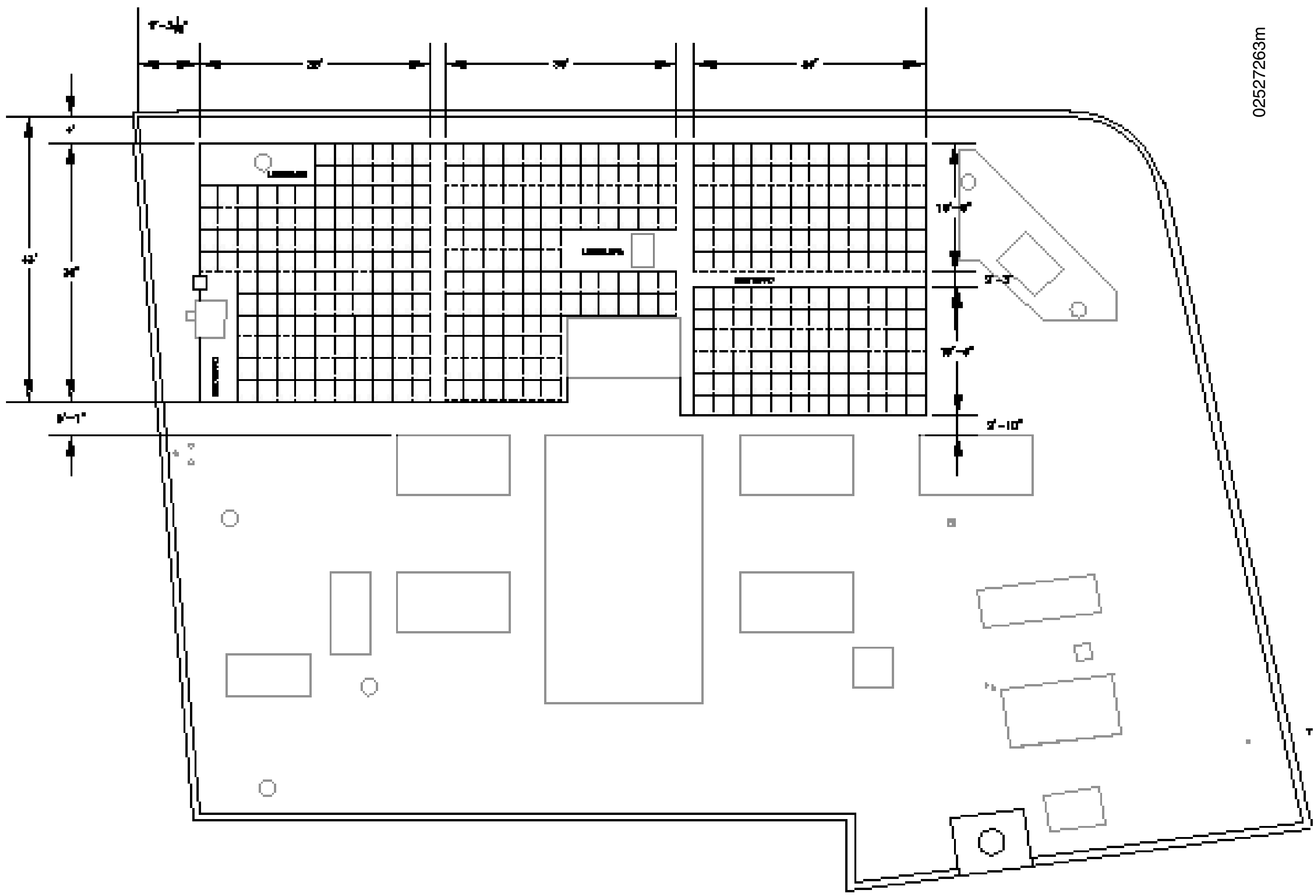


PIX08472

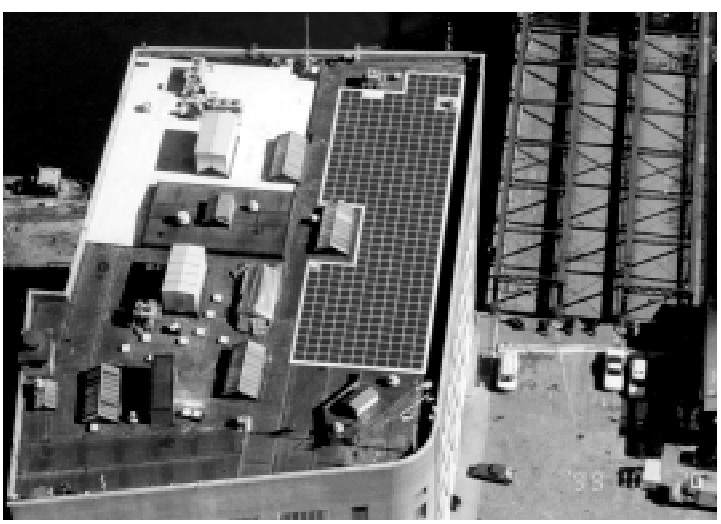
View of the new BIPV roof on the Williams Building, during and after construction

PIX08471

Pavers are in foreground, PV array is in background on the rooftop.



The plan for the roof of the Williams Building included a rooftop BIPV system consisting of 372 solar panels.



Jeff Ansley, PowerLight Corporation/PIX08461

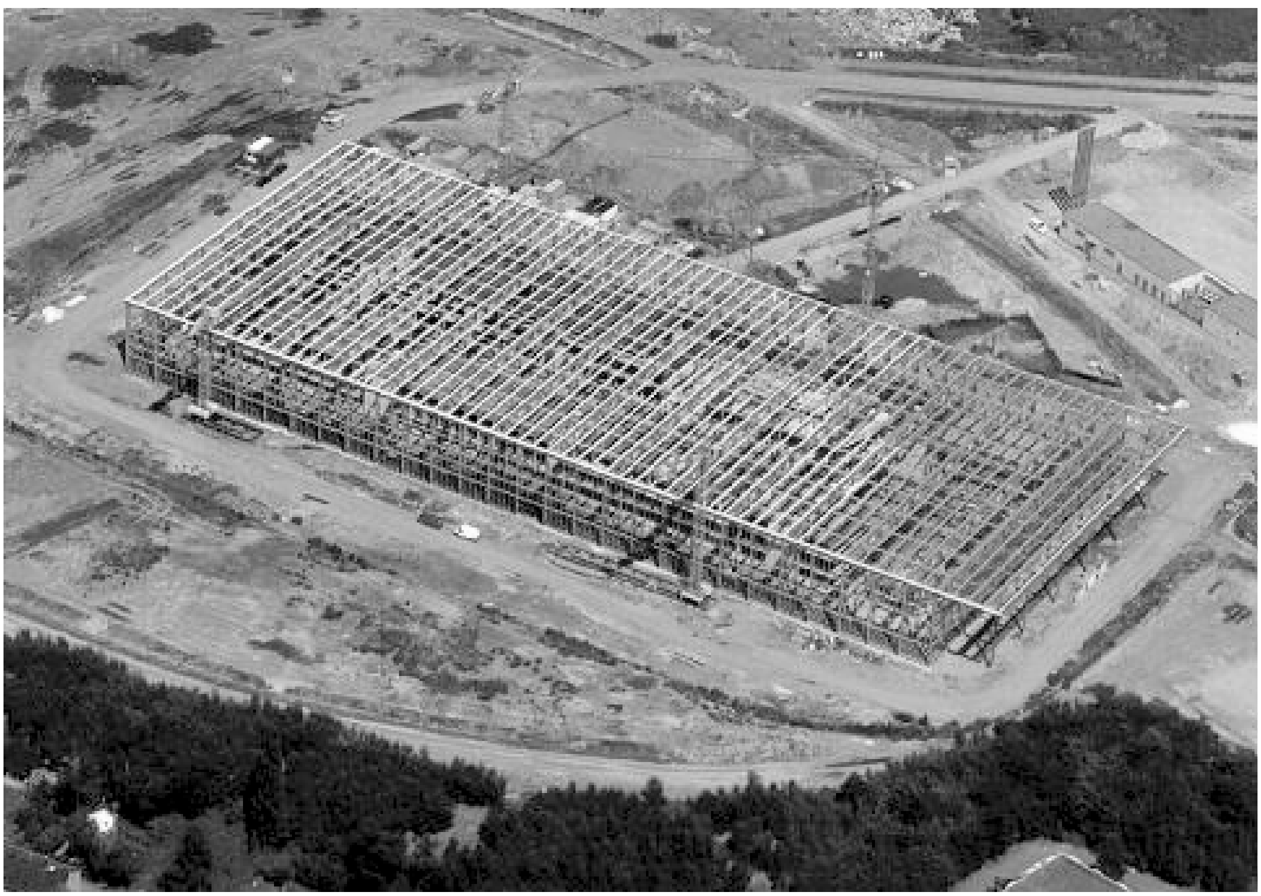
Co-funded by the DOE FEMP Renewable Energy Program, this BIPV application illustrates how the technology can be introduced into complex roof spaces.

Jeff Ansley, PowerLight Corporation/PIX08466

Shading from other buildings is not a problem at this site, which is in urban Boston.

Academy of Further Education

Location:	Herne, North Rhine-Westphalia, Germany
Owner:	EMC, Ministry of Interiors of North Rhine-Westphalia, City of Herne
Date Completed:	May 1999
Architect & Designer:	Jourda et Perraudin Architects, HHS Architects
Structural Engineers:	Schleich, Bergermann and Partner
Electrical Engineers:	HL-Technik
Tradesmen Required:	Glaziers, electricians
PV Product:	BIPV roof
Size:	1 MWp
Projected System Electrical Output:	750,000 kWh/yr
Gross PV Surface Area:	10,000 m^2
PV Weight:	130 kg per each 3.2 m^2 module
PV Cell Type:	Polycrystalline and monocrystalline silicon
PV Efficiency:	12.8% to 16%
PV Module Manufacturer:	Pilkington Solar International, Cologne
Inverter Number and Size:	600, 1.5 kW
Inverter Manufacturer and Model:	SMA, Kassel
Interconnection:	Utility-Grid-Connected



PIX08454

The Academy of Further Education under construction in Herne, Germany

Description

As part of the International Construction Exhibition, Emscher Park, the site of a former coal mine in Herne, Germany, is being used for a new purpose. A comprehensive urban development plan is providing the district of Sodingen with a new centerpiece: the Academy of Further Education, Ministry of Interior, North Rhine-Westphalia.

The large glass hall incorporates not only the Academy but also a hotel, library, and administrative municipal offices. The glass hall is multifunctional. It protects the interior from harsh weather and uses solar energy both actively and passively by producing heat as well as electric power.

Special Design Considerations

Approximately 3,180 multifunctional roof and facade elements are the core of the solar power plant. With a total area of 10,000 square meters, most of the roof and the southwest facade is covered by photovoltaics, making this system the largest building-integrated PV power plant in the world. It produces approximately 750,000 kWh of electric power per year. This is enough to supply more than 200 private residences. About 200,000 kWh is used directly by the Academy building, and the remaining 550,000 kWh is fed into the public power grid in Herne.

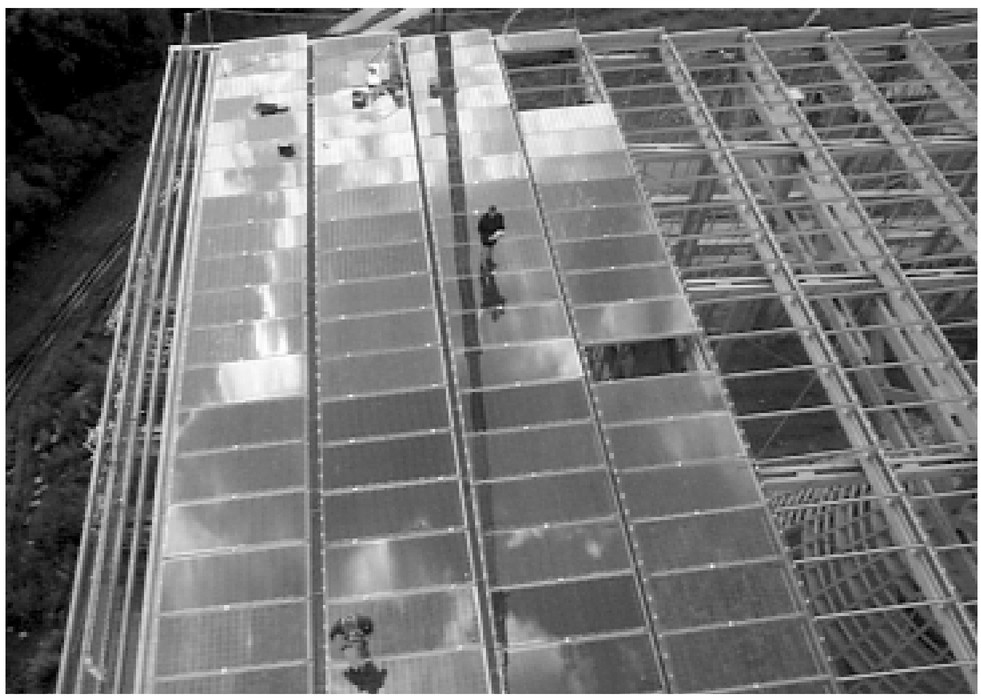
PV System Configuration

The Optisol photovoltaic elements were produced by Pilkington Solar at a site in Germany. The PV system consists of solar cells embedded between glass panes. Daylighting needs were taken into account in designing the roof- and facade-integrated system. The PV modules have areas of 2.5 to 3.2 square meters and an output of 192 to 416 peak watts each. This makes them larger and more powerful than most conventional solar modules.

Direct-current electricity is converted to 230 V alternating current by means of a modular inverter. This is made up of roughly 600 decentralized string inverters and allows optimal use of the incident solar radiation.

PIX08455

An inside view of the Academy building as construction progressed



PIX08456

This photo shows how the PV panels are angled to capture the sunlight shining on the roof.

Mounting and Attachment Details

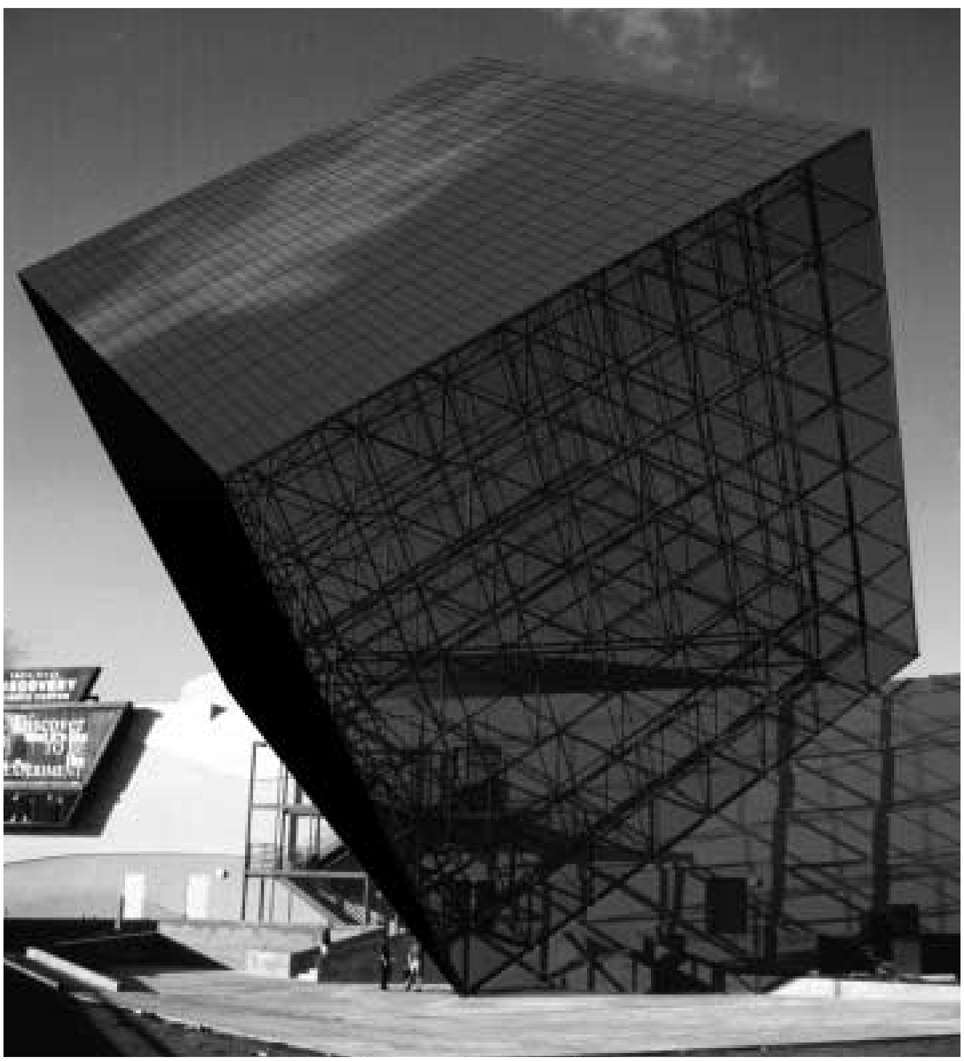
The building-integrated photovoltaic panels are set into aluminum mullions like skylights. The rooftop panels are positioned at an angle to capture as much of the incident sunlight as possible.


PIX08457

Rooftop view shows placement of insulation and PV panels.

Discovery Science Center

Location:	Santa Ana, California
Scheduled Completion Date:	November 1999
Architect & Designer:	Arquitectonica for the cube, Solar Design Associates for the PV system
Structural Engineers:	Advanced Structures, Inc.
Electrical Engineers:	Solar Design Associates, Inc.
Tradesmen Required:	Electricians
Applicable Building Codes:	Building Administrators Code Administrators International (BOCA)
Applicable Electrical Codes:	National Electric Code
PV Product:	Thin-film photovoltaic system
Size:	20 kWp
Projected System Electrical Output:	30,000 kWh/yr
Gross PV Surface Area:	4,334 ft^2
PV Weight:	3 lb/ ft^2
PV Cell Type:	Thin-film technology
PV Efficiency (%):	5.1 %
PV Module Manufacturer:	BP Solarex
Inverter Number and Size:	4
Inverter Manufacturer and Model:	Omnion 2400, Model 5015
Interconnection:	Utility Grid-Connected



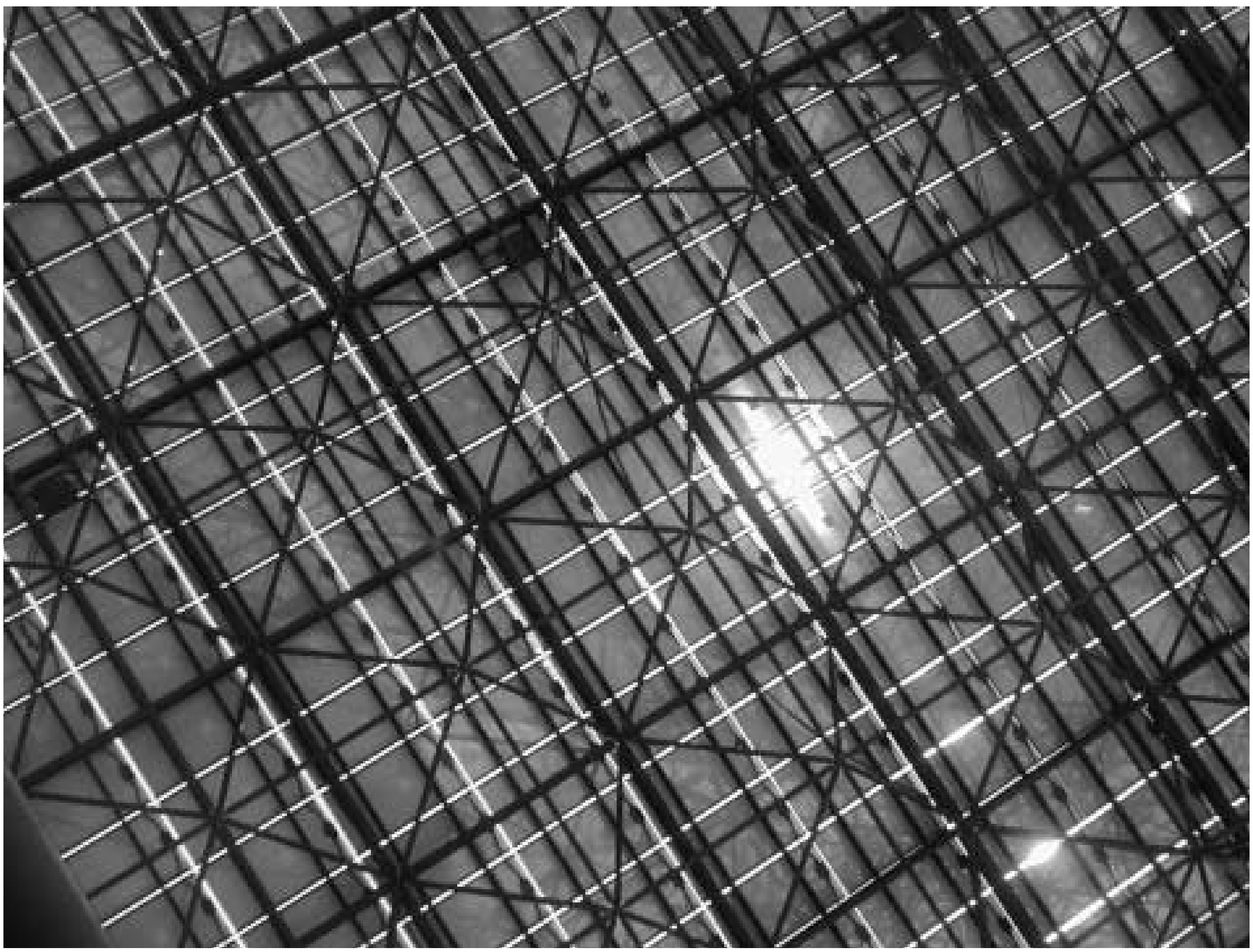
Solar Design Associates, Inc./02527271

Architect's rendering of the Discovery Science Center Cube in Santa Ana, California

Description

This solar electric system, located in Santa Ana, California, boasts one of the world's largest building-integrated thin-film applications to date. The PV-covered surface of the cube is tilted at 50° for maximum visual impact and optimal solar harvest. BP Solarex's Millennia modules cover the entire 4,334-ft² top of the cube The thin-film modules are treated as an architectural glazing element, replacing what would have been a glass canopy. They produce up to 20 kW of DC electricity at mid-day and 30,000 kWh of electrical energy per year, which is enough to run four typical homes.

The solar energy system is connected to the Discovery Science Center's main utility line. When the solar system produces energy, it feeds the energy to the Science Center, displacing conventional utility power. When the solar system produces more electricity than the Science Center needs, the excess electricity is "exported" to the utility, thereby effectively spinning the electric meter backwards.

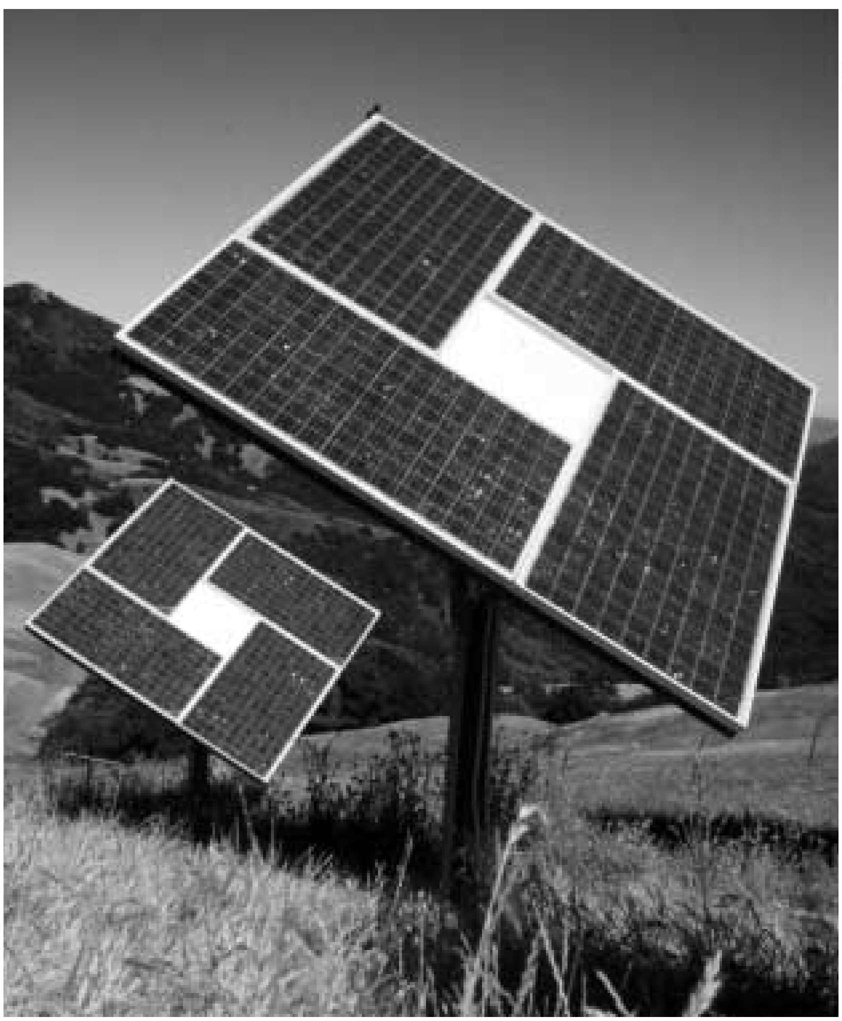


Solar Design Associates, Inc./02527277m

The view from inside the cube

Solar Sunflowers

Location:	Napa, California
Date Completed:	N/A
Architect & Designer:	Solar Design Associates, Inc.
Structural Engineers:	Solar Design Associates, Inc.
Electrical Engineers:	Solar Design Associates, Inc.
Tradesmen Required:	Electricians
Applicable Building Codes:	Building Officials Code Administrators International (BOCA)
Applicable Electrical Codes:	National Electric Code
PV Product:	BP Solarex
Size:	36,000 Wp
Projected System Electrical Output:	N/A
Gross PV Surface Area:	3,456 ft^2
PV Weight:	3.4 lb/ ft^2
PV Cell Type:	Polycrystalline
PV Efficiency:	11.1%
PV Module Manufacturer:	BP Solarex
Inverter Number and Size:	6
Inverter Manufacturer and Model:	Omnion Series 2400, Model 6018
Interconnection:	Utility-Grid-Connected



PIX08468

These Solar Sunflowers track the sun to produce electricity.

Description

Nestled atop a hillside in Northern California, 36 Solar Electric Sunflowers represent an elegant combination of art and technology. The clients requested an unconventional and artistic installation. They got just that.

Just like a sunflower, the Solar Electric Sunflowers look and act like nature's own variety. Making use of a two-axis tracking system, the sunflowers wake up to follow the sun's path throughout the day, enabling the system to produce enough energy for eight to ten homes.

PIX08467

Solar electric sunflowers resemble nature's own.

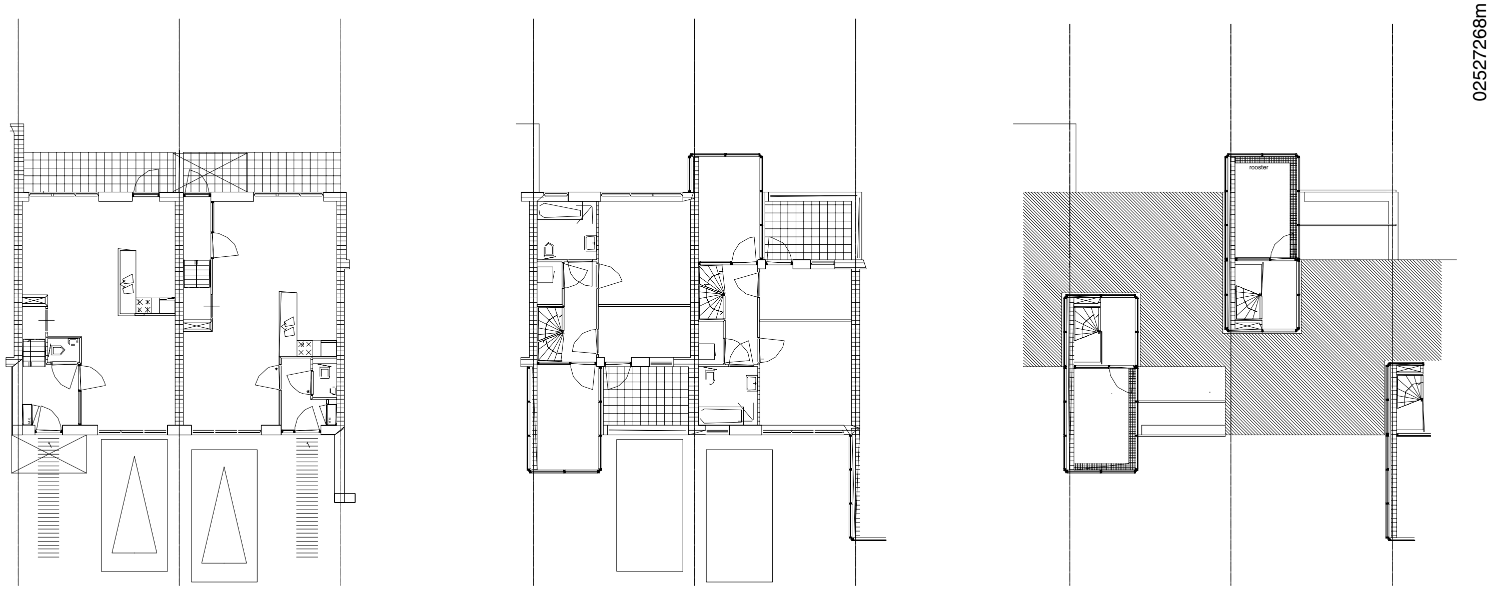
Ijsselstein Row Houses

Location:	Ijsselstein Zenderpark, Ijsselstein, The Netherlands
Date Completed:	Scheduled for completion in late 2000
Architect & Designer:	Han Van Zwieten, Van Straalen Architecten, co-designer; Gregory Kiss, Kiss + Cathcart Architects, co-designer
Structural Engineers:	N/A
Electrical Engineers:	N/A
Tradesmen Required:	Building tradesmen
Applicable Building Codes:	Dutch Building Code
Applicable Electrical Codes:	Dutch Electrical Code
PV Product:	Standard-size BIPV glass laminate panels
Size:	1.6 kWp per housing unit
Projected System Electrical Output:	1150 kWh/year per housing unit
Gross PV Surface Area:	30 m^2 per housing unit
PV Weight:	3.75 lb/ft^2
PV Cell Type:	Amorphous silicon, both opaque and 15% translucent
PV Efficiency:	6%
PV Module Manufacturer:	EPV
Inverter Number and Size:	N/A
Inverter Manufacturer and Model:	N/A
Interconnection:	Utility-Grid-Connected

02527269m

Fourteen planned new row-house units in the Netherlands demonstrate the aesthetic use of building-integrated photovoltaics: front (above) and back views.

02527270m



Sample floorplans for row-house units

Description

This Dutch-American design collaboration is intended to develop a new standard in Europe for moderately priced housing with integrated solar electric systems. The first phase consists of 14 row-house units, each with its own grid-connected BIPV array. As part of a highly ordered "new town" development adjacent to the city center of Ijsselstein, these units conform to strict space and budget guidelines as well as to advanced standards of PV integration.

The overall design is a composition of brick volumes and two-level, wood-framed sunrooms. The latter are partially clad in opaque and translucent PV units, and they are raised and staggered to maximize solar exposure. The sunroom volumes are wood-paneled on the sides facing north.

The Netherlands is home to some of the most advanced PV systems in the world. However, before this project began, little work had been done on integrating solar arrays into the prevailing Dutch architectural idiom of abstract cubic forms. The Ijsselstein row houses demonstrate how photovoltaics can be a fully participating element in the design, rather than just an applied system. Amorphous silicon modules in particular are generating very positive responses among many Dutch architects, who perceive them as looking much more like an architectural material than polycrystalline panels do.

Special Design Considerations

In marked contrast to the United States, The Netherlands favors residential design that is largely modern and rational in character. The ubiquitous pitched roofs of North American houses (which provide convenient mounting surfaces for PV arrays) were considered aesthetically undesirable at Ijsselstein. However, at higher latitudes with low sun angles, vertically mounted BIPV panels can generate power at output levels competitive with those of optimally angled panels. The design takes advantage of this by using standard-sized units as glazing and exterior enclosure combined in a simple wooden frame wall.

Extensive computer modeling studies were done to ensure that the complex massing of the row houses works to provide maximum solar exposure for each unit's array and minimum shadowing of BIPV surfaces by adjacent units.

Given that BIPV glass is a major cladding component for the sunroom elements, excessive interior heat loss or gain was a significant design consideration. The adjacent stair serves as a convection chimney that actually uses the heated air produced in the sunrooms to draw air currents through the entire row house, cooling it in warm weather. Cold weather conditions are addressed simply by providing a suitable layer of insulation between the cladding and the interior finish.

PV System Configuration

A 1.6-kW, grid-connected BIPV system is part of each row house. Each system will be individually metered, and there is no battery storage.

PV Module Mounting and Attachment Details

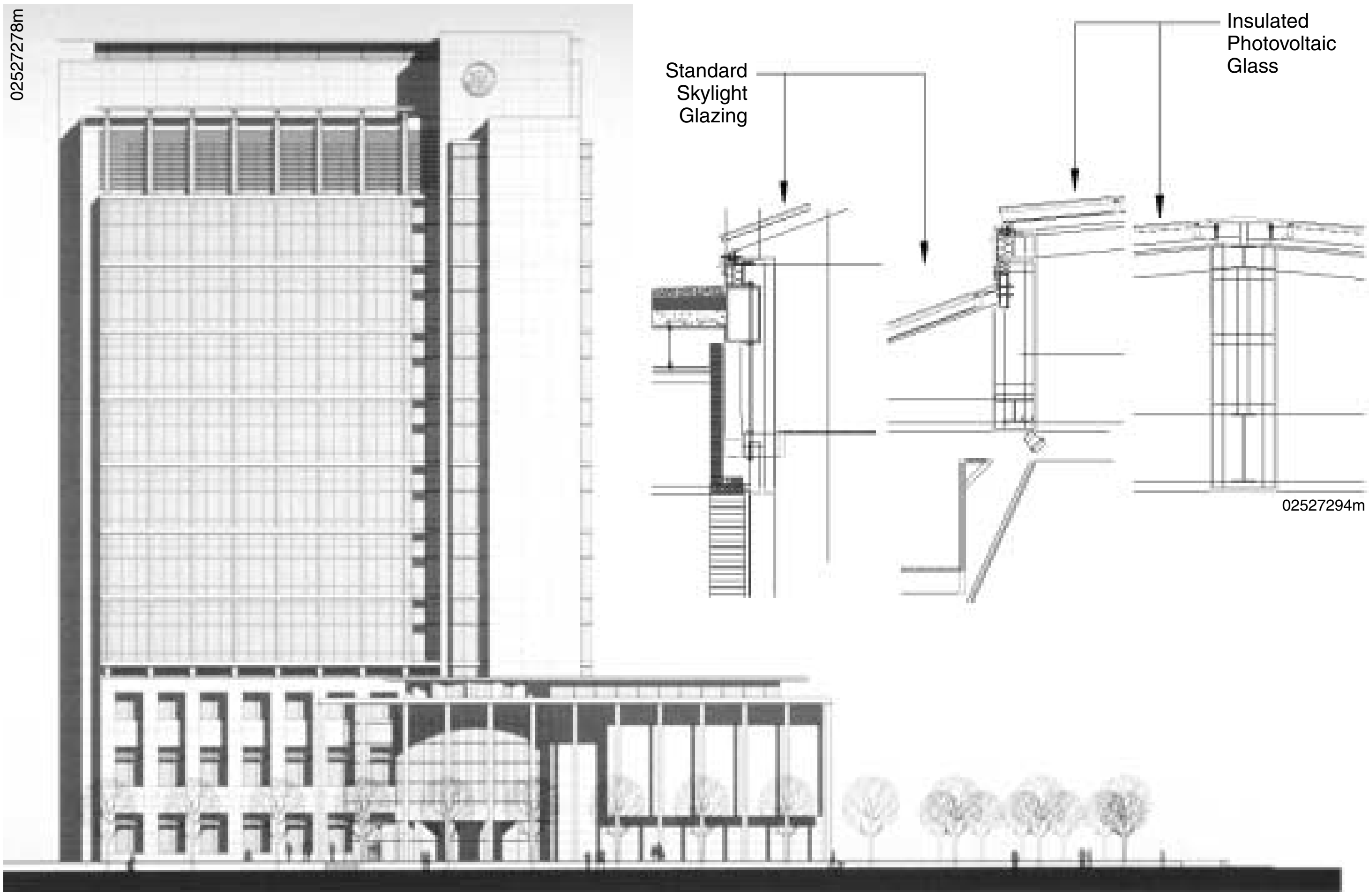
Standard PV modules are set into a wood framing system, which can be either site-built or prefabricated. The opaque units are set as typical single glazing, using minimum-profile glazing stops and caulk. The translucent panels are incorporated into double-glazed window units. The horizontal members of the wood frame have an absolute minimum exposed depth to prevent shadowing. The vertical members, which are not as likely to interfere with solar exposure, have a raised profile.

Denver Federal Courthouse

Location:	Denver, Colorado
Owner:	U.S. General Services Administration
Date Completed:	Scheduled for completion in 2002
Architect & Designer:	Anderson Mason Dale (Architects); Hellmuth, Obata, & Kassabaum, St. Louis (Designers); Architectural Energy Corporation (Energy Consultants)
System Integration:	Altair Energy (PV Consultant)
Structural Engineers:	Martin/Martin, Inc.
Electrical Engineers:	The RMH Group, Inc.
Tradesman Required:	Building tradesmen/glaziers
Applicable Building Codes:	Uniform Building Code (1997)
Applicable Electric Codes:	National Electric Code (1999)
PV Product:	Custom-sized BIPV glass laminate
Size:	15 kWp (roof); 3.4 kWp (skylight)
Projected System Electrical Output:	20,150 kWh per year (roof); 4,700 kWh per year (skylight)
Gross PV Surface Area:	172 m^2 (roof); 59 m^2 (skylight)
PV Module Weight:	4,661 kg (roof); 2,749 kg (skylight)
PV Cell Type:	Single- or polycrystalline silicon
PV Efficiency:	10% or greater
PV Module Manufacturer:	Pilkington Solar
Inverter Number & Size:	One 20-kW and one 3.4-kW inverter
Suggested Inverter Manufacturers:	Trace Technologies, Trace Engineering, Omnion
Interconnection:	Utility-Grid-Connected

02527279m

The U.S. Court House expansion in Denver will be a showcase for sustainable building design.



Photovoltaics will be integrated into the top roof louver of the tower and into a skylight above the lobby rotunda.

Description

The United States Courthouse Expansion in Denver, Colorado, consists of 17 new courtrooms and associated support spaces for an additional 383,000 ft^2 (35,600 m^2). The U.S. General Services Administration (GSA) approached the expansion of this Federal Courthouse in downtown Denver as a showcase building for sustainable design. One of the GSA's project goals was to "use the latest available proven technologies for environmentally sensitive design, construction, and operation. It should set a standard and be a model of sustainable design." Another goal was to create a building that would remain usable for its 100-year lifespan.

The design projects an image of respect and reflects the city's rich architectural heritage. The 11-story structure houses six floors of district courts, two floors of magistrate courts, offices for the United States Marshal, a jury assembly area, and a special proceedings courtroom. Anderson Mason Dale P.C. is the architect of record, and HOK served as the design architect.

Recalling a traditional town square courthouse, the two-story pavilion is an arrangement of two geometric forms under a large horizontal roof. It is the frontispiece of the entire composition. An open peristyle colonnade supports the roof and transparently encloses the entrance lobby and the drum-shaped secured lobby. As a series of vertically oriented rectangular planes, the courthouse tower caps the structure with an open framework and a floating horizontal roof of photovoltaic panels.

With technical assistance provided by FEMP, the project's sustainable design consultant, Architectural Energy Corporation of Boulder, Colorado, and the design team developed the building's overall sustainable design strategies. The building achieves a high level of energy efficiency through a combination of strategies that seek first to reduce building energy loads as low as possible and then to satisfy the remaining reduced

This chart summarizes the BIPV system design:

Component	Orientation	Effective Area (m^2)	Size (kW)	Annual kWh
Roof area	Horizontal	173.4	13.9	23,300
Lobby skylight	Horizontal	63.6	4.4	7,400

loads through state-of-the-art, high-efficiency mechanical and electrical systems and renewable energy sources. The unique attributes of the Denver climate, sunny skies and low humidity, are used throughout the design to minimize energy consumption. The resulting building is a visible expression of sustainability through features that work together in an integrated energy-efficient system.

The improved building envelope allows substantial reductions in energy use for lighting, ventilation, and cooling. These reductions, along with the energy generated from the BIPV system, will make the annual operating energy costs of the new courthouse 43% lower than those of a building designed according to Department of Energy standards for energy efficiency (10 CFR Part 436, which is based on ASHRAE 90.1-1989).

Energy savings were calculated by constructing a simulation model of the building that meets the minimum requirements of the Federal Energy Standard (10 CFR Part 435). This minimally compliant building (the base building) was the baseline from which energy savings were calculated. A comparison of the simulated annual energy costs for the base building and the proposed design is shown below.

Local materials, such as precast concrete and native stone, have been incorporated into the exterior cladding system. The building will have a steel frame with recycled material content. Most of the flooring materials in the building are made from recycled or native sources, including native stone, cork, or recycled plastics. Low-impact landscaping is used to minimize water use, reduce the "urban heat island" effect, and provide an attractive outdoor space. Low-flow lavatory faucets and water closets will be used throughout to minimize water use. All interior finish materials were carefully selected on the basis of their impacts on the environment and occupants.

The building is crowned by a series of glazing-integrated PV modules incorporated into the top horizontal roof louver of the tower and the skylight element above the cylindrical volume of the secure lobby rotunda. This bold architectural statement expresses both energy efficiency and adaptation to climate. The glazing-integrated PV array at the top horizontal roof louver of the tower is composed of crystalline cells covering approximately 87% of the visible glazing area. This is intended to be a highly visible element of the building's architecture, recognizable from many places around the city.

The cylindrical volume of the secure lobby rotunda culminates in an insulated BIPV glass skylight using crystalline cells covering approximately 60% of the visible glazing area; it provides necessary shading while generating power for the building and making a statement about alternative energy sources. Perimeter skylights around the outside of the rotunda are laminated glass. Setting the tone for other special places within the building, a perforated metal scrim ceiling diffuses this light.

The BIPV panels provide electricity during daylight hours, reducing the building's peak electricity requirements. Direct current from the BIPV system is fed into the building's electrical system via a DC to AC power-conditioning unit. Since the system is utility-interconnected, battery storage is not necessary. Estimated total energy production from the two systems is approximately 25,000 kWh per year, or about 2% of the building's total annual electrical consumption.

The new U.S. Federal Courthouse expansion lends an optimistic, forward-looking image to the City of Denver while making a strong case for sustainable design. Inside the courthouse, the design will project a bright, airy appearance. "Green" design features also improve the work environment, which can lead to increases in employee productivity and satisfaction.

By investing in improved materials and systems, and using an integrated, environmentally conscious design approach, the GSA will reduce environmental impacts as well as long-term operating costs. Because the courthouse expansion has been designated a "demonstration project" by GSA, it will be used to influence future courthouse design projects.

Special Design Considerations

The basic laminated BIPV glazing panels are a compilation of square polycrystaline cells measuring 125 mm x125 mm. The manufacturing process varies the density and coverage of these cells within the BIPV panel to accommodate the design intent. This ability to custom-design individual BIPV panels allowed the design team to specify skylight panels to be more light transmissive, thereby providing ample illumination of the lobby rotunda, and to design the roof louver panels with greater opacity, thereby providing increased power capabilities.

The laminated BIPV glazing panel of the skylights allows the phototvoltaic system to be responsive to indoor safety and security requirements. Condensation concerns also required that the skylight's BIPV panels be integrated into an insulated glazing element.

In addition, the inside glass pane is laminated with a milk-white, PVB (polyvinyl butyral) inner layer to diffuse direct sunlight and obscure the less visually appealing side of the crystalline cells from view.

PV System Configuration

A one-line electrical schematic is given for the two photovoltaic systems. The photovoltaic modules are wired in series and parallel to meet the voltage and current input requirements of the power conditioning unit (PCU). To simplify the wiring between the PV array and the PCU, combiners are installed near the array. The array combiners include reverse current protection, surge protection, and series string fusing, and they provide a convenient place for testing and troubleshooting the PV array.

DC and AC disconnects enable proper disconnection and protection for the PCU. Depending on whether the output of the PCU is compatible with utility voltage and grounding requirements, an external (to the PCU) isolation transformer may be needed. A utility-required relay mechanism provides over- and under-frequency protection and over- and under-voltage protection. The utility disconnect is a redundant measure required by the utility to ensure that the PV system will not backfeed utility lines that are not meant to be energized. The PCU has an anti-islanding feature that is the first line of defense against undesired backfeed onto the utility grid. The point of interconnection can be made in any electrical distribution panelboard with the proper voltage and current ratings.

Because the BIPV arrays are located in different places on the building, each array will be equipped with its own data acquisition system. The data acquisition systems will measure and record four parameters that can be used to scrutinize the performance of the BIPV systems. These parameters are the four required by the Utility Photovoltaic Group (UPVG) for its monitoring and rating program. This may also make the PV systems eligible for cost-sharing with UPVG. The following measurements and sensors will be employed:

(1) Plane-of-array global solar irradiance (W/m^2) will be measured with a Licor pyranometer mounted on the array.

(2) Wind speed (m/s) will measured with an NRG systems cup anemometer mounted near the array.

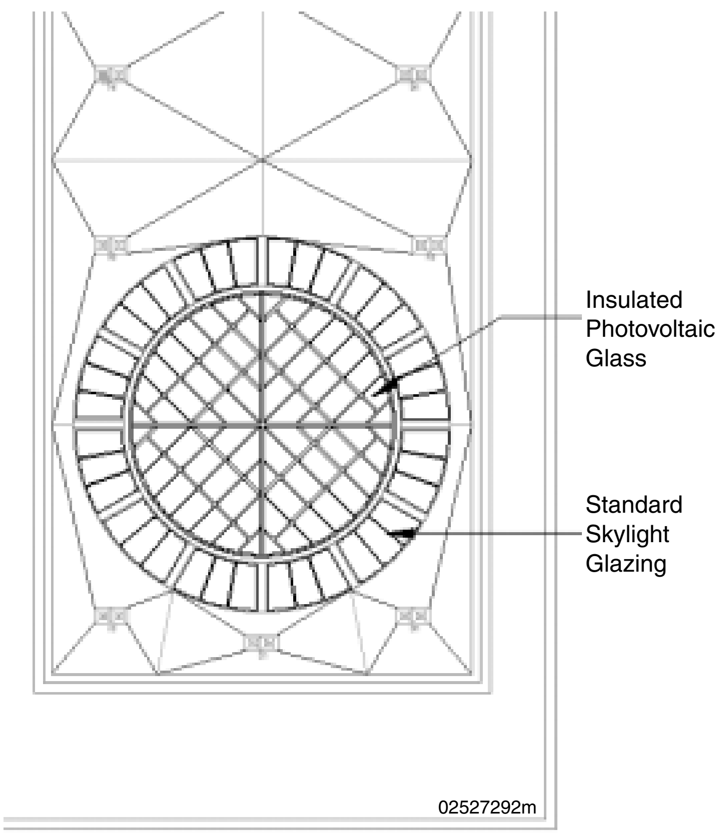
(3) Ambient temperature (°C) will be measured with a thermistor inside a radiation shield mounted near the array.

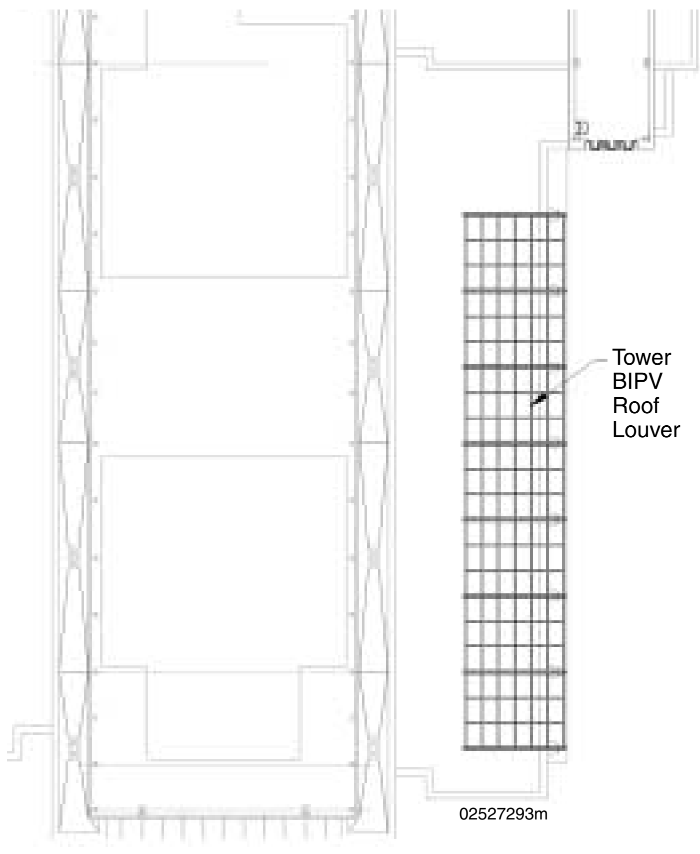
(4) PV system AC power/energy output (kW/kWh) will be measured with a standard accumulating energy meter with a special pulse output device. This device will be located near the PCU.

The data from the two data acquisition systems will go to a central computer via standard telephone wire. The computer will probably be in a busy area, such as the special proceedings lobby, to help educate the general public about BIPV systems. The computer will have custom-designed software for displaying the data in a "cockpit" format (i.e., with graphic elements such as dials and strip charts). Both real-time and archived data will be available on this display, along with educational screens.

PV Module Mounting and Attachment Details

The glazing-integrated PV modules will be shipped to the site individually with terminals for making electrical connections. Because the skylight installer will mount the modules into the mullions and make the electrical connections, the electrical connections must be very simple. Electrical terminals are located on the panel edges so they are concealed by the mullion system. Traditional modules have a junction box mounted on the back. Special plug-and-socket connectors will enable easy one-wire connections to be made between adjacent modules. The mullions will be constructed so that individual modules may be removed for repairs.





These drawings show the position of BIPV modules on the skylight and the tower roof louver.

BIPV Basics

Photovoltaic Technologies

A French physicist, Alexandre Edmond Becquerel, was the first to record his observation of the photovoltaic effect (*photo* denotes light and *voltaic* denotes the generation of electricity) in the 19th century. Since then, many scientists have worked to develop energy technologies based on this effect. It is a process in which electricity is generated in the boundary layers of certain semiconductor materials when they are illuminated. Today's photovoltaic semiconductor materials include silicon, gallium arsenide, copper indium diselenide, cadmium sulfide, and cadmium telluride.

Photovoltaic materials are classified as either crystalline, polycrystalline, or thin-film in form. These classifications represent the three major PV technologies. These are the building blocks for today's commercial PV products, which include consumer electronics (such as a solar-powered calculator or watch), remote electric power systems, utility-connected power systems, and building-integrated systems.

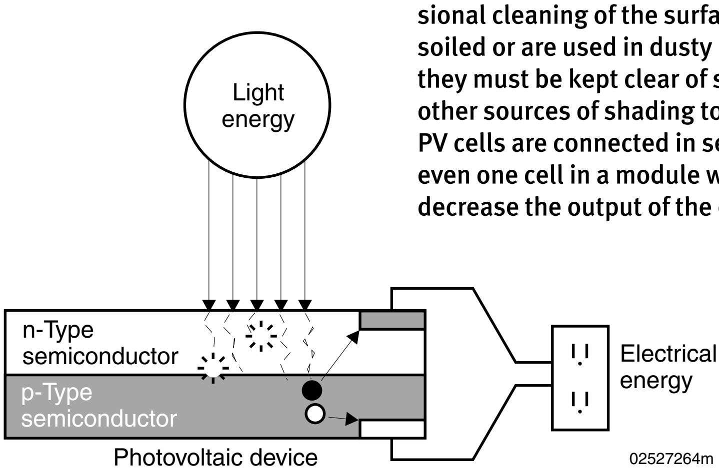
One of these PV materials, silicon, is highly abundant; it constitutes more than 25% of the Earth's crust. Silicon is used in more than 90% of all PV applications, including building-integrated photovoltaics or BIPV. Silicon solar technologies can be grouped in these three basic areas: single-crystal silicon, polycrystalline silicon, and thin-film amorphous silicon. The primary distinctions among the three technologies are their sunlight-to-electricity conversion efficiency rates, the methods by which they are manufactured, and their associated manufacturing costs.

The efficiency of each BIPV product is specified by the manufacturer. Efficiencies range from as low as 5% to as high as 15%–16%. A technology's conversion efficiency rate determines the amount of electricity that a commercial PV product can produce. For example, although thin-film amorphous silicon PV modules require less semiconductor material and can be less expensive to manufacture than crystalline silicon modules, they also have lower conversion efficiency rates. Until these conversion efficiencies increase,

The Photovoltaic Effect

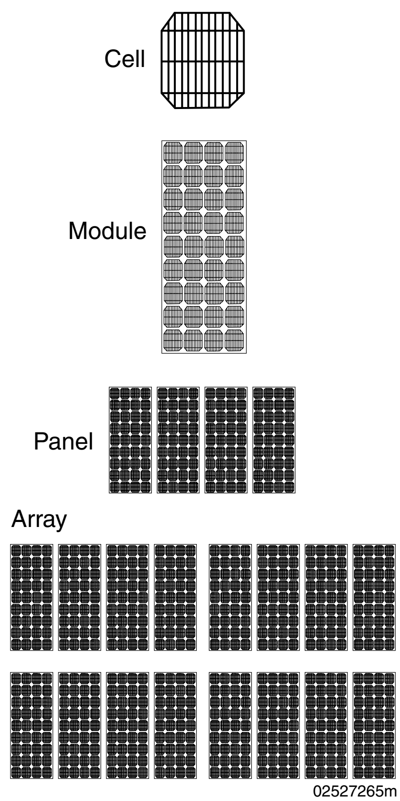
Sunlight is composed of photons—discrete units of light energy. When photons strike a PV cell, some are absorbed by the semiconductor material and the energy is transferred to electrons. With their new-found energy, the electrons can escape from their associated atoms and flow as current in an electrical circuit.

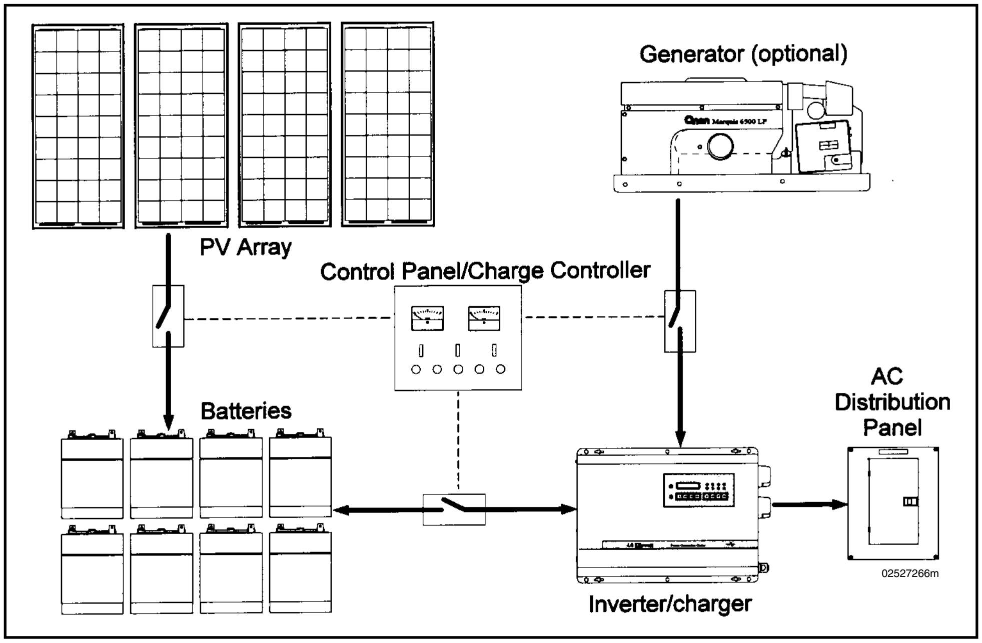
PV arrays require no care other than occasional cleaning of the surfaces if they become soiled or are used in dusty locations. However, they must be kept clear of snow, weeds, and other sources of shading to operate properly. PV cells are connected in series, so shading even one cell in a module will appreciably decrease the output of the entire module.



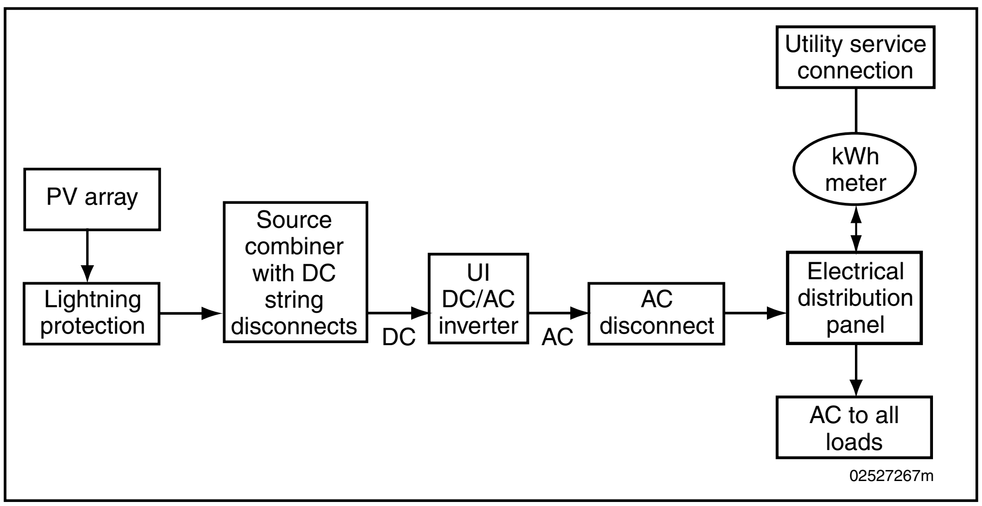
PV Cells

PV cells are the basic building blocks of PV modules. They are made of semiconducting materials, typically silicon, doped with special additives. Approximately 1/2 volt is generated by each silicon PV cell. The amount of current produced is directly proportional to the cell's size, conversion efficiency, and the intensity of light. As shown in the figure below, groups of 36 series-connected PV cells are packaged together into standard modules that provide a nominal 12 volt (or 18 volts @ peak power). PV modules were originally configured in this manner to charge 12-volt batteries. Desired power, voltage, and current can be obtained by connecting individual PV modules in series and parallel combinations in much the same way as batteries. When modules are fixed together in a single mount they are called a panel and when two or more panels are used together, they are called an array. (Single panels are also called arrays.)





Schematic of a typical stand-alone PV system



Block diagram of a utility-interactive PV system

more amorphous silicon modules will be required to generate the same amount of electric power produced by other silicon-based PV modules. Continuing research and development in thin-film silicon should increase its conversion efficiencies.

An important architectural consideration is aethetics, and PV modules do differ in appearance. Single-crystalline PV modules are dense blue (almost black), with a flat, uniform appearance. Polycrystalline modules are multicolored, having a variety of sparkling blue tones. Thin-film amorphous silicon modules are a reddish-brown to black; the surface may appear uniform or nonuniform, depending on how the modules are made. Consequently, typical system colors are blues, browns, and black. However, some PV manufacturers can fill special orders for colors such as gold, green, and magenta. These color variations will result in some loss in performance efficiencies.

BIPV Systems

PV applications for buildings began appearing in the United States and elsewhere in the 1970s. Aluminum-framed PV modules were connected to, or mounted on, buildings that were usually in remote areas without access to an electric power grid. In the 1980s, PV module add-ons to roofs began being demonstrated. These PV systems were usually installed on utility-grid-connected buildings in areas with centralized power stations. In the 1990s, BIPV construction products specially designed to be integrated into a building envelope became commercially available.

Internationally, the past decade has ushered in a myriad of BIPV demonstration buildings and other structures. In both new projects and renovations, BIPV is proving to be an effective building energy technology in residential, commercial, industrial, and institutional buildings and structures.

BIPV systems are considered to be multifunctional building materials, and they are therefore usually designed to serve more than one function. For example, a BIPV skylight is an integral component of the building envelope, a solar energy system that generates electricity for the building, and daylighting element.

The standard element of a BIPV system is the PV module. Individual solar cells are interconnected, encapsulated, laminated on glass, and framed to form a module. Modules are strung together in an electrical series with cables and wires to form a PV array. Direct or diffuse light (usually sunlight) shining on the solar cells induces the photovoltaic effect, generating unregulated DC electric power. This DC power can be used, stored in a battery system, or fed into an inverter that transforms and synchronizes the power into AC electricity. The electricity can be used in the building or exported to a utility company through a grid interconnection.

BIPV systems are made up of BIPV construction materials and balance-of-system (BOS) hardware. The BOS hardware is composed of cabling, wiring, and structural elements that hold the modules in place, as well as grid-metered connections, fault protectors, a power conditioning unit (inverter), and an electricity storage system (usually batteries), as needed.

Demonstrations of BIPV systems have greatly increased people's awareness of the potential of BIPV products. This is especially true for members of the building profession and construction trades. At the same time, the PV industry has gained experience in designing, manufacturing, and installing BIPV systems. The current challenge for the industry is to penetrate the commercial construction market. This is being achieved through new linkages between PV manufacturers and the building materials manufacturing industry.

The economics and aesthetics of BIPV systems are optimized when PV is integrated into the building during preliminary design stages. In order to be effective, BIPV products should match the dimensions, structural properties, qualities, and life expectancy of the materials they displace. Like standard construction glass, cladding, and roofing materials, they can then easily be integrated into the building envelope.

Design Issues

Beyond comfort and aesthetics, BIPV design considerations encompass both environmental and structural factors. Environmental factors include a structure's solar access as well as average seasonal outdoor temperatures at the site, local weather conditions, shading and shadowing from nearby structures and trees, and the site's latitude, which influences the optimum BIPV system orientation and tilt. Structural factors include a building's energy requirements, which influences the size of the system, and the BIPV system's operation and maintenance requirements. These factors must all be taken into account during the design stages, when the goal is to achieve the highest possible value for the BIPV system. Some of the major design considerations unique to solar energy systems are solar access, system orientation and tilt, electrical characteristics, and system sizing.

Solar access — Solar access, the incidence of solar radiation (insolation) that reaches a PV surface at any given time, determines the potential electrical output of a BIPV system. Solar radiation data for sites in the United States can be obtained from the Department of Energy's National Renewable Energy Laboratory (NREL). The data are available in publications such as the *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors and the Solar Radiation Data Manual for Buildings* (call (303) 275-4363 to request copies) or online from the Renewable Resource Data Center (http://rredc.nrel.gov). Statistical estimations of average daily insolation levels for specific locations are commonly used in the BIPV design process and measured as kilowatt-hours per square meter per day ($kWh/m^2/day$).

System Orientation and Tilt — To maximize solar access and power output, the physical orientation of the BIPV system and the tilt angle of the array should be considered relative to the geographical location of the building site. As a general rule of thumb, BIPV installations north of the equator perform optimally when oriented south and tilted at an angle 15 degrees higher than the site latitude. Conversely, BIPV installations south of the equator perform best when oriented north and tilted at an angle 15 degrees lower than the site latitude. The orientation and tilt may vary from this formula when a BIPV system's particular seasonal performance must be optimized. For example, a system might be designed to produce maximum power output only in the summer months in order to reduce peak electricity costs for air-conditioning loads; thus, the system should be installed at an optimum orientation and tilt for summer power output.

Demonstrations have shown that a system installed at a tilt angle equivalent to the site latitude produces the greatest amount of electricity on an annual basis. In comparison to a system's performance at latitude angle, annual performance losses for vertical facade systems can be as high as 30% or more. In contrast, annual performance losses for horizontal installations can be as high as 10%, in comparison to those of systems installed at latitude angle.

Electrical Characteristics — The pertinent electrical characteristics of a PV module or array are summarized in the relationship between the current and voltage. The amount and intensity of solar insolation controls the current (I); the temperature of the solar cells affects the voltage (V) of the PV module or array. Module I-V curves that summarise the relationship between the current and voltage are furnished by manufacturers. I-V curves provide information designers need to configure systems that can operate as close to the optimal peak power point as possible. The peak power point is measured, under standard testing conditions (STC), as the PV module produces its maximum amount of power when exposed to artificial solar radiation of $1000\ W/m^2$.

System Sizing — Choosing a BIPV type and sizing a system have three main components: energy loads, architectural or aesthetic considerations, and economic factors. To determine the desired power rating of a BIPV system for a building, the electrical requirements of the building should first be evaluated. The optimum power rating of the system can be calculated and sized, based on the portion of the building's electricity that will be supplied by the BIPV system. For example, an autonomous or off-grid building may require a large system with battery storage capabilities to provide 100% of the building's electricity requirements; a building owner desiring to reduce demand charges will require a small system that produces electricity only during peak utility charge hours.

Architecturally, the size of the BIPV system is physically limited to the dimensions of the building's available surface area. The balance between the amount of power required and the amount of surface area available can determine the type of PV technology that will be used. Each technology has an associated range of output in watts per square foot or per square meter and cost per watt. For example, systems made of amorphous silicon require a larger surface area but cost less than equivalent systems composed of single-crystal solar cells. Therefore, in projects that have a limited budget but include a large south-facing facade surface area, amorphous silicon can be the most suitable BIPV technology.To achieve the appearance of a uniform surface area, less expensive "mock" or imitation PV panels can also be provided by the manufacturer.

Once the building energy load requirement is determined, the watt-hour method can be used to design the electrical system. An evaluation of seasonal climatic conditions and variations (temperature and solar insolation) and the available surface area will determine the number of modules that will satisfy the voltage and current requirement of the load. After that, corresponding inverter requirements and BOS requirements can be specified. Currently, PV specialists, system integrators, and consultants provide electrical sizing information, assessments, and recommendations. However, BIPV manufacturers are increasingly providing full turn-key services for large systems for commercial buildings, and prepackaged, standardized, residential systems are being sold by distributors. For more information on software tools for optimizing PV systems, see Appendix B.

Electrical and Safety Issues

Electrical issues primarily involve the performance and reliability of the inverters. The variety available for BIPV systems include single inverters, master-slave inverter configurations, modular inverters, and parallel-independent or string inverters. A BIPV system is most vulnerable to a single-point failure where the power generated from the BIPV array must be transformed and synchronized through the inverter from DC to AC power and then fed into the building or an electric utility system. If the inverter fails, the entire system malfunctions.

Today, most inverters are highly reliable. However, the practice of relying on only one inverter for a BIPV system in a commercial building is problematic. When BIPV systems are made up of a large series of interconnected strings, there is a technical difficulty in determining where a system has failed. This is akin to the problem people had with old-fashioned Christmas tree lights. When one light malfunctioned, the entire string went down, and each bulb had be tested to determine the source of the problem.

A BIPV system designed so that multiple inverters work together ensures greater system reliability. If one inverter malfunctions or requires maintenance, it can be disconnected from the array and the BIPV system can still operate. A cascading hierarchy "master-slave" configuration includes one master inverter and multiple slave inverters that operate together for maximum efficiency

Modular, "micro," or "mini" inverters allow each module to be tested (each has its own address) through the use of a power line carrier signal injected into the building's electrical distribution system. This way, each unit's performance can easily be evaluated. Modular inverters also enable PV to be integrated into complex, geometric building designs.

Modular inverters are desirable for commercial buildings because they operate independently. Shading one module will not interrupt the power output of the whole array. In single or multiple inverter systems, a number of modules are connected in series to achieve the voltage needed by the selected inverter. Shading any one module in this series can negate the output of the entire string.

One design issue related to the modular inverter is whether it will last the lifetime of the PV module. If the inverter has a lifetime of only 5 years and the BIPV facade lasts 25 years, replacing the modular inverter has an associated periodic cost, and access needs to be anticipated and designed into the project.

The string inverter is the second generation of inverters for buildings. In Europe, one string inverter with the nominal power of 750 watts can connect as many as 10 PV modules in a series and be connected anywhere in the building's electricity distribution system. The flexibility, reliability, and increased efficiency offered by string inverters may further reduce the cost of BIPV systems.

New AC modules are being equipped with individual AC mini-inverters mounted on the backs of the PV panels. They are at the early commercial stages of development in the United States and Switzerland. One benefit of these is that they eliminate the need in the building for the high-voltage DC wiring associated with other BIPV systems.

In regard to electrical safety issues, it is important to note that lightning, ground faults, and power line surges can cause high voltages in otherwise low-voltage BIPV systems. National and international electric code regulations and building codes are being amended to include PV technologies and address fire and safety issues concerning BIPV design, installation, and maintenance.

Codes and Standards

The national model codes historically have been composed of three primary organizations: the International Conference of Building Officials (ICBO), Building Officials Code Administrators International (BOCA), and the Southern Building Code Conference International (SBCCI). These organizations have collaborated to create one umbrella organization, the International Code Conference (ICC). The ICC has begun the process of writing one model code, the International Building Codes. These codes began development in 1996, and the entire group will be published by the year 2000. Although these codes must be adopted by each municipality to have any authority, they will be the most up-to-date ones that can be adopted after the year 2000. This is a major step toward a unifying model code, reducing the duplication and diversity of the previous three code bodies. The change process for all ICC codes will occur annually until 2003 and at three-year intervals after 2003.

To date, these codes do not refer specifically to BIPV systems, leaving compliance to the discretion of local building inspectors. If BIPV is the structural equivalent of a current building material, only specific code provisions or compliance required for the structural equivalent will be necessary. However, the typical crystalline PV cell adds weight to the traditional building product relative to a thin filmed glazing, and this may require closer evaluation by code officials. Because of their multifunctional nature, BIPV systems must also comply with the National Electric Code (NEC), which addresses PV power systems but not BIPV specifically.

Local codes vary by state and municipality, and some covenant-controlled communities regulate the appearance of buildings for architectural aesthetics and homogeneity. This may affect decisions about the suitability of BIPV systems. Furthermore, a few communities in the United States have developed zoning ordinances relative to solar access laws that could affect BIPV systems and structures that may shade solar systems.

Residential Energy Codes — The Model Energy Code (MEC) has been published by the Council of American Building Officials (CABO). The MEC is no longer being updated, and is being replaced by the International Energy Conservation Code (IECC). The CABO requirement for one- and two-family dwellings is being replaced in the year 2000 by the International Residential Code. The CABO document is not being updated at this time, and changes will need to be made to the IRC. The change process for both the IECC and IRC will occur annually until 2003 and at three-year intervals after 2003.

Commercial Codes & Products — DOE supports commercial energy codes, especially ASHRAE 90.1, by helping to develop them and by providing tools and resources that make the codes easier to use. The COMcheck-EZTM materials were developed to simplify and clarify commercial and high-rise residential building energy code requirements. The materials include easy to use IBM-compatible software; compliance guides for envelope, lighting, and mechanical requirements; and prescriptive packages for county-based climate zones. Forms and a checklist are included to document compliance. All COMcheck-EZ materials can be downloaded at no cost. If you download any material, please register with the program so you will be notified of upgrades (online, see http://www.energycodes.org/comm/comm.htm).

Federal Building Codes — The current Federal code for low-rise residential energy efficiency (10 CFR Part 435, sub-part C) can be obtained online (see http://www.access.gpo.gov/nara/cfr/cfr-retrieve.html#page1). DOE has been updating this code. The proposed rulemaking for the Energy Efficiency Code for new Federal Residential Buildings was published in the May 2, 1997, edition of the Federal Register. A printed copy of the rulemaking can be obtained in Federal Register Volume 62, Number 85, pages 24163-24209, or at the online address above.

The proposed rule is based on the 1995 version of the Model Energy Code, but it contains more stringent envelope requirements and rules related to radon control and backdrafting from fossil-fuel-burning appliances. DOE has been preparing the final rule based on comments received on the proposed rule and expects to issue it in 1999. DOE is also preparing a code compliance package known as FEDcheck to assist users in understanding and complying with the code. For more information, contact Stephen Walder, DOE, 202-586-9209, or Robert Lucas, Pacific Northwest National Laboratory, 509-375-3789 (online, see http://www.energycodes.org/federal/federal.htm).

DOE has also prepared a third edition of its Building Standards and Guidelines Program catalogue. This catalogue is one of many services that promote the adoption, implementation, and enforcement of residential and commercial building energy codes. One of the primary goals of the program is to provide products and services that make it easy for builders, architects, designers, building code officials, and state energy officials to implement building energy codes.

The catalogue features many products that will quickly and efficiently implement the requirements of the Model Energy Code; the American Society of Heating, Refrigerating, and Air-Conditioning Engineers and Illuminating Engineering Society of North America Standard 90.1-1989; and the Federal Performance Standards for New Commercial and Multi-Family High-Rise Residential Buildings.

In addition to the catalogue, the MECcheck and COMcheck-EZ compliance tools and manuals may be downloaded at no cost from the Building Standards and Guidelines Web site at http://www.energycodes.org/. For more information, or to place an order, call the U.S. Department of Energy Building Standards and Guidelines program hotline at 1-800-270-CODE (online, see http://www.energycodes.org/news/catalog.htm).

State Energy Codes — The status of each state's building energy codes is current as of September 1997. The list is likely to become less accurate in time, however, as states adopt new codes. Thus, there will be continual updates. Printed copies of the State Building Codes Database are available for $15 by calling 1-800-270-CODE. To view the status of a particular state's energy codes, select a state from the list online (see http://www.energycodes.org/states/ states.htm). The status of the state energy codes can be found at http://www.bcap.com .

Maintenance

PV has no recurring fuel costs, and it is promoted as a simple energy technology that is durable and relatively maintenance-free because it has no moving parts. However, designers should ensure that BIPV installations allow easy access for inspecting, repairing, and replacing components. Maintenance costs can be divided into two categories: preventive and failure-related.

Preventative maintenance can ensure the performance of a BIPV system. Shadowing on the PV array caused by the natural or built environment reduces system output. Sunlight reflects off expanses of sand, snow, ice, and other light surfaces, and can increase output by reflecting additional solar energy onto arrays. However, other structures, trees, and bushes near a BIPV system can inhibit solar access and thus reduce system performance. This is in turn detrimental to the economic performance of the system.

In the case of building retrofits, landscaping can often shade parts of a roof and limit solar access, so landscape architecture must be considered, and trees must be trimmed periodically.

The electrical performance of a BIPV system can also be affected by accumulations of dirt on the modules. In most locations, normal rainfall removes the layers of dust and pollution that can accumulate on the outer surface. Where there is little rainfall, occasionally spraying the system with water from a standard garden hose to remove dirt and debris is adequate but not required.

The performance of a BIPV system can decline if it is located in a particularly dirty urban environment. Layers of grime, caused by fuel exhaust and other emissions, can accumulate on a system. This exhaust can combine with sun-baked atmospheric dust to reduce the amount of light that can reach the modules and thus reduce system performance. Such systems may require periodic cleaning with chemical agents to maximize the system's electrical output. Consequently, system designers must ensure adequate access to the system to perform these maintenance activities.

Failure-related maintenance involves repairs and replacements associated with poor performance or failures of the BIPV system. This can be covered under traditional and extended warranties.

Warranties

BIPV systems are generally covered by a limited 12-month replacement warranty that guards against defects and ensures system repair and product replacements or an optional full refund of the purchase price. In case of an accident, such as a fire, ancillary damage to a BIPV system may be covered by a conventional building insurance policy.

Currently, the major PV manufacturers offer power production warranties for as long as 10, 20, and 25 years. These manufacturers will replace the power output lost from modules that fail to produce at least 80% of the minimum power output specified on the back of the module. This warranty dates from the sale of the product to the original purchaser and is generally nontransferrable. Other suppliers also offer optional warranties on roofing through service and maintenance contracts.

BIPV Products

These are the types of BIPV systems commercially available:

Facade systems — The BIPV system is designed to act as an outer skin and weather barrier as part of the building envelope. An example is a BIPV system used for rainscreen overcladding. Glass BIPV products are typically used as facade systems.

Atrium systems — BIPV is a glass element that provides different degrees of shading and can be designed to enhance indoor thermal comfort as well as daylighting.

Awning and Shading systems — A variety of PV materials can be mounted onto a facade in aesthetic manner to serve as awnings.

Roofing systems — The BIPV system displaces conventional roofing materials such as tiles, shingles, and metal roofing.

The cost of a BIPV system depends on the type of system and the PV technology used in manufacturing it. Currently, only a few U.S. manufacturers produce custom and standardized BIPV products. For commercial and institutional structures and buildings, the two primary types of BIPV products, facades and roofing materials, are available for both new construction and refurbishment projects.

BIPV Facade Systems — BIPV facade systems include laminated and patterned glass, spandrel glass panels, and curtain wall glazing systems. These BIPV products can displace traditional construction materials. Laminated glass is a standardized BIPV product. It is composed of two pieces of glass with PV solar cells sandwiched between them, an encapsulant of ethylene-vinyl acetate (EVA) or another encapsulant material, and a translucent or colored tedlar-coated polyester backsheet. It can also be made with only one piece of glass and a tedlar backsheet. Architects can specify the color of the tedlar backsheet.

Spandrel panels are the opaque glass used between floors in commercial glass building facades. A glazed curtain wall is a non-load-bearing exterior wall suspended in front of the structural frame and wall elements. Patterned or fritted glass is semitransparent with distinctive geometric or linear designs.

Solar Design Associates, Inc./PIX04472

Figure 1. AC PV modules, Solar Design Associates

PIX08462

Figure 2. Architectural PV glazing system, Innovative Design, Inc.

FIRST, Inc./PIX03612

Figure 3. PV-integrated modular homes, Fully Independent Residential Solar Technology, Inc.

Tim Ellison, ECD/PIX04473

Figure 4. Rooftop PV systems, Energy Conversion Devices, Inc.

Some companies sell custom-made BIPV glazing products, available in any size or dimension and consisting of any PV technology (crystalline or thin film). The architect can indicate the spacing between solar cells, which will determine the power supply and also permit the design of passive solar features by regulating the amount of daylighting allowed to enter into the builiding. These products can be used in any commercial glazing application. Standard and custom products are available in many sizes (as large as 1.3 m x 1.7 m) and in a range of thicknesses (0.5 mm to 2.5 mm glass).

Curtain wall laminates are available for both AC and DC power. The AC panel has its own mini-inverter attached to the back of the laminate. The AC PowerWall™ operates with current at maximum power with 2.0 amps (A) and 110 volts (V). The DC PowerWall™ operates at maximum power with 3.5 A and 68.4 V. The PowerWall™ generates 250 watts (W) under standard test conditions (STC).

BIPV Roofing Systems — Roofing systems include BIPV shingles, metal roofing, and exterior insulation roof systems. These BIPV products can displace traditional construction materials.

Flexible thin-film amorphous silicon BIPV shingles can replace asphalt shingles. This BIPV product is nailed to the roof deck, very much the way that traditional asphalt shingles are attached to a roof. This technology was designed as a 2-kilowatt peak (kWp) BIPV system for the Southface Energy Institute in Atlanta, Georgia. Also available are fiber cement PV roofing shingles measuring 16 in. (40 cm) by 12 in. (30 cm) by 1/4 in. (0.6 cm) and weighing 5 pounds (2.27 kg). Crystalline silicon cells are laminated to fiber cement roofing shingles and are rated at 11 W of power output under STC.

BIPV metal roofing can replace an architectural standing seam. The thin-film amorphous silicon PV material is laminated directly onto long metal roofing panels. The BIPV metal roofing panels, with edges turned up, are laid side by side and a cap is placed over the standing edges to form a seam. These metal panels can be installed by a traditional roofer followed by an electrician.

As an exterior insulation BIPV roof system, PV laminates are attached to polystyrene insulation, and it provides thermal insulation rated R-10 or R-15. It rests on the waterproof membrane without penetrating or being mechanically fastened to the building. In an interlocking tongue-and-groove assembly, the panels are weighed down by pavers that surround the system to provide access for maintenance and repairs. Channels or raceways are designed to provide access to the electrical connections. This technology can be used to redo the roof of an existing building, as demonstrated by the New York Power Authority on a community center in Tuckahoe, New York. Additionally, the PV portion of the product can be tilted up to 12° to help optimize the system's orientation.

This system can be installed on built-up and single-ply membranes of flat commercial roofs and typically weighs 4 lb/ft^2 versus 10 lb/ft^2 for a conventional aggregate ballast roof. Any PV technology can be applied in this process and will provide power according to its solar cell and system efficiency rating.

The manufacturer claims that this product extends normal roof life by protecting insulation and membranes from ultraviolet (UV) rays and water degradation. It does this by eliminating condensation because the dew point is kept above the roofing membrane.

BIPV Product Development

Since the early 1990s, the U.S. Department of Energy's (DOE's) Photovoltaics: Building Opportunities in the United States (PV:BONUS) program has brought together PV and building product manufacturers in a coordinated effort to develop PV roofing shingles, facade glazing, and curtain wall products for buildings and other structures. Today there is a recognizable commercialization trend toward standardizing BIPV construction products. In the long run, product standardization will be an essential element in reducing the cost of manufacturing BIPV systems. The following section on new construction materials for buildings was extracted from a paper written by Sheila J. Hayter, P.E. (NREL) & Robert L. Martin (DOE). This paper, titled "Photovoltaics for Buildings, Cutting Edge PV," was presented at the UPEX conference in 1998. Below is the section on Building Opportunities in the U.S. for Photovoltaics (PV:BONUS).

The U.S. Department of Energy demonstrates its commitment to supporting new PV-for-buildings technologies by awarding Cooperative Agreement funding to U.S. manufacturers and organizations for product development. These agreements are within the Building Opportunities in the U.S. for Photovoltaics (PV:BONUS) program. The objective of the PV:BONUS program is to develop technologies and to foster business arrangements that integrate photovoltaics or hybrid products into buildings cost-effectively. Cost-effectiveness, either through design; integration (i.e., components, system, and/or building integration); dedicated end-use applications; or technology bundling (i.e., PV/thermal hybrids) is a major factor in selecting PV:BONUS projects. DOE is interested in products that can replace commercial building products and be installed without the necessity for specialized training. The ultimate goal of the PV:BONUS program is market demonstrations of commercially viable products that lead to manufacturer commitments to pursue production and sales.

In 1993, the U.S. Department of Energy awarded cooperative agreements for five PV:BONUS projects. The success of this initial effort resulted in DOE funding additional projects in 1997 under a second program known as PV:BONUS Two.

PV:BONUS (June 1993 – May 1999). The five projects originally funded by the PV:BONUS program have all been successfully installed in demonstration projects, and most are now commercially available to the buildings industry. These new technologies include the following.

- AC photovoltaic module and curtain wall application (Figure 1)
- Architectural PV glazing system (Figure 2)
- Dispatchable PV peak-shaving system
- PV-integrated modular homes (Figure 3)
- Rooftop BIPV standing-seam systems (Figure 4).

AC Photovoltaic Module and Curtain Wall Application. The product developed for this PV:BONUS project was a large-area PV module with a dedicated, integrally mounted, direct-current (DC) to alternating-current (AC) power inverter (Figure 1). The module is designed to be integrated into the vertical facades and sloped-roof construction of residential, commercial, or institutional buildings. Large spaces between the PV cells can be incorporated into the module design to allow direct sunlight to transmit through the module. The building designer can use this feature to enhance daylighting and provide passive solar heating to the space adjacent to the modules. Solar Design Associates, Inc., led development efforts for this project. Other team members included Mobil Solar Energy Corp., New England Electric, New York Power Authority, Pacific Gas and Electric, Kawneer, Maryland Energy Administration, and Baltimore Gas and Electric.

Architectural PV Glazing System. A system of matching building facade glazing products including opaque, semitransparent, and clear units was developed. A large-area, thin-film PV module option was available for the opaque and semitransparent units. The system was incorporated into the overhead glazing of a demonstration project in an Applebee's Neighborhood Grill and Bar in Salisbury, NC (Figure 2). The designers placed a high-absorptance metal pan approximately 1 in. (2.5 cm) below the back of the panel to increase effectiveness for solar heating of the air behind the panels. Fans operated by the PV system drew the heated air through an air-to-water heat exchanger to reduce the restaurant's energy demand for producing hot water. Drawing hot air off the back of the PV panels also increased the operating efficiency of the panels. Although the manufacturer of the PV panels and leader of this PV:BONUS team, Advanced Photovoltaic Systems (APS), is no longer in existence, the PV technology the company developed continues to be used by the PV industry. Innovative Design partnered with APS to design the Applebee's system.

Dispatchable PV Peak Shaving System. A fully integrated dispatchable peak-shaving system for commercial applications was designed for this PV:BONUS project. The focus of the project was to reliably control the PV system output for a prescribed length of time by including battery storage with the PV system. The dispatchable system made it possible to displace a load greater than the array's output during peak demand periods. This feature is especially important in commercial buildings where the peak demand period often extends beyond the period of peak power production of the PV system. Delmarva Power and Light Company was responsible for this PV:BONUS effort.

PV-Integrated Modular Homes. Installing residential photovoltaic systems onto homes constructed in a factory along with other energy-efficient features result in reducing the total construction cost of the manufactured homes to be comparable to typical site-built homes (Figure 3). The objective of this PV:BONUS project was to design a line of modular solar homes that include photovoltaic power. To meet this objective, it was necessary to minimize construction costs of the home so that the higher cost of the PV system could be absorbed into the overall cost of the home. The effort was lead by Fully Independent Residential Solar Technologies, Inc. (FIRST, Inc.), a non-profit organization teamed with Bradley Builders and Avis America (a builder of manufactured homes).

Rooftop Photovoltaic Systems. The result of this PV:BONUS project was the development of residential and light-commercial PV-integrated roofing materials. These amorphous-silicon modules are manufactured either to resemble asphalt shingles or to be laminated onto metal standing-seam roof modules (Figure 4). One of the goals of the project was to develop a product that required no special training to install the PV-roof on actual buildings. These products have been tested in demonstration projects and are now commercially available. The leader of this development team, Energy Conversion Devices, Inc., worked with United Solar Systems Corp., the National Association of Home Builders, Solar Design Associates, Inc., and a number of utility companies, construction companies, government agencies, and educational institutions to design, manufacture, and test this product.

PV:BONUS Two (September 1997 – early 2000s). PV:BONUS Two activities are being carried out in three phases. Phase I was the concept development and business planning phase. Prototype systems will be developed and tested in Phase 2, the product and business development phase. Product demonstration and marketing will occur in Phase 3. It is expected that viable products will be offered commercially during Phase 3. Participation in Phases 2 and 3 depend on the accomplishments of the previous phases.

The U.S. Department of Energy awarded 17 Phase I cooperative agreements. These project areas were divided into four categories: 1) glazing products; 2) roofing materials; 3) PV/thermal (PV/T) hybrid systems; and 4) other related projects (inverter technology, fire retardancy investigations, and development of a "mini-grid"). At the completion of Phase I, seven of these projects were selected for continued Phase II funding. Phase II is currently under way and the following projects are being pursued:

- PV-powered electrochromic windows
- Thin-film PV product line
- Hybrid PV/thermal collector
- Ballast-mounted PV arrays
- PV string inverters
- Field-applied PV membrane
- PowerRoof™ 2000.

PV-Powered Electrochromic Windows. Sage Electrochromics, in conjunction with Solarex, proposes to develop and commercialize photovoltaic (PV) powered electrochromic (EC) "smart windows." EC windows control the amount of sunlight and solar heat by dynamically switching between darkened and clear states and anywhere in between. They provide an opportunity to realize energy savings and reduce peak electrical demand in buildings. The low-power DC voltage required to power the EC window glazing will be supplied by PV solar cells incorporated in the double-pane insulating glass unit (IGU) so that no external hard-wired connections are needed.

Thin-Film Photovoltaics. With the support of subcontractors Kawneer, Solar Design Associates, Inc., and Viracon, Solarex will develop building-integrated photovoltaic products using tandem-junction amorphous silicon modules. Major objectives of the program include: 1) developing a commercial photovoltaic curtain wall module (Spandrel Module); 2) developing a commercial photovoltaic sunshade for curtain walls (PowerTint Window); and 3) developing a light-transmitting

Solar Design Associates, Inc./PIX06429

Figure 5. PV sunshades at the State University of New York, Albany

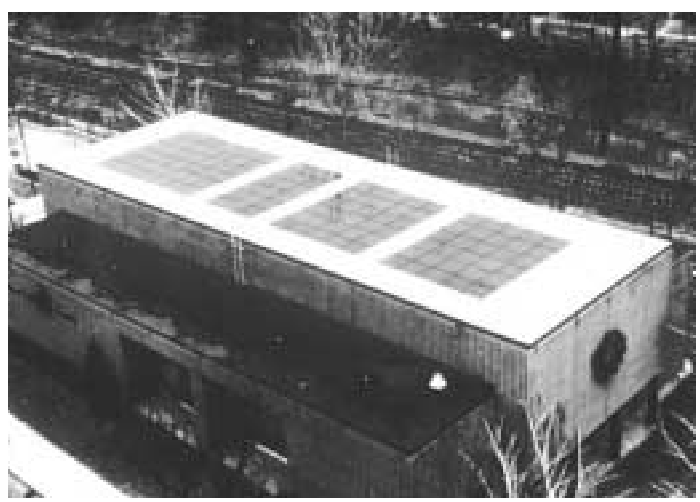
photovoltaic module and incorporating it into the curtain wall product.

Hybrid Photovoltaic/Thermal Collector. Solar Design Associates, Inc., United Solar Systems Corporation, and SunEarth, Inc., propose to design, develop, demonstrate, manufacture and commercialize a hybrid flat-plate photovoltaic/thermal (PV/T) collector to deliver both electricity and thermal energy. The PV/T collector design will employ a liquid thermal transfer medium and closely resemble conventional flat-plate solar thermal collectors in size, appearance, installation, and function. However, in place of the normal thermal absorber plate, it will employ a PV element of triple-junction amorphous silicon alloy solar cells made with United Solar's proprietary UNI-SOLAR technology, in which the material and thermal characteristics are well suited for combined PV/T applications.

Ballast-Mounted PV Arrays. Ascension Technology will develop analytic and experimental capabilities for quantifying the balance between driving (wind, seismic) forces and the restraining (gravitational/frictional) forces that must exist for the ballast-mounting approach to succeed. Ascension Technology has already developed a ballast-mounting system for PV arrays. The system is applicable for both new and retrofit construction on flat or nearly flat roofs, typically on commercial buildings.

PV String Inverters. Advanced Energy Systems, Inc., proposes to design and manufacture a low-cost string inverter system (SIS), which will minimize the cost of the BOS components (i.e., the inverter and the PV output circuit wiring). The SIS is an inverter and associated wiring that is designed to operate with a single string of photovoltaic (PV) modules. By using a single string, the need for an expensive string-combiner is eliminated. The paralleling of multiple strings is accomplished by the utility or AC side of the system, which can result in inexpensive installation costs.

Field-Applied PV Membrane. United Solar Systems Corp., in collaboration with Energy Conversion Devices, Inc., the National Association of Home Builders, Phasor Energy, Arizona Public Service, Southern California Edison Co., Southern Cal Roofing, ATAS International, Elk Corp., and San Diego Gas & Electric intend to develop a field-applied, flexible photovoltaic (PV) membrane product for the "built-environment." UNI-SOLAR PV Roll Membrane is a flexible PV laminate designed for a range of market applications, such as covered parking structures, "flat" roof commercial buildings, architectural and structural metal roofing (including new construction and retrofit, flat, and curved roofs), facades, prefabricated stress skin panel production, and fabric roofing systems. The UNI-SOLAR PV Membrane will be shipped directly to the site for field application or to a building product company for integration with its own products. The membrane uses United Solar Systems Corp.'s multijunction a-Si stainless steel PV cells laminated in flexible UL-approved materials.



Power Light Coproration/PIX04471

Figure 6. PowerLight roof on Tuckahoe Community Center

PowerRoof™ 2000. PowerLight Corporation, in cooperation with AstroPower, Solarex, BP Solar, and Siemens Solar, proposes to develop an innovative building-integrated PV roofing system called PowerRoof™ (Figure 6). PowerGuard® is the first core product in the PowerRoof family and has been successfully developed under prior programs. The PowerRoof 2000 proposal targets the development of two next-generation core PowerRoof building products, HeatGuard™ and PowerTherm™. Each builds upon the proven technological approach of the PowerGuard solar electric roofing system.

Other PV for Buildings Products on the Market and on the Horizon. Building designers have shown great interest in the new PV-for-buildings systems, as indicated by the number of participants in BIPV workshops for architects sponsored by DOE, the American Institute of Architects (AIA), and other organizations. In general, building designers want PV systems that can be integrated into the building envelope and blend well with other building envelope components and materials. Many of the products that have been or are being developed with assistance from the PV:BONUS Program meet these criteria.

New products such as transparent thin-film PV modules, for which the designer can specify the transmissivity, are expected to become commercially available in the near future. The designer will be able to specify both view glass and curtain wall PV modules, so that the entire facade of a building can be clad in PV. Manufacturers predict that the price of these PV modules will be close to that of high-end glass products, making it easier for designers to justify the cost of PV.

Designers are beginning to integrate photovoltaics into sunshade building components. Sunshades are used to reduce the direct solar gain into a building, which also reduces the building cooling loads (Figure 5). The angle of the sunshade can also be set to optimize the output of the PV/sunshade system.

Several PV-roofing products are now commercially available. One crystalline-silicon-cell product replaces traditional roofing materials and is usually used in new construction. Other products are designed to be used in flat-roof commercial retrofit applications. They include an insulated unit with PV integrated into the top layer and a roof membrane product with PV integrated into the membrane.

The cutting-edge PV products discussed in this paper are only an example of what is available or expected to become available for buildings applications. This is not an exhaustive list, however.

Source: Sheila J. Hayter, P.E., and Robert L. Martin, "Photovoltaics for Buildings, Cutting Edge PV," presented at the Utility PV Experience Conference & Exhibition, October 1998.

BIPV Terminology

Building-integrated photovoltaics (BIPV) is a relatively recent new application of photovoltaic (PV) energy technologies. These are some of the basic terms used in describing PV technologies, BIPV products, and their uses:

Antireflection coating — a thin coating of a material that reduces light reflection and increases light transmission; it is applied to the surface of a photovoltaic cell.

Balance of System (BOS) — Non-PV components of a BIPV system typically include wiring, switches, power conditioning units, meters, and battery storage equipment (if required).

Bypass diode — a diode connected across one or more solar cells in a photovoltaic module to protect these cells from thermal destruction in case of total or partial shading of individual cells while other cells are exposed to full light.

Conversion efficiency — Amount of electricity a PV device produces in relation to the amount of light shining on the device, expressed as a percentage.

Curtain wall — an exterior wall that provides no structural support.

Encapsulant — Plastic or other material around PV cells that protects them from environmental damage.

Grid-connected — Intertied with an electric power utility.

Inverter — Device that transforms direct-current (DC) electricity to alternating-current (AC) electricity.

Module — Commercial PV product containing interconnected solar cells; modules come in various standard sizes and can also be custom-made by the manufacturer.

PV array — Group or string of connected PV modules operating as a single unit.

PV laminate — Building component constructed of multilayers of glass, metal or plastic and a photovoltaic material.

PV solar cell — Device made of semiconductor materials that converts direct or diffuse light into electricity; typical PV technologies are made from crystalline, polycrystalline, and amorphous silicon and other thin-film materials.

Solar access — Insolation incidence of solar radiation that occurs on a PV system's surface at any given time; it determines the potential electrical output of a BIPV system.

Stand-alone — Remote power source separate from an electric utility grid; a stand-alone system typically has a battery storage component.

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Appendix A: International Activities

"Building with Photovoltaics — The Challenge For Task VII Of The IEA PV Power Systems Program" by T. Schoen[1], D. Prasad[2], P. Toggweiler[3], P. Eiffert[4] and H. Sørensen[5]

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Abstract

On January 1, 1997, a new Task started within International Energy Agency's Photovoltaic Power Systems (IEA PVPS) Program: Task VII. The objective of Task VII is to enhance the architectural quality, the technical quality and the economic viability of PV systems in the built environment and to assess and remove non-technical barriers to their introduction as an energy-significant option. The value of building integration for the introduction of grid-connected PV is recognized around the world. Rooftop programs, aiming at large-scale application in the next century, are carried out in many countries. In order to reach this widespread application, however, cost reductions still are essential. BIPV research and development should therefore focus on achieving these cost reductions, by optimizing integration concepts, by developing new building products and by the development of standardized products.

Building-integrated PV does more than offer perspectives for the next century. PV systems are installed today by building owners who appreciate the added value of solar roofs and facades, and who are willing to pay a premium for PV. This market potential must be captured and assisted. From the research and development side, this can be done by focusing on architectural issues and on non-technical barriers that impede short-term market penetration. The work in Task VII concentrates on all these aspects. The Task VII research and development strategy is to enhance systems technologies, to work on the architecture of building integrated PV, and to assess and remove non-technical barriers that impede the widespread application of PV in the built environment.

Note: One ECU is approximately equivalent to one U.S. dollar.

INTRODUCTION

It is generally expected that in the next century, photovoltaics will be able to contribute substantially to the mainstream power production, even though PV now is up to five times more expensive than grid power.

In densely populated areas, such as major parts of Europe, Japan and the US, large-scale realization of systems will only be possible through distributed PV systems in the urban environment since no land is available for the installation of ground-based systems. Rooftop programs in Japan (70,000+), US (1,000,000) and Europe (1,000,000) illustrate the worldwide attention given to building-integrated PV.

Integration of PV into buildings offers cost advantages that make this concept attractive for urbanized regions as well as for less densely populated areas with sufficient unoccupied land available. PV installations can be installed on surfaces of buildings and along roads or railways, with the possibility to combine energy production with other functions of the building or non-building structure. Compared with large-scale, ground-based PV power plants, cost savings through these combined functions can be substantial, e.g., in expensive facade systems where cladding costs may equal the costs of the PV modules.

Additionally, no high-value land is required, and no separate support structure is necessary. Electricity is generated at the point of use. This avoids transmission and distribution losses and reduces the utility company's capital and maintenance costs.

Following the advantages of building integration, more and more countries view distributed PV as a power source with a large potential for the future and are correspondingly starting to construct and operate building-integrated PV systems on a large scale [1].

THE COSTS OF BIPV

Figure 1 gives the breakdown of the average costs for building-integrated PV systems, though estimates vary from country to country.

As can be seen in this figure, the costs for building integration currently range from 30% to 50% of the total system costs. Reduction of module costs will enlarge the need for attention to optimal building integration, i.e., reducing the costs for substructures, mounting and wiring to the absolute minimum.

In order to achieve widespread application of PV as a competitive power source, PV electricity must be produced at the level of 0.05 to 0.10 ECU per kWh (5¢ to 10¢). From Fig. 1, it can be seen that even for Italy, this would require cost reductions by a factor 3 to 4. In the Netherlands, cost reductions by a factor 10 or more are required.

Here is where the major challenge lies for R&D programs in the field of BIPV: cost reductions are essential for large-scale introduction of building-integrated PV systems. R&D should focus on these cost reductions.

PV FOR THE FUTURE — PV FOR TODAY

In addition to cost reduction opportunities as previously mentioned (such as replacement of building materials and avoidance of land use), building integration offers interesting cost benefits. If PV systems are installed as decentralized power systems on buildings, and if net metering is used for selling back surplus power to utilities, PV electricity will only have to be produced at consumer tariff prices, ranging from 0.10 to 0.20 ECU per kWh. For the Netherlands this implies required cost reductions by a factor of 3 to 5. For Italy, cost reductions by a factor of 2 to 3, or in the optimistic scenario, a 50% cost reduction would be sufficient for market introduction.

Given the cost reductions that have been achieved by BIPV R&D programs in the last five years, it can be estimated that these cost reductions will be reached within only a few years, indicating that BIPV will rapidly become interesting and competitive.

PV, well integrated into the architectural design of the building, can enhance the aesthetics of the building and give the property owner a 'green' and self-sufficient image. Owners of commercial buildings are increasingly more interested in installing PV systems as a high-value feature of their property. Projects are being realized with limited or no government support at all, indicating that cost reductions of a mere 25% to 50% are sufficient for opening up the market.

The housing market is increasingly sensitive for this 'added value' of the PV system; house owners are willing to pay a premium price for a PV-clad house, thereby generating additional funding for the PV system.

The AC module system seems to be very attractive for this type of application. Property developers in the Netherlands have shown interest in introducing PV systems consisting of 4 AC modules on a regular basis in the building programs, if the prices are reduced to 5 ECU ($5) per Wp. This makes PV a technology not just for the future but also for today.

The challenge of national programs as well as international actions, such as Task VII, is to assist these emerging markets by developing photovoltaics into a cost-effective and clean power source, available for application in distributed systems of utilities, builders, and cities of the future as well as today. R&D should therefore not only address long-term developments for large-scale application as a bulk power source, but also short-term application as competitive feature of the built environment. The integration of PV into architecture and the building market are important issues in such an R&D strategy.

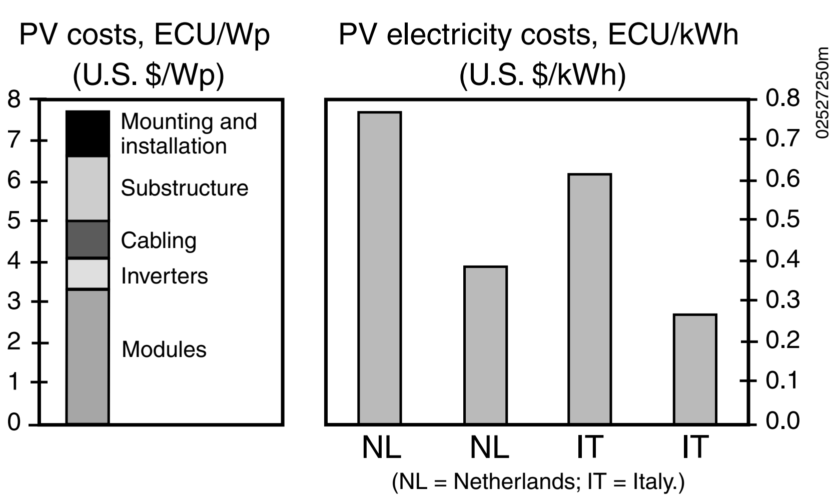

Figure 1. Overview of BIPV system costs in ECU/Wp (left) and the resulting PV electricity costs in ECU/kWh (right), for different countries and calculation methods (optimistic: maximum performance ratio, low interest rate; pessimistic: average performance ratio, high interest rate).

Note: Currently, the ECU is equivalent to one U.S. dollar.

Upscaling of the near-term BIPV market will, moreover, be possible only if non-technical barriers that impede the application of BIPV are addressed and dealt with successfully. The major barrier to overcome here could well be the involvement of builders and building owners in the design and implementation of building integrated PV. R&D, as well as pilot and demonstration projects, should work on the achievement of this involvement as well as on the removal of other non-technical barriers such as the lack of information, confidence, or appropriate financing mechanisms.

R&D STRATEGIES FOR TASK VII

In recognition of the potential of building-integrated PV to the development and introduction of photovoltaics, IEA's PV Power Systems Program in January 1997 launched a new task: Task VII - PV in the Built Environment.

The objective of Task VII is to enhance the architectural quality, the technical quality, and the economic viability of PV systems in the built environment and to assess and remove non-technical barriers to its introduction as an energy-significant option. This objective reflects the R&D strategies mentioned earlier.

The primary focus of Task VII is on the integration of PV into the architectural design of (roofs and facades of residential, commercial, and industrial) buildings and other structures in the built environment (such as noise barriers, parking areas, and railway canopies). Also important are the market factors, both technical and non-technical, that need to be addressed and resolved before wide adoption of PV in the built environment will occur.

Essential for the success of Task VII is the active involvement of urban planners, architects, building engineers, and the building industry. Task VII is very keen on the collaboration between these groups and PV system specialists, utility specialists, the PV industry, and other professionals involved in photovoltaics.

The joint effort will consist mainly of the evaluation and development of innovative concepts for the integration of PV into the built environment, the demonstration of integration concepts, contribution to the development of standards and guidelines, and the study of economic aspects and other market factors that impede the widespread application of PV in buildings.

In brief, Task VII will work on R&D in the following fields:

(1) BIPV technologies

(2) PV and architecture

(3) Non-technical barriers

BIPV Technologies

The technologies that are now available for the integration of PV into buildings are, in general, too expensive for large-scale introduction. Cost reductions are thus still essential. They can be achieved by carefully redesigning the PV support structure, and by integrating the PV system into well-known building components such as the prefabricated roof or the structural-glazing facade.

Development of standardized PV/building units

The development of low-cost, flat roof-mounting elements such as the Sofrel [3] show that, through careful redesign of substructures from the low-cost point of view, cost reductions up to 50% are possible for substructure and mounting costs. A similar strategy could be applied in the development of mounting structures for sloped roofs and facades. PV facades in general still use tailor-made solutions, suitable only for custom-made modules, requiring case-by-case engineering and installation by specialists, which lead to high-quality but high-price solutions.

For new buildings, integration of standard PV modules into low-cost, everyday cladding systems is required, whereas for existing buildings, low-cost add-on systems offer good cost perspectives. In order to make mounting concepts suitable for application in the vast number of existing buildings with a poor energy balance, add-on systems should include extra thermal insulation layers.

Integration of PV modules and cells into standard building materials

The integration of PV into well-known building materials, such as roof tiles, is under way. Attention to these developments around the world shows the cost reduction potential of this R&D path.

Optimal tuning of PV modules to existing building materials can result in substantial reduction of mounting and substructure costs. In the end, these costs might be fully omitted through the integration of PV cells into building materials. Similar attempts are being made in the field of stand-alone PV systems, where PV cells are being integrated into bus shelters, vessels, and other applications.

Integration of PV into prefabricated building elements

This R&D path is especially suitable for countries where the prefabricated buildings and building components are commonly used (e.g., the Netherlands, Japan). Preliminary research indicates that cost reductions up to 50% (compared with that of today's technology) through prefabrication are possible [4].

PV and Architecture

Market enhancement requires acceptance of PV by builders, architects, and users. Full integration into architecture is therefore essential.

The physical characteristics of PV products for integration in buildings must meet architectural requirements for color, size, and materials. Products that meet these requirements are being developed around the world. Cells are available in different colors and textures; modules can be produced to the designer's specification.

These developments have certainly assisted the creation of high-end, high-quality examples of building-integrated PV. They are thus very important to the introduction of BIPV.

It should, however, be noted that the application of custom-made PV products has economic consequences. The costs of modules can go down substantially if they are produced in bulk. At a production level of 500 MWp per year, costs of less than 1 ECU ($1) per Wp are achievable with today's technologies [5]. This cost level will not be reached with tailor-made modules produced on a smaller scale.

The challenge for the PV R&D community, together with architects and builders, is to develop high-quality integration concepts that can make use of the low-cost potential of bulk-produced modules.

As a first activity, Task VII has dealt with the evaluation of existing BIPV projects. The result is a list of architectural quality criteria for BIPV projects (please see Table 1).

Using these criteria in the design of new projects and integration concepts based on standard modules can enhance the architectural quality of BIPV without introducing high-cost (custom-made) products.

Non-Technical Barriers

As mentioned above, a number of non-technical barriers exist that impede the implementation of PV in buildings. Assessment and removal of these barriers will result in enhancement of both the near-term and the long-term PV market. A preliminary listing of barriers has been prepared by Task VII. Task VII will work on the analysis of these market barriers, followed by recommendations for their removal.

As can be expected, budgetary constraints are the main barrier. The removal of other barriers, however, will most certainly help overcome this prime barrier. A number of R&D actions are discussed here.

Development of financing schemes

The availability of appropriate financing mechanisms in Germany and Switzerland has been shown to have a major impact on the introduction of PV. In Germany, rate-based incentives have led to a substantial increase in the PV market, with annual growth figures larger than ever (1996: 3 MW;1997: 10 MW) [6].

The assessment of such financing schemes, tailored to the specific needs of individual countries, will be one of the key activities of Task VII.

Integration into the building process

If PV is to become a well-accepted technology readily available for architects, the building industry, and property owners, integration concepts will have to meet regular building quality standards. This can be achieved by fully integrating the PV system into building materials and by integrating the construction process of BIPV systems into the building construction process. Building integration must include integration into the contractual framework and the organizational structure of building projects.

Building integration also must include integration into the regular quality schemes for building components.

Table 1: Architectural criteria for the review of PV buildings and integration products

- Natural integration and visually acceptable
- Architecturally pleasing and visually pleasing
- Good composition between materials and colors
- Fit the grid, harmony, composition
- Appropriately links with the context of the project
- Well-engineered and designed
- Innovative new design

Figure 2: The National Association of Home Builders 21st Century Townhome at the National Research Home Park in Bowie, Maryland, USA; it is one of the Task VII projects to be evaluated.

PV will be largely accepted by builders, architects, and end-users only if the quality of BIPV systems fully meets the requirements of everyday construction elements.

The development of such quality schemes is a part of the work of Task VII as well as an import issue of the European BIPV programs. As an example, the Joule PRESCRIPT project aims at the development of guidelines and pre-standards for the testing and certification of building-integrated PV [7].

Training and education

PV can be included in building projects only if architects and principals have sufficient knowledge about PV technologies and appropriate design tools to assist them.

Design tools can range from planning instruments to tools for shaping and sizing the PV systems. Planning instruments are required to ensure that PV is taken into account from the very start of the building process, where the first decisions have a major impact on the ways to include PV in the building (e.g., the orientation of the building). Tools for shaping and sizing of the PV system can range from intricate software packages (linked to the overall energy design tools) to easy aids as an irradiation disk.

R&D is required in both energy planning and the design and sizing of PV systems, within the overall design of the energy system of the building.

Concerning education, 'PV at schools' programs have proven to be successful in a number of European countries [8]. In order to teach the architects, builders, and occupants of the future how to work with PV, integration of PV into educational programs at all levels is important. A follow-up of national activities at the European level could enhance this process.

FINAL REMARKS

The aforementioned R&D directions are reflected in the projected activities of Task VII. It can, therefore, be concluded that Task VII can contribute to the further development and implementation of PV in the Built Environment. The success of Task VII will of course depend on the effectiveness of the international collaboration and on the contributions of the participating countries to the overall framework of the Task.

The coming five years will show if Task VII can achieve its challenging objective. All experts in the countries participating in Task VII are requested to closely follow the task and, where appropriate, collaborate in its work.

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[5] Bruton, T.M, e.a. (1997). A study of the Manufacture of 500 Wp p.a. of Crystalline Silicon Photovoltaic Modules. In: Proceedings of the 14th EC Photovoltaic Energy Conference, 11–16.

[6] Gabler, H., Heidler, K., and Hoffmann, V.U. (1997). Market Introduction of Grid-Connected Photovoltaic Installations in Germany. In: Proceedings of the 14th EC Photovoltaic Energy Conference, 27–32.

[7] Van Schalkwijk, M., Hoekstra, K.J., Schoen, T., and Van der Weiden, T.C.J. (1997). Quality Assurance of PV Integration in Buildings: Experiences from Practice and Future Outlook. In: Proceedings. of the 14th EC Photovoltaic Energy Conference, 1616–1619.

[8] Nordmann, T. (1995). The Swiss 1 MWp PV-School Demonstration Program. In: Proceedings of the 13th EC Photovoltaic Energy Conference, 894–897.

Appendix B: Contacts for International Energy Agency Photovoltaic Power System Task VII — Photovoltaics in the Built Environment

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Appendix C: Design Tools

Dru Crawley, DOE Program Manager for Building Energy Tools, has established a Building Energy Software Tools Directory. This directory is available on the Internet online; see http://www. eren.doe.gov/buildings/tools_directory/.

Software building design tools are divided into categories that include Energy Simulation, Utility Evaluation, Energy Economics, Atmospheric Pollution, Envelope Systems, Solar Climate Analysis, Codes and Standards: Development and Compliance, and Load Calculations. The software tools described in this section may be particularly useful to those designing buildings and other structures into which photovoltaic power systems are integrated.

AWNSHADE

This program calculates the unshaded fraction of a rectangular window for any given solar position coordinates relative to the window. Calculations are made for window shading configurations, including awnings, with or without side walls or overhangs of arbitrary dimensions above the window. Awnshade can also calculate the unshaded fraction for a sequence of solar positions. It calculates the effective unshaded fraction of diffuse sky irradiance or illuminance incident on the window, assuming uniform sky radiance/luminance, and the effective ground-reflected unshaded fraction. It can handle cases in which shadows of the side of the awning/overhang cross the top of the window.

Audience: This is for architects, building designers, building energy performance simulators.

Expertise Required: Basic understanding of building shading geometry.

Input: User-friendly I/O screens, describing geometry of windows, awnings, and vertical side fins.

Output: Results can be printed directly to a printer, saved to a print file, or saved to files formatted for importing into graphic plotting programs.

Strengths: Outputs a table of unshaded fractions for a range of incident sun directions.

Weaknesses: No fancy graphics of window shadows or their movement across the window.

Availability: Awnshade version 2.0 is available from the contact at a cost of $45 (including shipping and handling).

Contact:
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BEES

A powerful technique for selecting cost-effective, environmentally preferable building products, BEES (Building for Environmental and Economic Sustainability) is based on consensus standards. The Windows-based decision support software, aimed at designers, builders, and product manufacturers, includes actual environmental and economic performance data for a number of building products.

BEES measures the environmental performance of building products by using the environmental life-cycle assessment approach specified in the latest versions of ISO 14000 draft standards. All stages in the life of a product are analyzed: raw material acquisition, manufacture, transportation, installation, use, recycling, and waste management. Economic performance is measured using the American Society for Testing and Materials (ASTM) standard life-cycle cost method, which covers the costs of initial investment, replacement, operation, maintenance, repair, and disposal. Environmental and economic performance are combined into an overall performance measure using the ASTM standard for Multi-Attribute Decision Analysis. For the entire BEES analysis, building products are defined and classified according to the ASTM standard classification for building elements known as UNIFORMAT II.

Audience: This is for designers, specifiers, builders, product manufacturers, researchers, and policy makers.

Expertise Required: None; there were more than 500 users in the first 6 months of availability, both in the U.S. and abroad.

Input: The user sets relative importance weights for (1) synthesizing six environmental impact scores (global warming, acid rain, nutrification, resource depletion, indoor air quality, solid waste) into an environmental performance score; (2) discounting future costs to their equivalent present value; and (3) combining environmental and economic performance scores into an overall performance score. Default values are provided for all of this Windows-based input.

Output: Summary graphs depicting life-cycle environmental and economic performance scores for competing building product alternatives. Detailed graphs are also available, depicting scores for the six environmental impacts underlying the life-cycle environmental performance score, and depicting first and future costs underlying the life-cycle economic performance score. Graphs are live in the sense that alternative graph types (pie graph, bar graph, etc.) may be displayed; rows and columns may be moved; colors, labels, and other display attributes may be customized; and graphs may be printed.

Computer Platform: Windows 95 or higher personal computer with a 486 or higher microprocessor, 32 megabytes or more of RAM, at least 10 megabytes of available disk space, and a 3.5-in. floppy diskette drive. The programming language is CA Visual Objects.

Strengths: The program offers a unique blend of environmental science, decision science, and economics. It uses life-cycle concepts, is based on consensus standards, and is designed to be practical, flexible, and transparent. It is practical in its systematic packaging of detailed, science-based, quantitative environmental and economic performance data in a manner that offers useful decision support. It is flexible in allowing tool users to customize judgments about key study parameters. It is transparent in documenting and providing all the supporting performance data and computational algorithms.

Weaknesses: It includes environmental and economic performance data for only 24 building products covering 12 building elements.

Availability: BEES 1.0 software and printed documentation available free of charge through the EPA Pollution Prevention Information Clearinghouse at 202-260-1023 or via e-mail, ppic@epamail.epa.gov. BEES was developed by the NIST Green Buildings Program with support from the EPA Environmentally Preferable Purchasing Program.

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BLAST

This program performs hourly simulations of buildings, air handling systems, and central plant equipment in order to provide mechanical, architectural, and energy engineers with accurate estimates of a building's energy needs. The zone models of BLAST (Building Loads Analysis and System Thermodynamics), which are based on the fundamental heat balance method, are the industry standard for heating and cooling load calculations. BLAST output may be utilized in conjunction with the LCCID (Life Cycle Cost in Design) program to perform an economic analysis of the building, system, and plant design.

Audience: Mechanical, energy, and architectural engineers working for architectural-engineering firms, consulting firms, utilities, Federal agencies, research universities, and research laboratories.

Expertise Required: High level of computer literacy not required; engineering background helpful for analysis of air-handling systems.

Input: Building geometry, thermal characteristics, internal loads and schedules, heating and cooling equipment and system characteristics. Readable, structured input file may be generated by HBLC (Windows) or the BTEXT program.

Output: More than 50 user-selected, formatted reports printed directly by BLAST; the REPORT WRITER program can generate tables or spreadsheet-ready files for more than 100 BLAST variables.

Strengths: PC Format has Windows interface as well as structured text interface; detailed heat balance algorithms allow for analysis of thermal comfort, passive solar structures, high and low intensity radiant heat, moisture, and variable heat transfer coefficients æ none of which can be analyzed in programs with less rigorous zone models.

Weaknesses: High level of expertise required to develop custom system and plant models.

Availability: Software prices range from $450 for an upgrade package to $1500 for new installations. This package contains complete sources, almost 400 weather files, numerous documents about using BLAST as well as documentation (all on CD ROM). Contact the Building Systems Laboratory for additional information.

Contact:
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1206 West Green Street
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E-mail support@blast.bso.uiuc.edu
Online: http://www.bso.uiuc.edu

BUILDING DESIGN ADVISOR

This provides a software environment that supports the integration of multiple building models and databases used by analysis and visualization tools, through a single, object-based representation of building components and systems. Building Design Advisor (BDA) acts as a data manager and process controller, allowing building designers to benefit from the capabilities of multiple analysis and visualization tools throughout the building design process. BDA is implemented as a Windows-based application. The 1.0 version has links to a Schematic Graphic Editor and two simplified simulation tools, one for daylight and one for energy analyses.

Audience: Architects and engineers working in early building design phases.

Expertise Required: Knowledge of Windows applications; there are at least 200 users.

Input: Graphic entry of basic building geometry and space arrangements. Default descriptive and operational characteristics can be edited by user.

Output: User-selected output parameters displayed in graphic form, including 2-D and 3-D distributions.

Computer Platform: PC-compatible, Windows 95/98/NT, 30 megabytes of hard disk space; the programming language is C++.

Strengths: It allows comparisons of multiple design solutions with respect to multiple descriptive and performance parameters. It also allows the use of sophisticated analysis tools from the early, schematic phases of building design, and does not require the user to have in-depth knowledge to use linked tools for energy, daylighting, and other analyses.

Weaknesses: Version 1.0 is linked to simplified tools for daylight and energy analyses.

Availability: Version 1.0 is available at the Web site below.

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Web: http://kmp.lbl.gov/BDA

CLIMATE CONSULTANT

This program graphically displays climate data in dozens of categories useful to architects. These include temperatures, wind velocity, sky cover, percent sunshine, psychrometric chart, timetable of bioclimatic needs, sun charts, and sun dials showing hours when solar heating is needed and when shading is required. The psychrometric analysis recommends the most appropriate passive design strategy as outlined in Givoni, *Man, Climate and Architecture* (ref. date). It also develops the kind of data incorporated in Watson and Labs, *Climatic Design* (ref. date).

Audience: Architects, students of architecture.

Expertise Required: Intended to be self-instructional, the program requires only basic familiarity with computers and architectural vocabulary.

Input: Typical Meteorological Year (TMY) weather data in short format.

Output: Graphic plots of weather data.

Strengths: Highly graphic, user-friendly.

Weaknesses: Requires weather data in TMY weather data format.

Availability: Not copy protected; sharing is encouraged. It is most easily aquired by copying a disk or by downloading off the Web; otherwise, users can send a check to the technical contact for $35, payable to the Regents of the University of California.

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DOE-2

This is an hourly, whole-building energy analysis program calculating energy performance and life-cycle cost of operation. It can be used to analyze the energy efficiency of given designs or the efficiency of new technologies. Other uses include utility demand-side management and rebate programs, development and implementation of energy efficiency standards and compliance certification, and training a new corps of energy-efficiency-conscious building professionals in architecture and engineering schools.

Audience: Architects, engineers in private A&E firms, energy consultants, building technology researchers, utility companies, state and Federal agencies, and university schools of architecture and engineering.

Expertise Required: A high level of computer literacy is required; a 5-day session of formal training in basic and advanced DOE-2 use is recommended. There are 800 user organizations in the United States and 200 user organizations internationally; user organizations consist of 1 to 20 or more individuals.

Input: Hourly weather file plus Building Description Language input describing geographic location and building orientation, building materials and envelope components (walls, windows, shading surfaces, etc.), operating schedules, HVAC equipment and controls, utility rate schedule, building component costs. The program is available with a range of user interfaces, from text-based to interactive/graphical windows-based environments.

Output: Twenty user-selectable input verification reports, 50 user-selectable monthly/annual summary reports, and user-configurable hourly reports of 700 different building energy variables.

Computer Platform: PC-compatible; Sun; DEC-VAX; DECstation; IBM RS 6000; NeXT; 4 megabytes of RAM; math coprocessor; compatible with UNIX, DOS, VMS; the programming language is FORTRAN.

Strengths: Detailed, hourly, whole-building energy analysis of multiple zones in buildings of complex design; it is widely recognized as the industry standard.

Weaknesses: A high level of user knowledge and computer literacy is required.

Availability: The cost is $300 to $2000, depending upon the hardware platform and software vendor.

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Web: http://gundog.lbl.gov

EMISS

This software generates a file of local air-pollution emission coefficients. It is used with the BLCC life-cycle cost program to estimate reductions in emissions associated with energy conservation projects. Three types of emission factors are currently included: carbon dioxide, sulfur dioxide, and nitrous oxide. Emissions factors are specified separately for six different end-use energy types: electricity, distillate and residual fuel oil, natural gas, liquid petroleum gas, and coal. It is distributed in connection with the BLCC life-cycle cost program to several thousand users.

Audience: Federal energy managers and energy coordinators; engineers and architects; budget analysts and planners.

Expertise Required: None required.

Input: Regional or local emissions factors or fuel-specific end-use data.

Output: Preformatted tables of computed emission factors by type of fuel.

Strengths: Emission factors for fossil fuels can be regionalized or localized. Program contains state-specific electricity emission factors and U.S. average sulfur content of fossil fuels as default data. A users guide is included as file with program.

Weaknesses: The quality of the emissions factors depends on the user's knowledge of the factors that contribute to these emissions.

Availability: Free to Federal agencies through the Energy Efficiency and Renewable Energy Clearinghouse, 1-800-DOE-EREC (363-3732).

Contact:
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ENERGY-10

This is a design tool for smaller residential or commercial buildings (e.g., those that are less than 10,000 square feet in floor area) or buildings that can be treated as one- or two-zone increments. The software performs a whole-building energy analysis for 8760 hours per year, including dynamic thermal and daylighting calculations. It is specifically designed to facilitate the evaluation of energy-efficient building features in the very early stages of the design process.

Audience: This is for building designers, especially architects; HVAC engineers; utility companies; university schools of architecture and architectural engineering.

Expertise Required: A moderate level of computer literacy is required; two days of training are advised.

Input: Only four inputs are required to generate two initial generic building descriptions. Virtually everything is defaulted but modifiable. User adjusts descriptions as the design evolves, using fill-in menus, including utility-rate schedules, construction details, materials.

Output: Summary table and 20 graphical outputs are available, generally comparing current design with base case. Detailed tabular results are also available.

Strengths: Fast, easy-to-use, accurate. Automatic generation of base cases and energy-efficient alternate building descriptions; automatic application of energy-efficient features and rank-ordering of results; integration of daylighting thermal effects with thermal simulation; menu display and modification of all building-description and other data.

Weaknesses: Limited to smaller buildings and HVAC systems that are most often used in smaller buildings.

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Online: http://www.psic.org/energy10.htm

FRESA

This is a first-order screening tool to identify potentially cost-effective applications of renewable energy technology on a building and facility level. FRESA (Federal Renewable Energy Screening Assistant) is useful for determining which renewable energy applications require further investigation. Technologies represented include active solar heating, active solar cooling, solar hot water, daylighting with windows, daylighting with skylights, photovoltaics, solar thermal electric (parabolic dish, parabolic trough, central power tower), wind electricity, small hydropower, biomass electricity (wood, waste, etc.), and cooling load avoidance (multiple glazing, window shading, increased wall insulation, infiltration control). Life-cycle cost calculations comply with 10 CFR 436.

Audience: Building energy auditors.

Expertise Required: Must be able to gather summary information on building and installation energy use patterns; intended for use by trained auditors; results should be interpreted by someone familiar with the limitations of the program.

Input: Summary energy load data; solar and wind resource data provided in a database indexed by ZIP code; biomass and solid waste resource data must be gathered by the auditor.

Output: Annual cost and energy savings; life cycle economics; a red flag if an option is viable; viable options ranked by savings-to-investment ratio.

Strengths: Establishes consistent methodology and reporting format for a large number of audits in varying locations and with varying building use types; sophisticated analyses of technology performance and cost while keeping data requirements to a minimum.

Weaknesses: Provides only first-order screening, to focus design; requires more detailed feasibility analyses on applications most likely to be cost-effective; requires high level of knowledge about energy audits and the limitations of the program; not suitable for general use.

Availability: Available from the technical contact.

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IDEAL

This software is designed to read electronic data records of facilities' electrical energy use; the data records are compiled by electric utility companies and normally used internally only for billing purposes. Upon request, the utility will release the data to the customer for analysis purposes. These data records are formatted in more than 25 distinct file types identified thus far. IDEAL (Interval Data Evaluation and Analysis of Load) translates all these formats into a common database and produces informative graphs and reports to assist the user, the energy management team, or consultants in quickly identifying periods of serious power mismanagement. Extensions to the basic program will perform power bill calculations, time-of-use analysis, temperature and humidity plots, and optimum standby generator sizing and run times.

Audience: Industrial and large commercial accounts who have electronic metering on their electrical power service (typically, loads with more than 500 kilowatts demand, and virtually all with time-of-use metering).

Expertise Required: No special expertise required.

Input: Data file, normally obtained from the electric utility company, which includes interval recordings of power usage. Program requires data to be an ASCII-formatted data file on diskette.

Output: Both detailed and summary reports of facility electrical usage. More than 70 preformatted graphs visually depict power usage by day, week, or month. Variables include kilowatts at a minimum and may include kilovars and kilovolt-amperes, if the source data file contains this information.

Strengths: Identifies, by time of day, periods of excessive power demand and consumption. Also useful in benchmarking a facility's power usage before energy measures are implemented and tracking the results after implementation. Ability to immediately utilize more than 25 data formats without prior conversion of the data by the user.

Weaknesses: Limits analysis to month-by-month studies. Can produce records suitable for greater-than-one-month analysis using conventional spreadsheets. Must use DOS sequences for printing reports and graphs.

Availability: Download demos from the Web to determine suitability to task. Price negotiable based on number of copies; list price $1,000.

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PV-DesignPro

This program simulates photovoltaic system operation on an hourly basis for one year, based on a user-selected climate and system design. PV-DesignPro is recommended for designs that include battery storage, which can be either stand-alone systems with generator backup or utility-interconnected systems. The purpose of the program is to aid in photovoltaic system design by providing accurate, in-depth information on the likely system power output and load consumption, backup power needed during system operation, and the financial impacts of installing the proposed system. The program CD-ROM includes a climate database of 239 locations in the continental United States, Alaska, Hawaii, Puerto Rico, and Guam and a Worldwide Hourly Climate Generator Program that generates hourly climates for 2,132 global locations from monthly data. The SolarPro 2.0 solar water heating program is also included. Six types of panel surface tracking are incorporated into the program: fixed slope and axis, tracking on a horizontal east-west axis, tracking on a horizontal north-south axis, tracking on a vertical axis with a fixed slope, tracking on a north-south axis parallel to the Earth's axis, and continuous tracking on two axes. Panel shading information can also be input.

Audience: This program is for PV system design professionals, architects, engineers, energy offices, universities, and students.

Expertise Required: Knowledge of electrical design, PV basics.

Input: Windows 95-based interface; uses the electrical system load by hour for weekdays, weekends, and holidays; requires panel type from database, number of parallel connections and series strings of similar panels; battery backup charging parameters; AC inverter requirements; and climate file.

Output: Solar Fraction charts by month, battery states of charge by month (maximum, average, minimum), annual performance table (energy produced, necessary backup, and states-of-charge), prospective cash-flows of purchased and sold energy, system costs, costs of backup energy, prices of sold energy, maintenance and replacement costs, and the estimated life of the system. A rate of return is calculated, as well as an overall price per kWh of the system and payback years.

Strengths: Most information needed for PV designs is included in databases.

Weaknesses: Resistive loads, such as water pumping with a motor only, cannot currently be modeled.

Relatively high level of PV expertise recommended.

Availability: CD-ROM, $149.00 + $10.00 shipping and handling. Price includes Worldwide Hourly Climate Generator 1.0 program and SolarPro 2.0 solar water heating program. See Web site or call for more information.

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Quick BLCC

This program is used to set up multiple project alternatives for life-cycle costing analysis in a single input file. The Quick BLCC (Quick Building Life-Cycle Cost) program provides a convenient method for solving relatively simple LCC problems that require finding the lowest LCC design alternative among many mutually exclusive alternatives for the same project. Input data files are transferrable to BLCC for more detailed analysis.

Audience: Federal energy managers and energy coordinators; engineers and architects; budget analysts and planners.

Expertise Required: Familiarity with present-value concept is helpful.

Input: Initial investment costs; base-year annual energy costs; maintenance, repair, and replacement costs; time period.

Output: Preformatted tables of input data summary and LCC and comparative analyses results. Exportable data files.

Strengths: Ideal for preliminary economic evaluation of multiple design alternatives. Users guide is included as file with program.

Weaknesses: No private-sector tax analysis included.

Availability: Free to Federal agencies through the Energy Efficiency and Renewable Energy Clearinghouse, 1-800-DOE-EREC (363-3732).

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Online: http://www.eren.doe.gov/femp/techassist/softwaretools/softwaretools.html

SOLAR-2

This software plots sunlight penetrating through a window with any combination of rectangular fins and overhangs. It also plots an hour-by-hour, three-dimensional suns-eye view "movie" of the building. It prints annual tables of the percentage of the window in full sun, radiation on glass, and other data.

Audience: This is for architects, students of architecture, building managers, and knowledgeable homeowners.

Expertise Required: Intended to be self-instructional, it requires only basic familiarity with computers and architectural vocabulary.

Input: Window, overhangs, and fins geometry.

Output: Graphic plots, tables.

Strengths: User-friendly, highly graphic.

Weaknesses: Allows only rectangular shading elements.

Availability: Not copy protected; sharing is encouraged. The software is most easily aquired by copying a disk or by downloading off the Web; otherwise, users can send a check to the technical contact for $35, payable to the Regents of the University of California.

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Online: http://www.fsec.ucf.edu

SOLAR-5

This program displays 3-D plots of hourly energy performance for the whole building or for any of 16 different components. SOLAR-5 also plots heat flow into and out of thermal mass as well as indoor air temperature, output of the HVAC system, cost of electricity and heating fuel, and the corresponding amount of air pollution. It uses hour-by-hour weather data. It contains an expert system to design an initial base case building for any climate and any building type, which an architect can copy and redesign. Contains a variety of decision-making aids, including combination and comparison options, color overlays, and bar charts that show for any hour exactly where the energy flows.

Audience: This is for architects, students of architecture, building managers, and knowledgeable homeowners.

Expertise Required: It is intended to be self-instructional, with built-in help options; requires only basic familiarity with computers and with architectural vocabulary.

Input: From only four pieces of data initially required (floor area, number of stories, location, and building type), the expert system designs a basic building, filling in hundreds of items of data; the user can make subsequent revisions, usually beginning with overall building dimensions, window sizes, etc.

Output: Dozens of different kinds of three-dimensional plots, tables, and reports. For example, displays heat gain or loss for more than a dozen different building components; shows heat flow into and out of the thermal mass of the building, as well as the output of the heating and air conditioning systems; displays air temperatures (outdoors or indoors) and air change rates; predicts the cost of heating fuel and electricity.

Strengths: Intended for use during the very earliest stages of the design process (when most critical energy decisions are made); extremely user friendly and rapid, calculating a full year using TMY data in less than a minute on a 486 MB machine.

Weaknesses: Not intended for complex mechanical system design or equipment sizing.

Availability: SOLAR 5.4 is the most recent public release, updated in September 1997. It writes out its own users manual. Not copy protected; sharing is encouraged. Most easily aquired by copying a disk or by downloading off the Web; otherwise, users can send a check to the technical contact for $35, payable to the Regents of the University of California.

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SOMBRERO

In designing both active (domestic hot water, photovoltaics) and passive solar energy systems, shading of collectors or windows by other objects plays an important role. SOMBRERO provides quantitive solutions to these problems. It calculates geometrical shading coefficients, which can be used either directly for visualization or as quantitative input to other thermal simulation programs.

Audience: Architects, engineers for thermal simulations of buildings or solar plants.

Expertise Required: Basic knowledge of geometry and solar radiation.

Input: Three-dimensional objects are built up by their boundary planes. Up to 300 plane areas with 12 points each can be treated. Objects like houses and trees are predefined and described by parameters like height, width, and position in space. Single planes are described by their vertex-points in the two-dimensional co-ordinate system related to the plane itself (in case of rectangles simply by their length and height) and positioned by indication of azimuth, elevation, and origin in the three-dimensional space. Time steps for simulation can be selected freely. Foliage of trees and reflection factors of the ground can be given as monthly schedules.

Output: Values of the daily course of geometrical shading coefficients are calculated hourly.

Computer Platform: MS-DOS 5.0 and MS-Windows 3.1 or better; PC-compatible system with VGA-compatible graphic-board (at least 640 x 480 pixels); about 5 MB free space on hard disk. The programming language is Delphi.

Strengths: Easy to handle.

Weaknesses: Unknown.

Availability: A demonstration version can be downloaded free; it expires 5 days after it is first started up. The full version sells for $230.

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SUN POSITION

The program calculates time series of sun angles (such as solar altitude and solar azimuth) for a given location and outputs them as text files that can be imported into spreadsheets and solar energy analysis programs. Sun Position is highly customizable; it can calculate angles for one specific day, once a month for one year, once a week, daily, etc., and in a given day calculate the angles once a day, hourly, every 15 minutes, etc. Its primary purpose is to assist architects and solar designers.

Audience: Architects, passive solar designers, PV and solar thermal energy system designers.

Expertise Required: Understanding of fundamentals of sun angles (see www.crest.org/staff/ceg/sunangle/ for an introduction to sun angle concepts).

Input: The user inputs the geographical location, the frequency of the data desired, and the output format desired; the program has a graphical user interface.

Output: The output is text files consisting of tables of sun angle data; the specific sun angles, format of the data, etc., are specified by the user.

Computer Platform: Windows and Macintosh; the programming language is MacroMedia Director.

Strengths: Best for people performing analyses of buildings or solar energy systems over a year who need to know solar altitude and azimuth angles for their analysis.

Weaknesses: While Sun Position can compute individual sun angles (i.e., at one specific time instead of throughout the year), it would be more efficient to use the internet SunAngle calculator for single calculations.

Availability: Free.

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SUNSPEC

This software calculates clear-sky direct beam and diffuse-sky solar spectral irradiances and the sum of these two spectra for sun positions and atmospheric conditions specified by the user. Sunspec also calculates the spectral irradiances from the direct beam, diffuse sky, or ground reflections that are incident on an arbitrarily tilted plane. Sunspec integrates these spectra to determine the total irradiances, illuminances, and luminous efficacies for each component.

Sunspec offers the user a menu of typical atmospheric conditions to choose from and follows this with detailed editing screens permitting the user to change any input parameter. The input parameters include values for ozone concentration, water vapor, turbidity, ground reflectance (albedo), solar altitude and azimuth angles, and tilted plane altitude and azimuth angles. Sunspec includes a loop option permitting repeated calculations at different solar positions for the same atmospheric conditions. It also has an option for outputting solar spectral data files that can be read by the Window 4 program, which calculates the solar optical and heat transfer properties of windows in buildings.

Audience: This is for architects, building designers, fenestration energy performance simulators, atmospheric scientists, and others interested in determining the spectrum of radiation from the sun and sky.

Expertise Required: Basic understanding of solar geometry.

Input: User-friendly I/O screens, solar position, atmospheric conditions.

Output: Results can be printed directly to a printer, or saved to a print file or to files formatted for importing into graphic plotting programs.

Strengths: Provides a solar spectrum data file with columns for wavelength, direct normal, direct horizontal, direct tilted, diffuse horizontal, and diffuse tilted spectral irradiances, as well as the global (both direct and diffuse) versions of these. Also outputs the integrated total irradiances in W/m2 and the total integrated illuminances in lux for all these beams.

Weaknesses: Current menu of typical atmospheric conditions is limited. It does not yet have the latest version of the SMARTS algorithm and is not as user-friendly as a planned future version.

Availability: Sunspec 1.0 is available from the contact at a cost of $35 (including shipping and handling).

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TRNSYS

This modular system simulation software includes many of the components commonly found in thermal energy systems as well as component routines to handle input of weather or other time-dependent functions and output of simulation results. TRNSYS (TRaNsient SYstem Simulation Program) is typically used for HVAC analysis and sizing, solar design, building thermal performance, and analysis of control schemes.

Audience: Engineers, researchers, and architects.

Expertise Required: None to use standard package; FORTRAN knowledge is helpful for developing new components

Input: TRNSYS input file, including building input description, characteristics of system components and manner in which components are interconnected, and separate weather data (supplied with program). Input file can be generated by graphically connecting components.

Output: Life-cycle costs, monthly summaries, annual results, histograms, plotting of desired variables (by time unit), online variable plotting (as the simulation progresses).

Strengths: Because of its modular approach, the program is extremely flexible for modeling a variety of thermal systems at different levels of complexity; supplied source code and documentation provide an easy method for users to modify or add components not in the standard library; extensive documentation on component routines, including explanation, background, typical uses and governing equations; supplied time step, starting, and stopping times allow choice of modeling periods. Version 14.2 moves all the TRNSYS utility programs to the MS Windows platform (95/NT), including a choice of graphical drag-and-drop programs for creating input files, a utility for easily creating a building input file, and a program for building TRNSYS-based applications for distribution to nonusers. Web-based library of additional components and frequent downloadable updates are also available.

Weaknesses: No assumptions about the building or system are made (although default information is available) so the user must have detailed information about the building and system and enter this information into the TRNSYS interface.

Availability: Version 14.2, Commercial, $4000; Educational, $2000. Free demonstration diskette and information are available from the technical contact. International distributors are located in Germany, France, Belgium, and Sweden in addition to two distributors in the United States.

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About the Authors

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Dr. Eiffert is a project leader in the National Renewable Energy Laboratory's (NREL's) Deployment Facilitation Center. NREL is a U.S. Department of Energy (DOE) national laboratory. As a Deputy Team Leader within NREL's Federal Energy Management Program (FEMP) team, Dr. Eiffert has had experience managing projects that assist in implementing renewable energy in the Federal sector. Primary activities range from conducting economic feasibility analysis and design studies through assessment and exploration of alternative financing mechanisms. Dr. Eiffert leads national activities under the Save with Solar: Federal Participation in the Million Solar Roofs Initiative on behalf of DOE FEMP.

Additionally, Dr. Eiffert co-represents the United States in the International Energy Agency, Photovoltaic Power Systems (PVPS) Task VII, Photovoltaics in the Built Environment, along with Steven Strong of Solar Design Associates. In this position, as an internationally recognized expert in Building Integrated Photovoltaics (BIPV), Dr. Eiffert leads the effort to develop International Guidelines for the Economic Evaluation of BIPV and is the Activity Leader for Subtask 3: Non-technical Barriers.

Dr. Eiffert completed her doctorate in Architecture on building-integrated photovoltaics at Oxford Brookes University Post-Graduate Research School in the United Kingdom. Dr. Eiffert has authored many articles and publications related to renewable energy systems and programs and is a guest lecturer at universities across the country.

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Gregory J. Kiss

Mr. Kiss, a specialist architect, has been a principal of Kiss + Cathcart since 1984. His work has focused on the integration of solar technologies into architecure and product design, and has included built projects research and education. Kiss + Cathcart have won a number of awards and invited competitions, including top prizes in every solar-architecture competition since 1992. Kiss + Cathcart's projects range from first-of-a-kind photovoltaic buildings in Port Jarvis, New York, and Fairfield, California, to major PV buildings projects in progress at Four Times Square in Manhattan, New York; in Yosemite National Park; and in Hamburg, Germany.

Research by the firm has included three studies on building-integrated photovoltaics commissioned by NREL. In conjunction with Energy Photovoltaics of Princeton, New Jersey, Kiss + Cathcart has developed several BIPV construction products, including large-area lamiations for facades and skylights. The firm is also developing custom patterned, semitransparent PV panels for building use.

Consulting activities include the Whitehall Ferry Terminal project in New York and solar housing in Winslow, Arizona, as well as the projects listed in the design briefs in this book.

Kiss + Cathcart designed "Under the Sun," a major exhibition of solar design and architecture at the Cooper Hewitt, National Design Museum, Smithsonian Institution. The exhibit is an investigation of the design implications of the solar future; it was originally held in one of the most prestigious garden sites in the United States. This is now a traveling exhibit.

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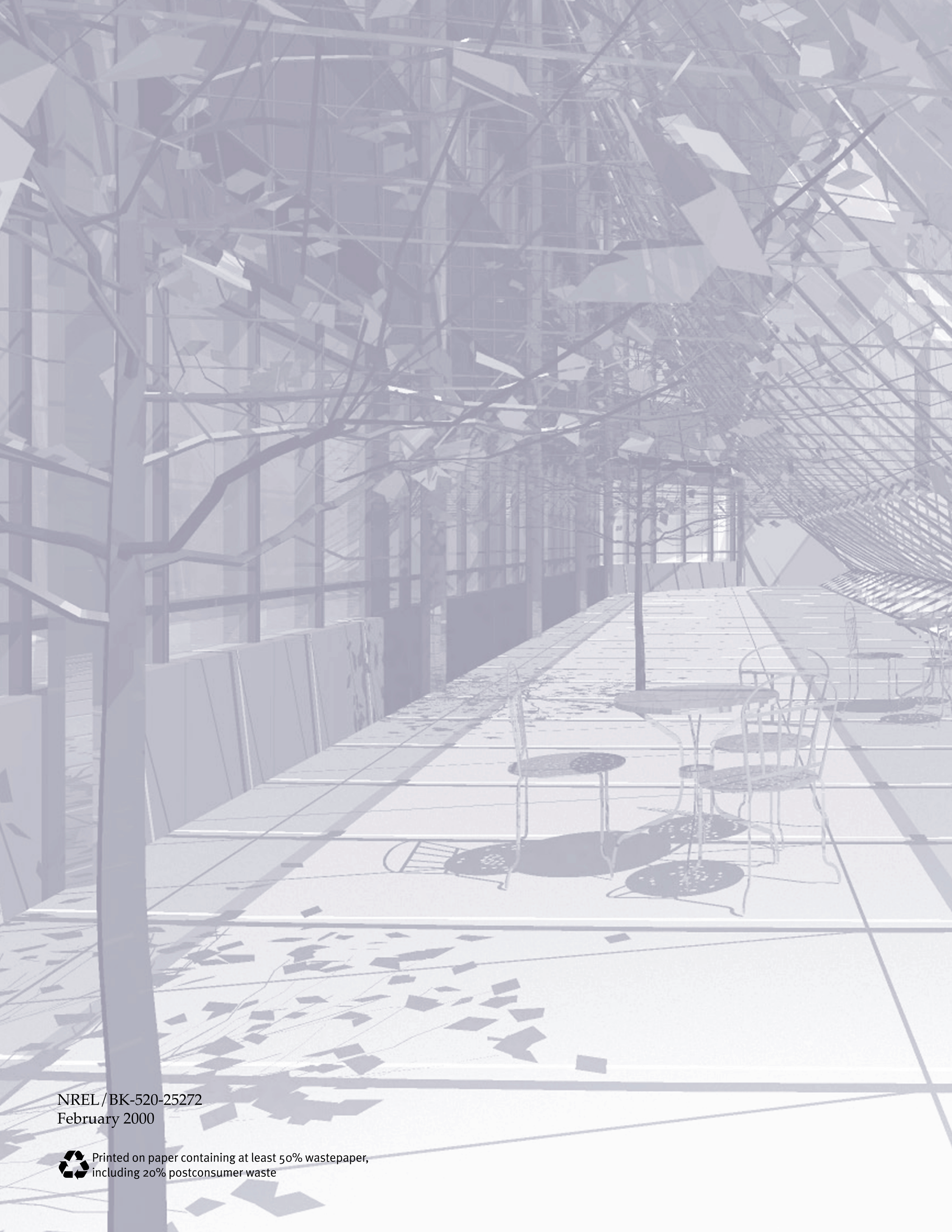

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