Building Integrated Photovoltaics

a White Paper on its principles
and applications

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INTRODUCTION

One of the most promising renewable energy technologies is photovoltaics. Photovoltaics (PV) is a truly elegant means of producing electricity on site, directly from the sun, without concern for energy supply or environmental harm. These solid-state devices simply make electricity out of sunlight, silently with no maintenance, no pollution, and no depletion of materials.

There is a growing consensus that distributed photovoltaic systems that provide electricity at the point of use will be the first to reach widespread commercialization. Chief among these distributed applications are PV power systems for individual buildings.

Interest in the building integration of photovoltaics, where the PV elements actually become an integral part of the building, often serving as the exterior weather skin, is growing worldwide. PV specialists and innovative designers in Europe, Japan, and the U.S. are now exploring creative ways of incorporating solar electricity into their work. A whole new vernacular of Solar Electric Architecture is beginning to emerge.

A Building Integrated Photovoltaics (BIPV) system consists of integrating photovoltaics modules into the building envelope, such as the roof or the façade. By simultaneously serving as building envelope material and power generator, BIPV systems can provide savings in materials and electricity costs, reduce use of fossil fuels and emission of ozone depleting gases, and add architectural interest to the building.

A PV skylight entryway
(Courtesy of DOE/NREL)

While the majority of BIPV systems are interfaced with the available utility grid, BIPV may also be used in stand-alone, off-grid systems. One of the benefits of grid-tied BIPV systems is that, with a cooperative utility policy, the storage

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system is essentially free. It is also 100% efficient and unlimited in capacity. Both the building owner and the utility benefit with grid-tied BIPV. The on-site production of solar electricity is typically greatest at or near the time of a building's and the utility's peak loads. The solar contribution reduces energy costs for the building owner while the exported solar electricity helps support the utility grid during the time of its greatest demand.

DESCRIPTION

Photovoltaics (PV) Technologies

There are two basic commercial PV module technologies available on the market today:

1. *Thick crystal products* include solar cells made from crystalline silicon either as single or poly-crystalline wafers and deliver about 10-12 watts per ft² of PV array (under full sun).
2. *Thin-film products* typically incorporate very thin layers of photovoltaicly active material placed on a glass superstrate or a metal substrate using vacuum-deposition manufacturing techniques similar to those employed in the coating of architectural glass. Presently, commercial thin-film materials deliver about 4-5 watts per ft² of PV array area (under full sun). Thin-film technologies hold out the promise of lower costs due to much lower requirements for active materials and energy in their production when compared to thick-crystal products.

A photovoltaic system is constructed by assembling a number of individual collectors called modules electrically and mechanically into an array.

Building Integrated Photovoltaics (BIPV) System

Building Integrated Photovoltaics (BIPV) is the integration of photovoltaics (PV) into the building envelope. The PV modules serve the dual function of building skin—replacing conventional building envelope materials—and power generator. By avoiding the cost of conventional materials, the incremental cost of photovoltaics is reduced and its life-cycle cost is improved. That is, BIPV systems often have lower overall costs than PV systems requiring separate, dedicated, mounting systems.

A complete BIPV system includes:

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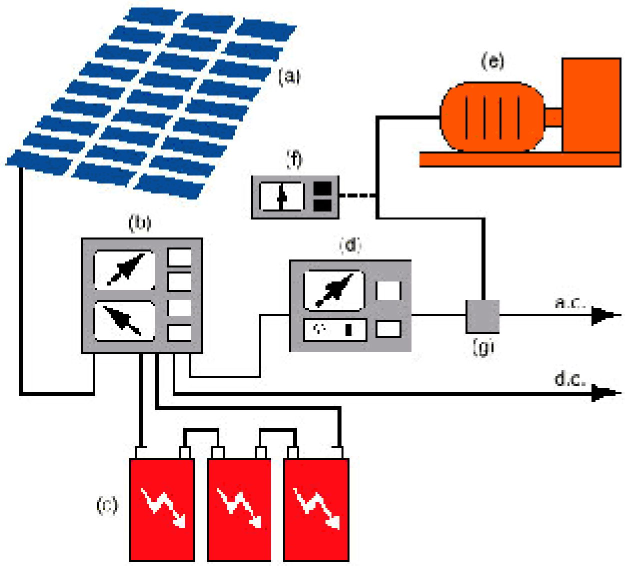
a. the PV modules (which might be thin-film or crystalline, transparent, semi-transparent, or opaque);
b. a charge controller, to regulate the power into and out of the battery storage bank (in stand-alone systems);
c. a power storage system, generally comprised of the utility grid in utility-interactive systems or, a number of batteries in stand-alone systems;
d. power conversion equipment including an inverter to convert the PV modules' DC output to AC compatible with the utility grid;
e. backup power supplies such as diesel generators (optional-typically employed in stand-alone systems); and
f. appropriate support and mounting hardware, wiring, and safety disconnects.



BIPV system diagram (Courtesy of Australian CRC for Renewable Energy Ltd.)

BIPV systems can either be interfaced with the available utility grid or they may be designed as stand-alone, off-grid systems. The benefits of power production at the point of use include savings to the utility in the losses associated with transmission and distribution (known as 'grid support'), and savings to the consumer through lower electric bills because of peak shaving (matching peak production with periods of peak demand). Moreover, buildings that produce power using renewable energy sources reduce the demands on traditional utility generators, often reducing the overall emissions of climate-change gasses.

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DESIGN OF A BUILDING INTEGRATED PHOTOVOLTAICS (BIPV) SYSTEM

BIPV systems should be approached to where energy conscious design techniques have been employed, and equipment and systems have been carefully selected and specified. They should be viewed in terms of life-cycle cost, and not just initial, first-cost because the overall cost may be reduced by the avoided costs of the building materials and labor they replace. Design considerations for BIPV systems must include the building's use and electrical loads, its location and orientation, the appropriate building and safety codes, and the relevant utility issues and costs.

Steps in designing a BIPV system include:

1. *Carefully consider the application of energy-conscious design practices and/or energy-efficiency measures to reduce the energy requirements of the building.* This will enhance comfort and save money while also enabling a given BIPV system to provide a greater percentage contribution to the load.
2. *Choose Between a Utility-Interactive PV System and a Stand-alone PV System:*
    - The vast majority of BIPV systems will be tied to a utility grid, using the grid as storage and backup. The systems should be sized to meet the goals of the owner—typically defined by budget or space constraints; and, the inverter must be chosen with an understanding of the requirements of the utility.
    - For those 'stand-alone' systems powered by PV alone, the system, including storage, must be sized to meet the peak demand/lowest power production projections of the building. To avoid over sizing the PV/battery system for unusual or occasional peak loads, a backup generator is often used. This kind of system is sometimes referred to as a "PV-genset hybrid."
3. *Shift the Peak:* If the peak building loads do not match the peak power output of the PV array, it may be economically appropriate to incorporate batteries into certain grid-tied systems to offset the most expensive power demand periods. This system could also act as an uninterruptible power system (UPS).
4. *Provide Adequate Ventilation:* PV conversion efficiencies are reduced by elevated operating temperatures. This is truer with crystalline silicon PV cells than amorphous silicon thin-films. To improve conversion efficiency, allow appropriate ventilation behind the modules to dissipate heat.

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5. *Evaluate Using Hybrid PV-Solar Thermal Systems:* As an option to optimize system efficiency, a designer may choose to capture and utilize the solar thermal resource developed through the heating of the modules. This can be attractive in cold climates for the pre-heating of incoming ventilation make-up air.
6. *Consider Integrating Daylighting and Photovoltaic Collection:* Using semi-transparent thin-film modules, or crystalline modules with custom-spaced cells between two layers of glass, designers may use PV to create unique daylighting features in façade, roofing, or skylight PV systems. The BIPV elements can also help to reduce unwanted cooling load and glare associated with large expanses of architectural glazing.
7. *Incorporate PV Modules into Shading Devices:* PV arrays conceived as "eyebrows" or awnings over view glass areas of a building can provide appropriate passive solar shading. When sunshades are considered as part of an integrated design approach, chiller capacity can often be smaller and perimeter cooling distribution reduced or even eliminated.
8. *Design for the Local Climate and Environment:* Designers should understand the impacts of the climate and environment on the array output. Cold, clear days will increase power production, while hot, overcast days will reduce array output;
    - Surfaces reflecting light onto the array (e.g., snow) will increase the array output;
    - Arrays must be designed for potential snow- and wind-loading conditions;
    - Properly angled arrays will shed snow loads relatively quickly; and,
    - Arrays in dry, dusty environments or environments with heavy industrial or traffic (auto, airline) pollution will require washing to limit efficiency losses.
9. *Address Site Planning and Orientation Issues:* Early in the design phase, ensure that your solar array will receive maximum exposure to the sun and will not be shaded by site obstructions such as nearby buildings or trees. It is particularly important that the system be completely unshaded during the peak solar collection period consisting of three hours on either side of solar noon. The impact of shading on a PV array has a much greater influence on the electrical harvest than the footprint of the shadow.
10. *Consider Array Orientation:* Different array orientation can have a significant impact on the annual energy output of a system, with tilted arrays generating 50%-70% more electricity than a vertical façade.

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11. *Reduce Building Envelope and Other On-site Loads:* Minimize the loads experienced by the BIPV system. Employ daylighting, energy-efficient motors, and other peak reduction strategies whenever possible.
12. *Professionals:* The use of BIPV is relatively new. Ensure that the design, installation, and maintenance professionals involved with the project are properly trained, licensed, certified, and experienced in PV systems work.

In addition, BIPV systems can be designed to blend with traditional building materials and designs, or they may be used to create a high-technology, future-oriented appearance. Semi-transparent arrays of spaced crystalline cells can provide diffuse, interior natural lighting. High profile systems can also signal a desire on the part of the owner to provide an environmentally conscious work environment.

APPLICATION

Photovoltaics may be integrated into many different assemblies within a building envelope:

- Solar cells can be incorporated into the façade of a building, complementing or replacing traditional view or spandrel glass. Often, these installations are vertical, reducing access to available solar resources, but the large surface area of buildings can help compensate for the reduced power.
    - APS Factory, Fairfield, CA
- Photovoltaics may be incorporated into awnings and saw-tooth designs on a building façade. These increase access to direct sunlight while providing additional architectural benefits such as passive shading.
    - Intercultural Center, Georgetown University, Washington, DC
- The use of PV in roofing systems can provide a direct replacement for batten and seam metal roofing and traditional 3-tab asphalt shingles.
    - Energy Resource Center, Southface Institute, Atlanta, GA
- Using PV for skylight systems can be both an economical use of PV and an exciting design feature.
    - Olympic Natatorium, Georgia Institute of Technology, Atlanta, GA

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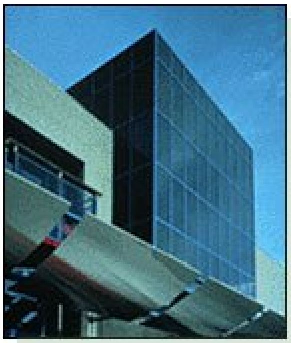


Left to right: APS Factory in Fairfield, CA and Intercultural Center, Georgetown University in Washington, DC

RELEVANT CODES AND STANDARDS

Building-Integrated Photovoltaic Designs for Commercial and Institutional Structures: A Sourcebook for Architects
Energy Policy Act of 2005 (PDF 1.9 MB, 550 pgs)

ADDITIONAL RESOURCES

Manufacturers and Suppliers

Atlantis USA Sunslates™
bp solar
Energy Photovoltaics, Inc.
RWE SCHOTT Solar
Shell Solar
United Solar Ovonic Corp.

Computer-Based PV Design and Sizing Tools

PV F-Chart—Provides analysis and rough sizing of both grid-connected and stand-alone PV systems.
PVFORM—Offers simulation of grid-connected and stand-alone systems, including economic analysis. Available from Sandia National Labs, Albuquerque, NM.

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TRNSYS—Simulation system for renewable energy applications; originally for solar thermal, now has extensions for PV and wind.

PV Planner—A spreadsheet analytical tool for grid-connected applications. Available from the Center for Energy and Environmental Policy, University.

HOMER—Hybrid Optimization Model for Electric Renewables (HOMER) is a design optimization model that determines the configuration, dispatch, and load management strategy that minimizes life-cycle costs.

PVnode—Calculates the electric behavior of large and inhomogeneously illuminated PV arrays. Available from D. Stellbogen, ZSW Baden-Wurttemberg Hessbruhlstr., 21c, D-70565 Stuttgart, Germany.

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