NREL/CP-550-25764

Photovoltaics for Buildings Cutting-Edge PV

S.J. Hayter and R.L. Martin
National Renewable Energy Laboratory

Presented at UPVG Utility PV Experience (UPEx) '98
San Diego, California
September 28--30, 1998

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401-3393
A national laboratory of the U.S. Department of Energy
Managed by Midwest Research Institute
for the U.S. Department of Energy
under contract No. DE-AC36-83CH10093

Work performed under task number PV908201

November 1998

Available to DOE and DOE contractors from:
Office of Scientific and Technical Information (OSTI)
P.O. Box 62
Oak Ridge, TN 37831
Prices available by calling 423-576-8401

Available to the public from:
National Technical Information Service (NTIS)
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
703-605-6000 or 800-553-6847
or
DOE Information Bridge
http://www.doe.gov/bridge/home.html

Printed on paper containing at least 50% wastepaper, including 10% postconsumer waste

Photovoltaics for Buildings – Cutting-Edge PV

Sheila J. Hayter, P.E.
Photovoltaics for Buildings Task Leader
National Renewable Energy Laboratory

Robert L. Martin
U.S. Department of Energy, Golden Field Office

Abstract

Photovoltaic (PV) technology development for building-integrated applications (commonly called PV for Buildings) is one of the fastest growing areas in the PV industry. Buildings represent a huge potential market for photovoltaics because they consume approximately two-thirds of the electricity consumed in the United States. The PV and buildings industries are beginning to work together to address issues including building codes and standards, integration, after-market servicing, education, and building energy efficiency. One of the most notable programs to encourage development of new PV-for-buildings products is the PV:BONUS program, supported by the U.S. Department of Energy. Demand for these products from building designers has escalated since the program was initiated in 1993. This paper presents a range of PV-for-buildings issues and products that are currently influencing today's PV and buildings markets.

Introduction

The buildings sector consumes approximately one-third of the energy and about two-thirds of the electricity produced annually in the United States (Figures 1 and 2). (1) In addition, the United States is the largest energy consumer in the world. As the PV and buildings industries begin to recognize the impact buildings in the United States have on national and global energy consumption, there is a growing interest in meeting some of this energy demand with alternative energy systems, such as photovoltaics.

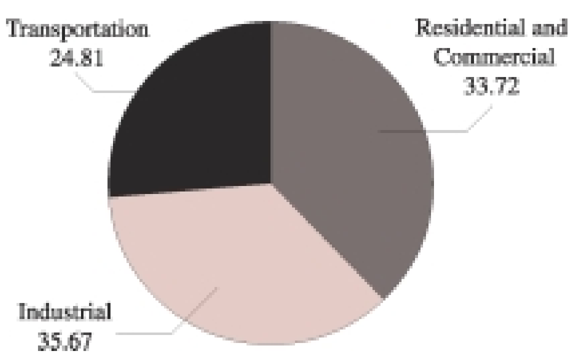

Figure 1. 1997 energy flow in quadrillion Btu (1)

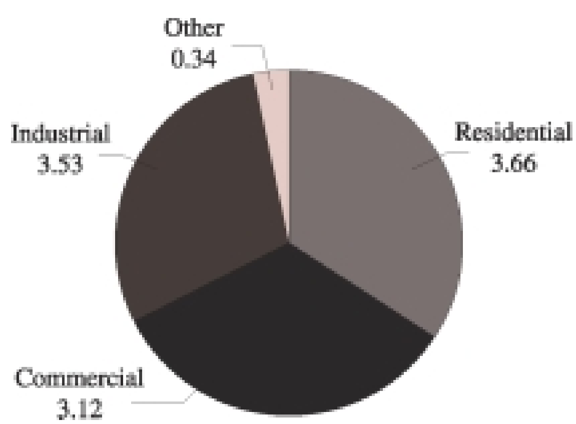

Figure 2. 1997 electricity end use flow in quadrillion Btu(1)

Terminology such as building-integrated photovoltaics (BIPV) and PV for buildings have entered into the everyday language of the PV and buildings industries. Building-integrated PV often refers to the incorporation of photovoltaic systems into the envelope of a building. In BIPV systems, the PV panels replace part of the building's skin, including roof materials, glazings (e.g., windows and skylights), and wall components. PV-for-buildings systems do more than just replace envelope components. These PV systems also: (1) operate "active" windows (electrochromic windows) and systems for air movement (fans), fluid movement (pumps); (2) operate heating, ventilating, and air-conditioning (HVAC) systems and lighting systems; and (3) work with building control systems to reduce building peak electrical demand and ultimately lower customer utility bills. Table 1 summarizes some benefits of PV-for-buildings systems.

TABLE 1. Benefits of PV-for-Buildings Systems

Benefit	**Description**
Market growth	Building market is large, provides significant growth potential for PV
Eliminates T&D losses	PV-for-buildings systems provide power at the point of use and eliminate utility transmission and distribution losses
BIPV offsets costs	PV costs are partially offset by replacement of building materials
Land and support structure not needed	Land and support structure are unnecessary when the system is integrated with the building skin
Less cost justification needed for some BIPV systems	Fewer barriers exist when expensive architectural elements are added to a building that only serve to improve look of the building; building image enhanced by PV
Lowers building peak electrical demand	PV-for-buildings systems offset peak loads because system output corresponds to typical daily electrical demands

PV-for-Buildings Issues

The benefits listed in Table 1 reveal both opportunities for growth and areas that should be of concern to the PV industry. As soon as the PV system is integrated with a building in any way (e.g., by replacing building-envelope elements, by linking directly to building electrical systems, or by being mounted on a building structure), it is subjected to the following buildings-related issues.

- Building codes and standards
- Integration
- After-market servicing
- Education
  - System designers
  - System installers
  - Building owners/operators
  - Standards and codes developers
- Warranties and insurance policies
- Energy efficiency and conservation.

Building Codes and Standards. Efforts spearheaded by the National Center for Photovoltaics (NCPV) and individual PV system product manufacturers have resulted in the inclusion of PV systems in electrical codes. More recently, most PV systems products have begun to undergo testing to be listed by the Underwriters Laboratory. Little effort has been made, however, to evaluate how other national-consensus building codes and standards may affect construction of PV-for-buildings systems. Conflicts will arise when existing building codes do not address PV systems in buildings, sometimes making it impossible, or very expensive, to install these systems.

Integration. It is important to have the buildings industry involved in developing new products and improving existing products. Products introduced to the market that are awkward to integrate with the building envelope, difficult to connect with the building electrical system, or are difficult to maintain will not be accepted by the buildings industry. The products must also address those areas important to building designers. For example, designers and manufacturers must ensure that products do not adversely affect building thermal loads and that they can be easily integrated into new and retrofit applications.

After-Market Servicing. There must be a network of qualified technicians to service PV-for-buildings systems after they have been installed. Unless solar systems are reliable and can easily be maintained and serviced, the public will not invest in these systems. Current activities within the NCPV address these issues for the PV and balance of system components. Not as much emphasis has been given to servicing the integration of the PV system within the building envelope or with the building electrical system.

Education. It is important that all the players involved with the design, installation, ownership, operation, and servicing of a PV-for-buildings system learn are educated about BIPV systems within their respective disciplines. Architects and engineers will be given the confidence to design PV-for-buildings systems after training. Members of the construction industry who will be installing various components of the PV-for-buildings systems must understand how to properly install the systems for safety and durability. Building owners should understand the benefits and risks involved with owning these systems. Building operators must know how to optimize the PV-for-buildings system performance and be familiar with proper maintenance of the systems. Finally, those responsible for developing building codes and standards need to know how to address PV-for-buildings systems.

Warranties and Insurance Policies. Providing warranties for the entire PV-for-buildings system (not just the PV component) will build customer confidence to purchase what is still considered in the buildings industry to be a new technology. Warranties will also encourage insurance companies to insure these systems. When establishing warranties for the entire PV/buildings systems, the varying life expectancies of each component in the system should be considered. For example, the electronics and balance of system (BOS) components often have shorter lifetimes than the PV modules.

Energy Efficiency and Conservation. The value of the building component the BIPV system is replacing reduces the initial cost of BIPV systems. However, only high-end, architectural components such as fritted glass have costs comparable to that of PV systems. Especially in residential applications, the cost of building materials such as asphalt shingles is insignificant compared to the cost of PV systems. Even with credit taken for replacing building materials and the long-term "free" energy supplied by the PV system, it is often difficult to justify the initial cost of BIPV systems.

In today's market, the simplest method for justifying the cost of a PV system is to increase its effect on the total energy consumption of a building. This increased effect is achieved not by increasing the capacity of the PV system, but by decreasing the building's electrical load. A building's electrical load is decreased through energy-efficient building design using passive solar design strategies (e.g., daylighting to reduce lighting loads, building orientation to reduce solar gains/cooling loads), through energy-efficient appliances and equipment, and by optimizing the control of the electrical loads.

Another method for increasing the impact the PV system has on a building is to use the PV-produced to decrease a building's peak electrical demand. In many cases, decreasing the demand saves enough in utility demand changes to justify the cost of the PV system.

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 a program called Building Opportunities in the U.S. for Photovoltaics (PV:BONUS). The objective of the PV:BONUS program is to develop technologies and to foster business arrangements that cost-effectively integrate photovoltaics or hybrid products into buildings. Cost-effectiveness is achieved through design, integration (i.e., components, system, or building integration), dedicated end-use applications, and technology bundling (e.g., PV/thermal hybrids). DOE is interested in products that can replace commercial building products and can be installed without the need 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.

PV:BONUS (June 1993 through May 1999)

In 1993, the U.S. Department of Energy awarded cooperative agreements for five PV:BONUS projects. These projects have been successfully installed in demonstration projects and most are now commercially available to the buildings industry. The original PV:BONUS projects are:

- AC photovoltaic module and curtain wall application (Figure 3)
- Architectural PV glazing system (Figure 4)
- Dispatchable PV peak shaving system
- PV-integrated modular homes (Figure 5)
- Rooftop photovoltaic systems (Figure 6).

Figure 3. AC PV modules

Figure 4. Architectural PV glazing system

Figure 5. PV-integrated modular homes

Figure 6. Rooftop PV systems

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. 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 (Figure 3). 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 façade glazing products 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, North Carolina (Figure 4). The designers placed a high-absorptance metal pan approximately 1 inch (2.5 cm) below the back of the panel to increase the effectiveness of solar heating 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 the leader for this PV:BONUS team, Advanced Photovoltaic Systems (APS), is no longer in existence, the PV technology APS 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 an electrical load greater than the array's electrical output during utility peak demand periods. This feature is especially important to commercial buildings in which the peak demand period often extends beyond the period of peak power production by the PV system. Delmarva Power and Light Company was responsible for this PV:BONUS effort.

PV-Integrated Modular Homes. The energy efficiency and PV system design of homes constructed in a factory were optimized so that the total cost remained similar to the cost of typical site built homes (Figure 5). The objective of this PV:BONUS project was to design a line of modular solar homes that included passive solar design strategies and 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 led by a non-profit organization known as Fully Independent Residential Solar Technologies (FIRST), Inc. FIRST 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 to either resemble asphalt shingles or to be laminated onto metal standing-seam room modules (Figure 6). One of the goals of the project was to develop a product that required no special installation training. 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 through early 2000s)

PV:BONUS Two activities occur in three phases. Phase I is 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 depends on the accomplishments from Phases 1.

The U.S. Department of Energy awarded 17 Phase I cooperative agreements. These projects 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 photovoltaics
- 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 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 so that no electrical connections hard-wired to the building electrical system are needed.

Thin Film Photovoltaics. With the support of subcontractors Kawneer, Solar Design Associates, Inc., and Velux, Solarex will develop building-integrated photovoltaic products using tandem-junction amorphous silicon modules. Major objectives of the program include developing: (1) commercial PV curtain wall module; (2) PV sunshade to be used with commercial building curtain walls for external, passive control of solar gains through curtain wall view glass; (3) residential PV skylight product; and (4) light-transmitting PV module and incorporating it into the curtain wall and skylight products. Light-transmitting PV modules will be partially transparent and produce electrical power.

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 (a-Si) alloy solar cells made with United Solar System Corp.'s proprietary UNISOLAR technology, which has characteristics that are well suited for combined PV/T applications.

Ballast-Mounted PV Arrays. Ascension Technology developed a ballast-mounting system for PV arrays on flat or nearly flat roofs, typically on commercial building roofs. For this PV:BONUS Two project, they 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 under various conditions.

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 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, lending to 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, intends to develop a field-applied, flexible PV membrane product for the 'built-environment." UNISOLAR 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 UNISOLAR PV membrane will be shipped directly to the site for field application or to a building product company for integration with the company's products. It uses United Solar Systems Corp.'s multi-junction a-Si stainless steel PV cells laminated in flexible materials.

PowerRoof 2000. PowerLight Corporation, in cooperation with AstroPower, Solarex, BP Solar, and Siemens Solar, proposes to develop a building-integrated PV roofing system called PowerRoof . PowerGuard is the first core product in the PowerRoof family and has been successfully developed under prior programs (Figure 8). The PowerRoof 2000 proposal targets development of two next-generation core PowerRoof building products, HeatGuard and PowerTherm . With these products, the PowerRoof system will provide both thermal energy and electrical power. Each product 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 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 and are currently being developed with assistance from the PV:BONUS Program meet these criteria. (2)

New products such as transparent thin-film PV modules that allow the designer to 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 façade of a building can be clad in PV. Manufacturers foresee the price of these PV modules to be close to that of high-end glass products, making it easier for designers to justify the cost of PV. (2)

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. 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 (Figure 7) and is usually in new construction. Other products are designed to be used in flat-roof commercial retrofit applications and include an insulated unit with PV integrated into the top layer (Figure 8) or a roof membrane with PV integrated into the membrane.

Figure 7. Sunslates manufactured by Atlantis Energy

Figure 8. PowerGuard roof tiles manufactured by PowerLight

Summary

The PV industry has been extremely active in developing new PV-for-buildings products and introducing those products to the market. The examples given in this paper represent only some of the recently available or soon-to-appear products introduced by U.S. PV product manufacturers. Building designers are in general extremely interested in using these new products, especially when these products are easy to integrate into the building envelope and/or with building systems. Partnerships among DOE, private industries, and public institutions when developing new products and introducing them to the marketplace will ensure that the buildings-related issues discussed earlier in this paper are addressed. Resolving these issues will increase the likelihood of success for all emerging PV-for-buildings products.

Acknowledgements

Support for the Photovoltaics for Buildings Task is provided to the National Renewable Energy Laboratory by the U.S. Department of Energy's Office of Utility Technology. Robert Hassett is the program manager. The Photovoltaics for Buildings Task is within the National Center for Photovoltaics (www.nrel.gov/ncpv).

The PV:BONUS and PV:BONUS Two projects receive funding from the U.S. Department of Energy though the Golden Field Office. Robert L. Martin manages DOE PV:BONUS Two activities.

References

(1) Energy Information Administration (EIA), U.S. Department of Energy. Data obtained from the EIA Web site, "Annual Energy Review, 1997." <http://www.eia.doe.gov/emeu/aer>. 3 September 1998.

(2) Conversation with Steven J. Strong, president of Solar Design Associates and instructor for many of the DOE/AIA-sponsored workshops on BIPV. 8 September 1998.