A NEW GENERATION
OF
SOLAR ELECTRIC ARCHITECTURE

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Introduction

The last two decades have brought significant changes to the design profession. In the wake of traumatic escalations in energy prices, shortages, embargoes, and war, along with heightened concerns over pollution, environmental degradation, and resource depletion, awareness of the environmental impact of our work as design professionals has dramatically increased.

In the process, the shortcomings of yesterday's buildings have also become increasingly clear: Inefficient electrical and climate conditioning systems squander great amounts of energy; combustion of fossil fuels on-site and at power plants adds greenhouse gasses, acid rain, and other pollutants to the environment; inside, many building materials, furnishings and finishes give off toxic by-products contributing to indoor air pollution; and, poorly designed lighting and ventilation systems can induce headaches and fatigue.

Architects with vision have come to understand that it is no longer the goal of good design to simply create a building that's aesthetically pleasing—buildings of the future must be environmentally responsive as well. These architects have responded by specifying increased levels of thermal insulation, healthier interiors, higher-efficiency lighting, better glazings and HVAC equipment, air-to-air heat exchangers, and heat-recovery ventilation systems. Significant advances have been made, and this progress is a very important first step in the right direction.

Fig. 1. The Georgetown University Intercultural Center in Washington, DC. was designed purposefully to receive a 325-kWp BIPV roof by Solarex and Kawneer. (Solar Design Associates, Inc.)

However, it is not enough. For the developed countries to continue to enjoy the comforts of the late twentieth century, and for the developing world to ever hope to attain them, sustainability must become the cornerstone of our design philosophy. Rather then merely using less of the non-renewable fuels and creating less pollution, we must come to design sustainable buildings that rely on renewable resources to produce some or all of their own energy and create no pollution.

It may come as a surprise to most architects and their clients but every building designed to rely on fossil fuel will become obsolete within its lifetime as the world's remaining reserves of oil are drawn down and prices rise to the point that simply burning oil for its thermal content can no longer be justified.

Oil industry analysts (who should know the subject) expect world oil extraction to peak within the next 5 - 10 years - that is, before 2010. We will then begin the long and irreversible downward slide where demand will greatly exceed supply and prices will escalate exponentially. As the era of cheap oil draws to a close, we must begin in earnest to develop other energy options to power our buildings as well as transportation, agriculture and industry. (See The Coming Oil Crisis by Dr. Colin Campbell noted at the end of this paper).

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. Photovoltaics are also exceedingly versatile—the same technology that can pump water, grind grain and provide communications and village electrification in the developing world can produce electricity for the buildings and distribution grids of the industrialized countries.


Fig. 2: A semi-transparent Solarex BIPV array serves as the entry canopy of the natatorium at the Georgia Institute of Technology in Atlanta, site of the 1996 Summer Olympic games. The building also features 350 kWp of roof-top BIPV. (Solar Design Associates, Inc.)

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

Interest in the building integration of PV (known as BIPV), where the PV elements actually become an integral part of the building, often serving as the exterior weathering skin, is growing world-wide. Photovoltaic specialists from more than 15 countries are working within the International Energy Agency on a 5-year effort to optimize these systems, and architects in Europe, Japan, and the United States are now beginning to explore innovative ways of incorporating solar electricity into their building designs.

A worldwide overview of building-integrated PV activity follows with a description of component and systems development along with selected built examples of solar electric buildings. View these early PV-powered buildings as a first glimpse into the coming new era of energy-producing architecture where this elegant, life-affirming technology will become an integral part of the built environment.

The Opportunity

Energy planners have long envisioned large central-station utility-scale PV plants covering huge expanses of desert. While this vision has many favorable attributes, the downsides include the costs of the land, site development, support structures, electrical distribution, utility interface, and real estate taxes. In Europe and Japan, the lack of large open tracts of land effectively has precluded the central-station PV option. Another problem with centralization is the losses inherent in the grid's transmission and distribution system, which can be significant as power is transmitted over greater and greater distances. In addition, centralization fails to take advantage of the modular, distributable nature of PV technology. On the other end of the spectrum, distributed PV is an ideal response to the need for electrification of remote villages in developing countries, many of which lie in the sunniest areas of the world.

While both central-station and remote village power markets for PV are viable and growing today, both will be eclipsed by the BIPV market in the years to come. In this market, building owners are already paying for facade and roofing materials and the labor to install them. The land is already paid for, the support structure is already in place as the building, the building is already wired, the utility is already connected, and developers can finance the PV as part of their overall project. Another benefit comes from distributing the BIPV installations over a very broad geographic area and a large number of buildings, mitigating the effects of local weather conditions on the aggregate, and producing a very resilient source of supply.

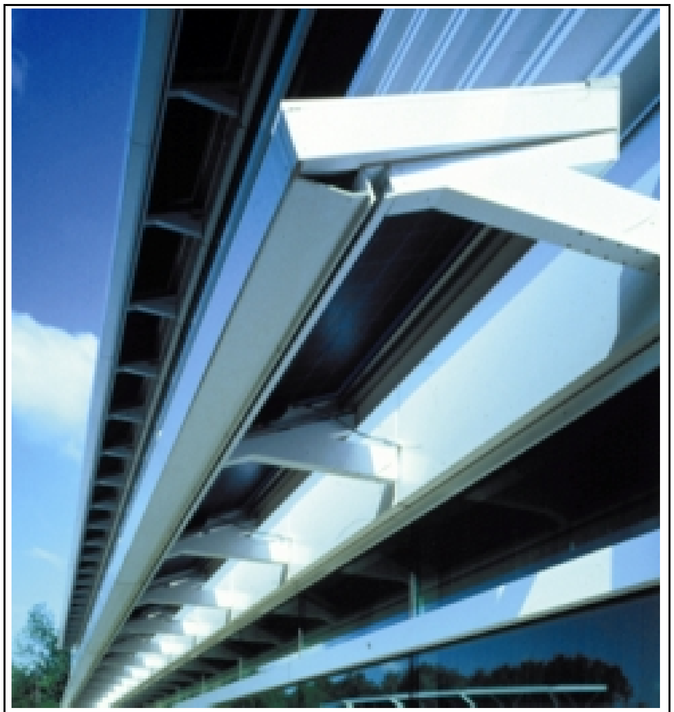


Fig. 3: BIPV sunshades in the curtainwall deliver shading and electricity at the Center for Environmental Sciences and Technology Management, at the State University of New York at Albany (SUNY) (Kawneer Company)

Innovative architects the world over are now beginning to integrate PV into their designs, and PV manufacturers are responding with modules specifically for BIPV applications, including integral roof modules, roofing tiles and shingles, and modules for vertical curtain wall facades, sloped glazing systems, and skylights.

Development of BIPV

The earliest BIPV system was a 7.5-kWp residential application completed in 1980. The Carlisle House as it became known, was designed by Solar Design Associates, and sponsored by the Massachusetts Institute of Technology and the U.S. Department of Energy. The house was all-electric with no fossil fuel burned on-site and it generated a surplus of electricity which was exported to the local utility grid via a ‘net metering’ arrangement.

Other early projects in the United States included the 200-kWp Solarex facility in Frederick, MD (1982); and, the 325-kWp Georgetown University Intercultural Center in Washington, DC (1985). Aggressive efforts in Europe and Japan begun in the early 1990s have pushed the technology toward broader commercial acceptance. Today, more than 15 countries are participating in coordinated international activities, under the International Energy Agency's Task 7 working group to develop and implement BIPV.

Designing with BIPV
It is essential to appreciate the context within which solar electricity can best function in and contribute to a building. BIPV systems are only a part of the solution. We must address both sides of the energy use equation - supply *and* consumption. To maximize the solar contribution, the building should be designed to use energy most efficiently. Energy generated from renewable resources will contribute a great deal more to an energy-efficient building.

A high-integrity thermal envelope with monolithic air and moisture barriers and superior, high-R-value glazing is desired. Further, passive solar strategies which reduce heating and cooling requirements should be employed along with daylighting and energy-efficient equipment, systems and end-use loads. Advanced mechanical systems such as heat-recovery ventilation and geothermal heat pumps should be considered. And, solar thermal systems should be considered for space and water heating. All of these measures are good economic investments and, only within the context of this comprehensive energy-conscious design strategy can BIPV achieve its full potential.

In the past, incorporating PV into a building design required trade-offs and concessions in the architectural design process. Today, as PV manufacturers match products to building-industry standards and architects' requirements, this is changing. Companies in the United States, Japan, and Europe are actively pursuing new module designs that displace traditional building materials. We are now also seeing the initial introduction of 'custom color' crystalline solar cells including gold, violet, and green, to add aesthetic variety in BIPV systems. In Europe, BP and Sunware Solartechnik have offered solar cells in colors while, in Japan, Showa Shell, Daido Hoxan, and Kajima Corp. are working on similar technologies.

In the United States, in 1992, the U.S. Department of Energy launched a 5-year cost-shared program, called "Building Opportunities in the U.S. for Photovoltaics (PV:BONUS), to encourage the development of BIPV systems. Under this program, BP Solarex, of Frederick, Maryland, a division of BP Amoco, working in conjunction with architectural curtainwall giant Kawneer of Atlanta, developed a line of pre-engineered building-integrated PV components for commercial building facades and sloped glazing applications called PowerWall™.

Other PV building products have also been developed under the program, including United Solar Systems' of Troy, MI triple-junction amorphous silicon (a-Si) PV roof shingles and standing-seam architectural metal roofing with PV laminates. BP Solarex is currently developing a line of transparent thin-film modules suitable for overhead glazing systems and vision glass under a second round of the PV:BONUS program, while glass fabricator Viracon (Owatonna, MN) is working on insulated glass BIPV components which will come to compete with and, eventually replace architectural glazing.

Fig. 4: Architectural standing-seam metal roof BIPV system on a townhome in Bowie, MD. (United Solar)

Other architectural module designs employ glass-superstrate, crystalline modules with space between the cells and opaque backings, to provide diffuse daylighting along with their electric production. Swiss companies such as Atlantis and Solution are making modules in unique sizes and shapes, with custom cell sizes and spacings. Pilkington, with its expertise as a glass manufacturer, is building modules that replace conventional facade view and spandrel glass. PowerLight supplies insulated PV roofing systems for flat roofs; and, Sanyo, BMC Solar Industries GmbH, Atlantis and Plaston-Newtec are each building PV roofing tiles.

These new building-integrated photovoltaic components are providing a window into the future toward a whole new generation of solar architecture. With the right design, the sunlight falling on a building and its site can provide much of the power it requires. In urban areas, you can only imagine the power which will be generated by incorporating PV into the thousands of square kilometers of empty flat roofs and other available building surfaces which receive generous amounts of sunlight each day just waiting to be harvested.

Incentives

The US federal government presently offers two attractive tax incentives to encourage private investment in solar energy equipment and systems: an investment tax credit and an accelerated depreciation allowance. Both of these incentives apply to building-integrated photovoltaic systems.

<u>Investment Tax Credit:</u> A 10% Federal investment tax credit is available on certain solar energy equipment and systems. This credit, otherwise known as the Business Energy Tax Credit, has been <u>permanently</u> incorporated as part of tax code with the passage of the Energy Policy Act of 1992. (U.S. Code Citation: 26 USC Sec. 48)

<u>Accelerated Depreciation</u>: The federal government offers a 5-year accelerated depreciation option for certain solar energy equipment and systems. (U.S. Code Citation: 26 USC Sec. 168). The total contribution of these two incentives toward the cost of a BIPV system amounts to 42% for those clients with a federal tax liability.

Net Metering is an attractive arrangement whereby the electric utility credits a BIPV system owner, on a one-to-one cost basis, for their surplus solar power produced versus the ‘conventional’ electricity consumed. This allows the BIPV system owner to effectively use the utility grid in lieu of on-site storage.

With net metering, surplus solar-generated electricity in excess of instantaneous loads is fed back into the utility grid, effectively spinning the revenue meter backwards (this actually happens in many states, whereas some utilities require two single-direction meters). At the end of the billing period, any power produced in excess of the amount consumed is typically repurchased by the utility at the lower "avoided cost" rate, while any power consumed beyond the level of the power produced is sold to the customer at the utility's standard rate.

Net metering is a win-win-win proposition, with the utility offsetting its very expensive peak-load kiloWatt-hours with customer-supplied power in exchange for lower-cost off-peak, or base-load, power, while the PV-system owner benefits by using the utility as a backup, avoiding the cost and maintenance of a battery storage system. This synergistic relationship reduces the utility's need for building additional power plants or wheeling power from outside its service territory. The ‘third win’ is that society benefits from the development of clean power sources based on renewable energy.

Fig. 5: The roof-integrated BIPV system on this solar home in Maine produces an annual surplus of electricity. (Solar Design Associates, Inc.)

Currently, Japan, Switzerland, the Netherlands and Germany, and some 28 states in the United States (including: Arizona, California, Colorado, Connecticut, Idaho, Indiana, Iowa, Maine, Maryland, Massachusetts, Minnesota, Nevada, New Hampshire, New Jersey, New Mexico, New York, North Dakota, Oklahoma, Oregon, Pennsylvania, Rhode Island, Texas, Vermont, Washington and Wisconsin) mandate Net Metering. Implementation is currently pending in Montana, Nebraska, and Virginia. Net Metering is of most value to owners of residential and small-to-medium scale commercial PV applications where the solar harvest is more likely to exceed the load. When PV is used in larger commercial applications, the load is likely to be greater than the solar harvest at all times and no surplus will be available.

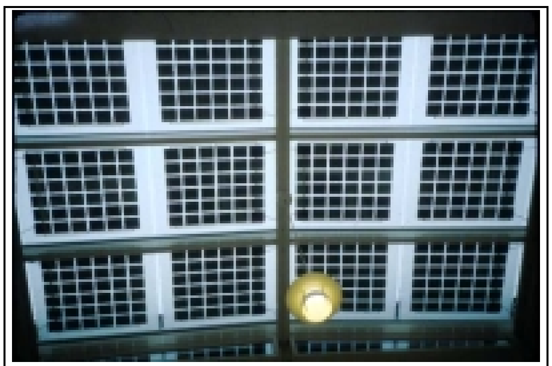


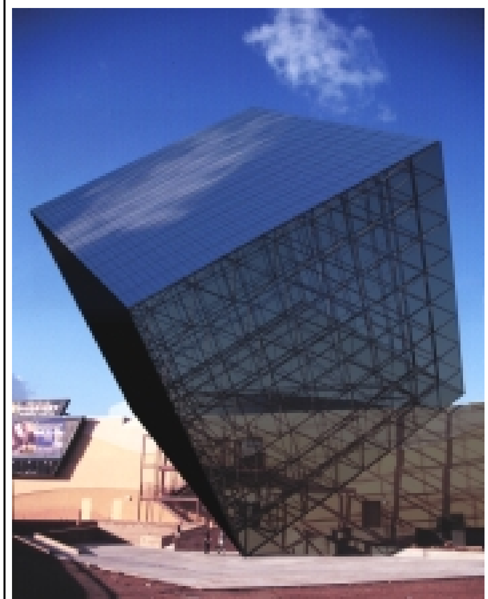
Fig. 6: PV skylight system at the Thoreau Center, in San Francisco, CA (NREL)

In June 1997, the President of the United States announced that the U.S. government would work with businesses and communities to promote the installation of solar thermal panels and/or PV modules on one million roofs across the United States by the year 2010, with the goal of slowing the release of greenhouse gas emissions.

Under this initiative, the Department of Energy will work with partners in the building industry, local governments, state agencies, solar industry, electric service providers, and non-governmental organizations to remove market barriers and strengthen grassroots demand for building applications of solar technologies. The Million Solar Roofs Initiative promises to bring together available national resources in the federal government and among key national organizations, and focus them on creating a strong market for solar building applications.

Future Outlook

Today, there are more than 500,000 homes worldwide using PV to supply or supplement their electricity requirements, though all but about 10,000 are rural or remote off-grid applications. In addition, there are already many thousands of commercial buildings powered by PV systems interfaced with the utility grid in Europe, Japan and the United States.



The giant Solar Cube is a highly visible display of renewable energy in use at the Discovery Center in Santa Ana, CA (Solar Design Associates, Inc.)

The potential opportunity for building-integrated PV systems is enormous, and many companies are now beginning to work on the development and commercialization of specialized BIPV components and systems. Residential and commercial BIPV will likely be the nearest-term large-scale markets for PV in the developed countries. Residential and commercial buildings provide substantial surface area, allowing architects and systems designers to displace the cost of conventional materials and labor with PV; building-integrated systems produce power at the point of use, avoiding the costs and losses of transmission and distribution; and, PV-powered buildings send an important message to the world about their owners' environmental philosophy and commitment. This has proved to be a very important motivation for the 'early market adopters'.

A major change in the world's energy use patterns and systems is coming as the era of cheap oil draws to a close. Over the past two decades, PV has moved from the research laboratory to commercial applications and the technology is now ready for wide-spread commercialization. With participation of architects and building engineers, the technology is taking a progressively more sophisticated, elegant, and appropriate role in building design, putting energy-producing buildings within our reach. As building-integrated PV components become an integral part of the form and aesthetic of the built environment, these systems will contribute greatly to a more sustainable future for their owners, their communities, and society at large.

For further reading, see

The Coming Oil Crisis, Campbell, C.J., PhD, 1997, Multi-Science Publishing Co, LTD., Essex, England, ISBN # 0-906-522-110

"New photovoltaic products are integrated into the building skin", Strong, S.J., Architectural Record, December, 1999.

"Towards a new solar architecture", Strong, S.J., Environmental Design and Construction, July, 1999

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About the author

Steven J. Strong is President and founder of Solar Design Associates, Inc., an engineering and architectural firm specializing in environmentally responsive building technology and the engineering and integration of renewable energy systems, - especially solar electricity. Mr. Strong is the U.S. representative to the International Energy Agency's experts' group on Building-Integrated Photovoltaics which involves professionals from some 15 countries. In the Spring of 1999, TIME Magazine honored him as 'An Environmental Hero'.

Much of Solar Design's current work is supporting architects in the integration of solar technologies in their designs. Mr. Strong presents day-long workshops on the building integration of solar electricity for practicing architects co-sponsored by the AIA and frequently lectures on the subject at colleges and universities.