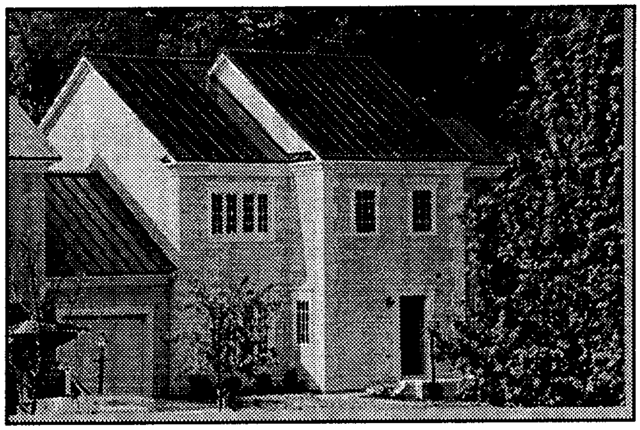
Photovoltaics:
A Background Paper for HomeBuilders, Remodelers and Editors



Photovoltaic roof on a Twenty-First
Century Townhouse in the
NAHB Research Home Park, Bowie, Maryland

NAHB RESEARCH CENTER
UPPER MARLBORO, MARYLAND

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Introduction

The NAHB Research Center has installed a first-of-its-kind photovoltaic (PV) system on the roof of a demonstration townhouse in the NAHB Research Home Park in Bowie, Maryland. In this system, photovoltaic modules have been incorporated into metal roofing units. The units simultaneously serve as roofing and generate electricity for use in the home.

The Townhouse is one of a group of four townhouses, called the Twenty-First Century Townhouses, built by the Research Center in the Research Home Park. The houses are designed to demonstrate two themes: alternatives to lumber in home construction, and advanced energy efficiency.

For further information on the Twenty-First Century Townhouses, see *The Twenty-First Century Townhouses: an Illustrated Guide*, available for $10.00 plus $4.00 postage and handling from the NAHB Research Center, 400 Prince George's Blvd., Upper Marlboro, MD 20774-8731, phone 301/249-4000.

The NAHB Research Center receives many queries from builders, remodelers, and the press about PV. This paper is designed to provide background information on PV technology in general, and on the PV installation at the Twenty-First Century Townhouses. For further information, contact Joe Wiehagen, NAHB Research Center, 310/249-4000, x533.

WHAT IS PHOTOVOLTAICS?

Photovoltaics, usually called PV, is the generation of electricity from sunlight. PV is one of the most environmentally friendly forms of renewable energy. Its many attractive features include the following:

- It has no moving parts;
- It is easy to install;
- It requires minimal maintenance;
- It consumes no fuel;
- It produces no pollution;
- It operates silently;
- The equipment has a long life-span.

The United States developed the first practical PV cell in the 1950s to power satellites. With the coming of the energy crisis in the early 1970s, the technology was brought down to earth and was used in commercial applications. The first PV house was built in Carlisle, Massachusetts in 1981. This important technology is now heading toward mainstream home building and remodeling. The time for builders and remodelers to learn about PV is now.

HOW PV WORKS

Anyone who has used a pocket calculator has seen PV at work. Light is a form of energy. It travels from light sources such as the sun in streams of energy units called photons. As photons of light hit the window above the calculator's buttons, they generate an electrical current in the silicon wafer that is in the window. The current is sufficient to power the calculator's computer chip.

Silicon PV Cells

Silicon, which is a basic constituent of sand and is one of the most plentiful substances on earth, reacts to light. When light shines on a silicon crystal, the photons strike the silicon atoms and dislodge electrons. The electrons form a current that can be conducted into electrical circuits and devices.

To augment the process, silicon PV cells are coated with boron, which lacks electrons and attracts them, and phosphorus, which has an excess of electrons and can provide an extra supply. A typical silicon PV cell, called a solar cell, consists of a layer of phosphorus-coated silicon in contact with a layer of boron-coated silicon. The cell, when connected in an electrical circuit and illuminated by sunlight, produces an electrical current which flows in the circuit. The stronger the light, the more electrons are dislodged and the larger the current that is produced.

Groups of PV cells are mounted together to form a *module*. Typical modules range in size from a few square inches to about 25 square feet. Groups of modules are mounted together to form an *array*.

Crystalline Silicon and Amorphous Silicon

Throughout its period of development, PV has utilized crystalline silicon as its electrical conversion material. In the most common manufacturing process, purified silicon is melted into a large crystal. Thin "slices" are cut, which are coated as described above. These become PV cells. With current technology, crystalline silicon PV cells can convert more than 12 percent of the sunlight that they receive, into electricity.

An alternative material called amorphous silicon is attracting increasing attention for home building. Amorphous silicon has no crystalline structure, and can be applied to substrates, including flexible substrates, in thin films. The conversion efficiency is generally lower than that of crystalline silicon, but it offers the potential of lower mass production cost.

The conversion efficiency of amorphous silicon has typically been less than 6 percent. However, with funding from the U.S. Department of Energy, thin-film amorphous silicon cells that convert over 10 percent of sunlight to electricity are being developed.

Components of a Home PV System

In addition to the array, components of a home PV system may include an *inverter* and *storage batteries*. These can be located in the basement or garage area of the home. PV arrays produce direct current (dc) rather than the alternating current ordinarily used in homes. The electricity generated by the array is fed into an inverter that converts the dc from the array to ac for the home. PV systems utilize storage batteries to store electricity generated at times of peak output, and make it available to the house during portions of the 24-hour cycle when the array's output is low or has ceased.

Electrical Output

Considered in terms of wattage, a four-square-foot crystalline silicon module has a generating capacity of about 40 watts. The output of a PV array varies in proportion to the available sunshine. The highest output, called the *peak wattage*, occurs at noon on sunny days.

Peak wattage and total electrical output are affected both by geography and by the season of the year. For example, in Albuquerque, New Mexico, for each peak watt that an array will produce on a sunny noon in winter, the array will produce an average of 6.1 watt-hours of electricity per day. By contrast, in Pittsburgh, which is farther north and which experiences many more cloudy days in winter, a PV module would produce an average of 2.4 watt-hours per day for each peak watt.

PV-generated electricity is not likely to accommodate the full electrical needs of a typical American home, but it can carry a helpful part of the load. DOE states that roofing "shingles" designed to function both as roofing and as solar collectors, could supply all the daytime electric power needs of a south-facing home.

THE ECONOMICS OF PV

Amortization of the cost of PV equipment and its installation constitute the basic factors in the cost of PV-generated power. Equipment costs have been steadily declining. Photovoltaic modules that sold for $50 per rated watt of peak generating capacity in 1970 dollars, sell for $5 to $7 per watt today.

Recent costs for PV electricity have run from 25 cents to 50 cents per kilowatt hour, but new products and technology are pushing the lower range of the cost down to about 15 cents per kilowatt hour. By comparison, the average cost to the consumer of utility-generated electricity in the U.S. is about 8 cents per kilowatt hour. However, prices for less accessible homes can range to 15 cents and even to 20 cents per kilowatt hour. PV is therefore already competitive on a dollar-to-dollar basis for certain homes in rural locations. It is often cheaper to install a PV system than it is to extend utility service a quarter of a mile to a remote home.

Environmental Issues

While PV power is still not price-competitive on a dollar-to-dollar basis with utility-generated power in most circumstances, such comparisons leave out many important types of direct or indirect cost. First, there are broad environmental considerations to which a precise price tag cannot be affixed.

- The growth of "distributed generation" of electrical power -- that is, generation at points of use -- can relieve the pressure to construct capital-intensive and environmentally controversial central generating facilities.
- PV power is generated without using depletable fuel resources, and without generating the pollution that is an inescapable feature of utility operation.
- PV reduces the requirements for creating new or increased electrical transmission infrastructure.

The "Fuel" is Free

Other factors have a direct present or future impact on the home owner's pocketbook. Once a PV system has been purchased and installed, there is no cost for fuel. Utilities are permitted to pass increased fuel costs on to their customers. Utility costs are subject to uncertainty arising from natural disasters, increasing depletion of the world's fuel supply, or adverse occurrences in international affairs. A PV-equipped home escapes this future cost hazard for the portion of the electrical needs that is supplied by PV.

Feeding Electricity Back Into the Grid

Another factor relates to the capability of PV systems to generate power that can be fed back into the utility grid. A number of states are currently considering regulations governing what is called "net metering." With net metering, utilities would be required to buy PV-generated power that the home owner wishes to sell, at the same price that the consumer pays for electricity. In effect, the home owner's meter would "run backward" for the amount of PV power that is fed into the grid, reducing the PV home's electric bill.

Two Systems, But Not Twice the Price

Finally, developments in PV technology include the creation of "PV shingles" and PV steel roof modules, both of which are described below. These materials serve both as roofing and as PV systems. A major portion of the cost of installing a PV array is therefore absorbed in the cost of installing the roof, which must be done anyway.

INTEGRATING PV INTO HOME DESIGN

An important issue for bringing PV into the home building mainstream is the successful integration of PV systems into home design. Solar collectors mounted on rooftops, sometimes at angles to the roofline in order to face the sun, have functioned successfully but have not always been regarded as improvements to neighborhood aesthetics.

With funding from the U.S. Department of Energy, the NAHB Research Center is conducting a program to foster the development of building-integrated photovoltaic products and systems, and to help bring them into the marketplace. The Research Center is working with utilities and builders to demonstrate simple, cost-effective designs and construction methods.

Combining Roofing and PV

A highly promising approach to integrating PV into home building involves roofing materials that incorporate modules. With support from DOE, Energy Conversion Devices and its America joint venture company, United Solar Systems Corp., have developed, and are demonstrating and commercializing, two types of flexible roofing/PV products that utilize amorphous silicon. One is designed as an exact substitute for asphalt roofing shingles and the other as an exact substitute for standing seam metal roofs.

For the modules, ECD and United Solar have developed a low-cost, roll-to-roll continuous manufacturing process for the amorphous silicon solar cell substrate, and a high-efficiency, thin-film amorphous silicon alloy. These technologies offer relatively low material and process costs, and produce a lightweight, rugged, flexible substrate that lowers the installed cost of PV.

The Metal Roofing Module

The metal roofing module is an exact replacement for a standing seam metal roofing pan made by ATAS International, a manufacturer of steel roofing. An array utilizing these modules retains the watertight features of the ATAS roofing system, and integrates with the steel portion of any roof that utilizes the ATAS system. The PV modules can be installed by metal roofing tradespersons without the necessity for any additional or specialized training.

There are no electrical feedthroughs or conduits on the roof. Each module has a pair of leads and a ground wire that the roofer permits to fall through the ridge vent at the top of the module during installation. The electrical hookup is performed independently by an electrician working in the attic area.

PV AT THE TWENTY-FIRST CENTURY TOWNHOUSES

The Twenty-First Century Townhouses are a group of four townhouses constructed by the Research Center in the NAHB Research Home Park in Bowie, Maryland (Figure 1). The townhouses were built with products that feature two themes: innovative structural systems in home building, and approaches to achieving advanced residential energy efficiency.

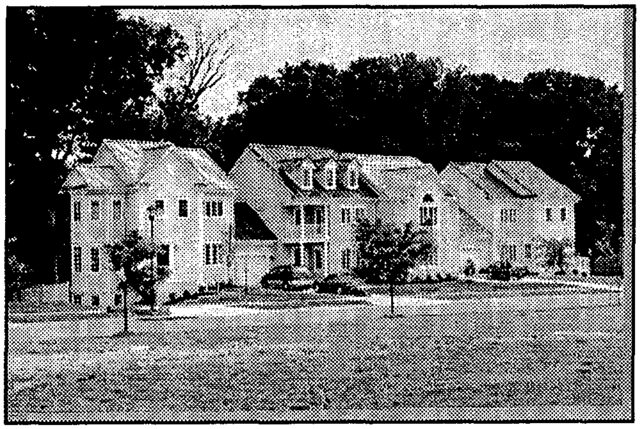

Fig. 1. The Twenty-First Century townhouses in the NAHB Research Home Park, Bowie, Maryland. The house with the PV roof is on the right.

The group of houses, which face 20 degrees east of south, all have 8:12 sloped roofs fitted with metal roofing. In a first-of-its-kind installation, metal roof PV modules were installed on House #4, the right-hand house of the group. The installation was a joint public-private team effort, with DOE and DOE's National Renewable Energy Laboratory providing project support, Energy Conversion Devices, Inc., manufacturing the modules, ATAS supplying the metal roof pans onto which the solar cells were integrated and training the roofers, and the NAHB Research Center designing and supervising the installation on the Townhouse roof.

Due to different schedules for the townhouse construction and the PV metal roofing module fabrication, the modules were installed as retrofit for 18 of the existing pans on House #4's roof.

The modules, each measuring 19 feet x 15.25 inches, were installed on two of the roof's three sections. Twelve modules cover the entire south-facing side of the center section, providing about 260 square feet of photoelectric surface. Six modules were applied to the left south-facing section, providing about 130 more square feet. These modules were joined to an additional 60 square feet of standard roofing (Figure 2).

Fig. 2. PV roof modules being installed.

Installation by Roofing Tradespersons

One of the purposes of installing the array on the demonstration townhouse was to determine whether installation of the PV modules would pose any problems for roofers experienced in working with standing seam metal roofs, but with no experience in working with PV systems. The same roofers who installed the original roofs were called back to install the modules. Their introduction to the modules consisted of about five minutes of instructions, which included a caution to handle the modules with care in order to avoid damage to the laminate.

The roofers installed the 18 panels in about five minutes each. The bulk of their time was spent on trim work that was independent of the PV installation. The roofers reported that installing the PV modules was no more time-consuming than installing a conventional metal roof. The modules, which were somewhat heavier than conventional metal pans, were actually somewhat easier to handle because of their increased stiffness from the lamination.

System Equipment and Performance

The eighteen modules were wired into an array of nine series-connected sets, with nominal voltage of 48 volts and nominal power of 2 kw. The balance of the system consists of a combiner panel in the attic incorporating surge protection and fusing (Figure 3), and a power center, inverter, and rack of eight storage batteries, all in the garage (Figure 4).

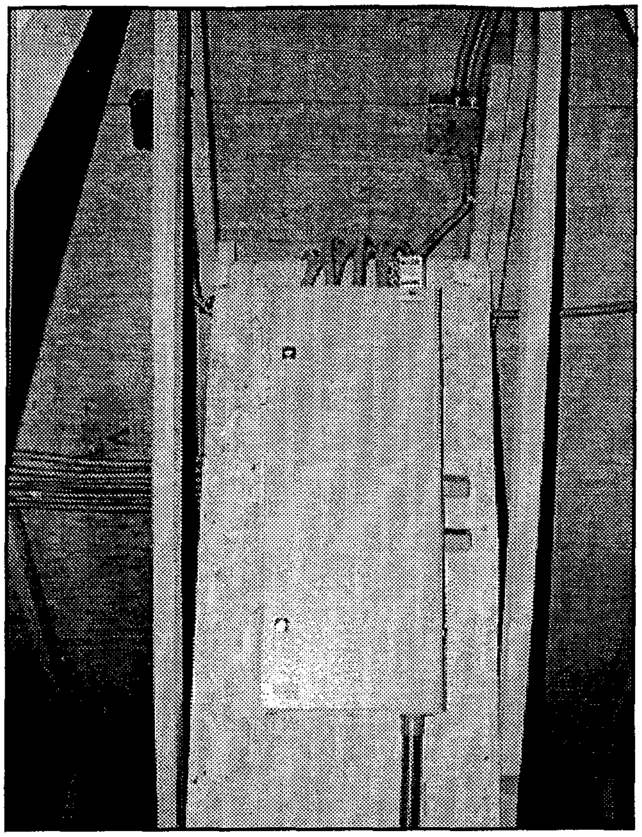

Fig. 3 Combiner panel in attic, incorporating surge protection and fusing.

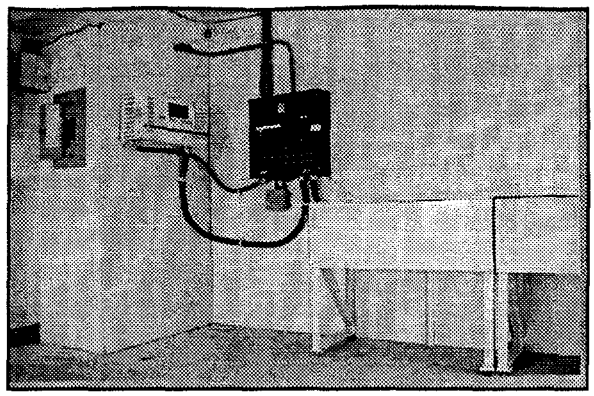

Fig. 4 Power center, inverter, and rack of eight storage batteries in the garage.

In the system, the dc power from the array on the roof can flow in one or more of several paths: from the array to the batteries for storage; from the array to the inverter for conversion to ac, from the batteries to the inverter, and from the inverter to the batteries. The system can also feed power into the utility grid.

The system operated steadily and successfully from the moment that it was turned on. In tests running from May 21 through September 17, 1996, the system provided 21 percent of the house's electrical requirements. In addition, 17 percent of the energy provided by the array was fed back to the utility. If this energy had been used in the home, the system would have provided 25% of the house's demand for the period.

WHERE DO WE GO FROM HERE?

The answer is -- to market, and to the site.

Roofing/PV products are expected to enter the housing market in 1997. Manufacturers expect substantial markets in both new housing and remodeling.

For builders and remodelers, both the economic and the environmental features of PV, and its universally favorable public image, make it one of the most important products on the frontiers of housing innovation.

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