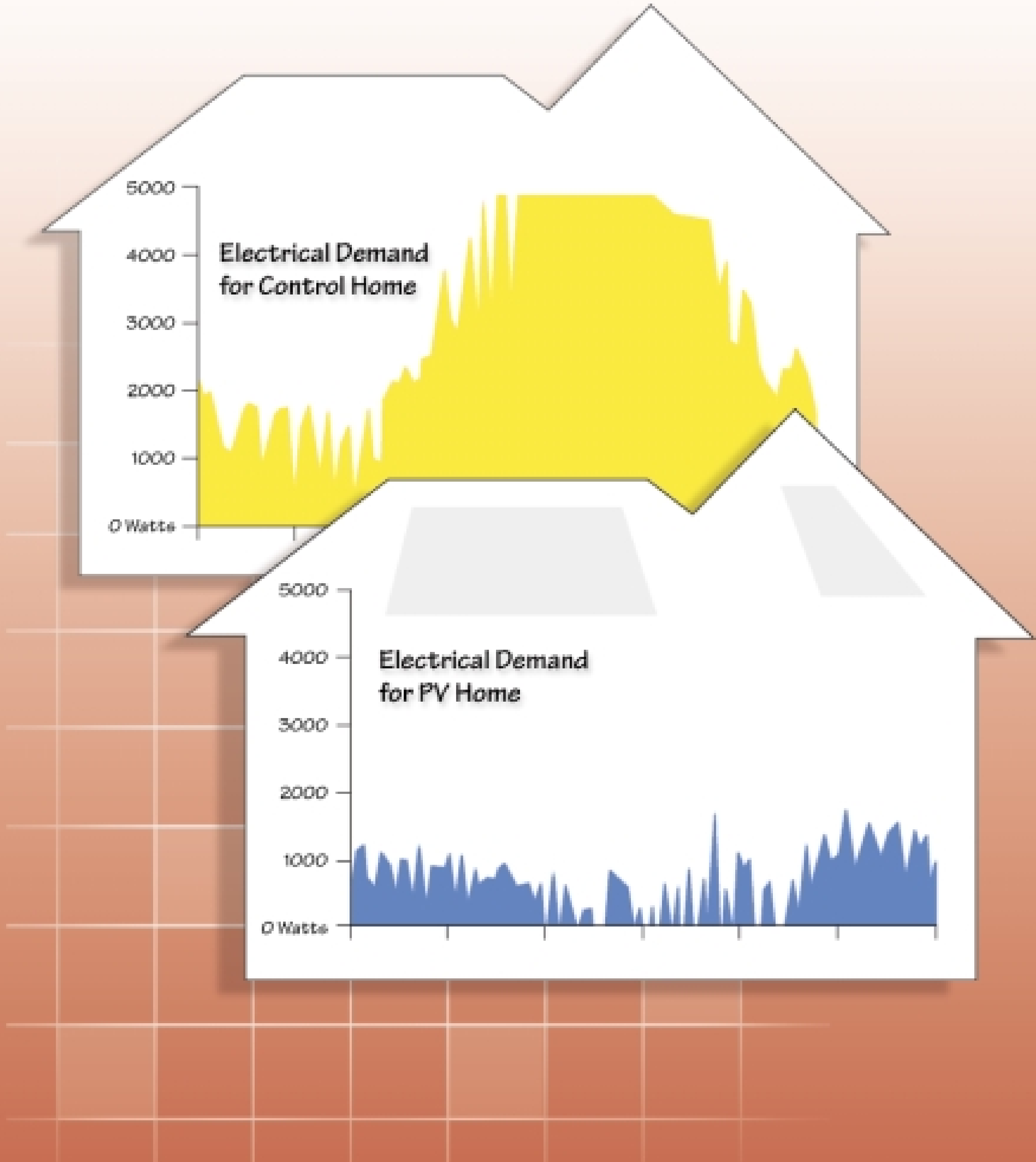
# Making the Most of Residential Photovoltaic Systems




PV home gets a boost from energy efficiency. In side-by-side test, this comfortable, innovative home outperforms conventional model.

# Cooling Off Under the Sun

Just imagine living in Florida and your fantasies might turn to swaying palms, fresh orange juice... and lots of air-conditioning. For most people, a summer spent in Florida's heat and humidity would be unbearable without it.

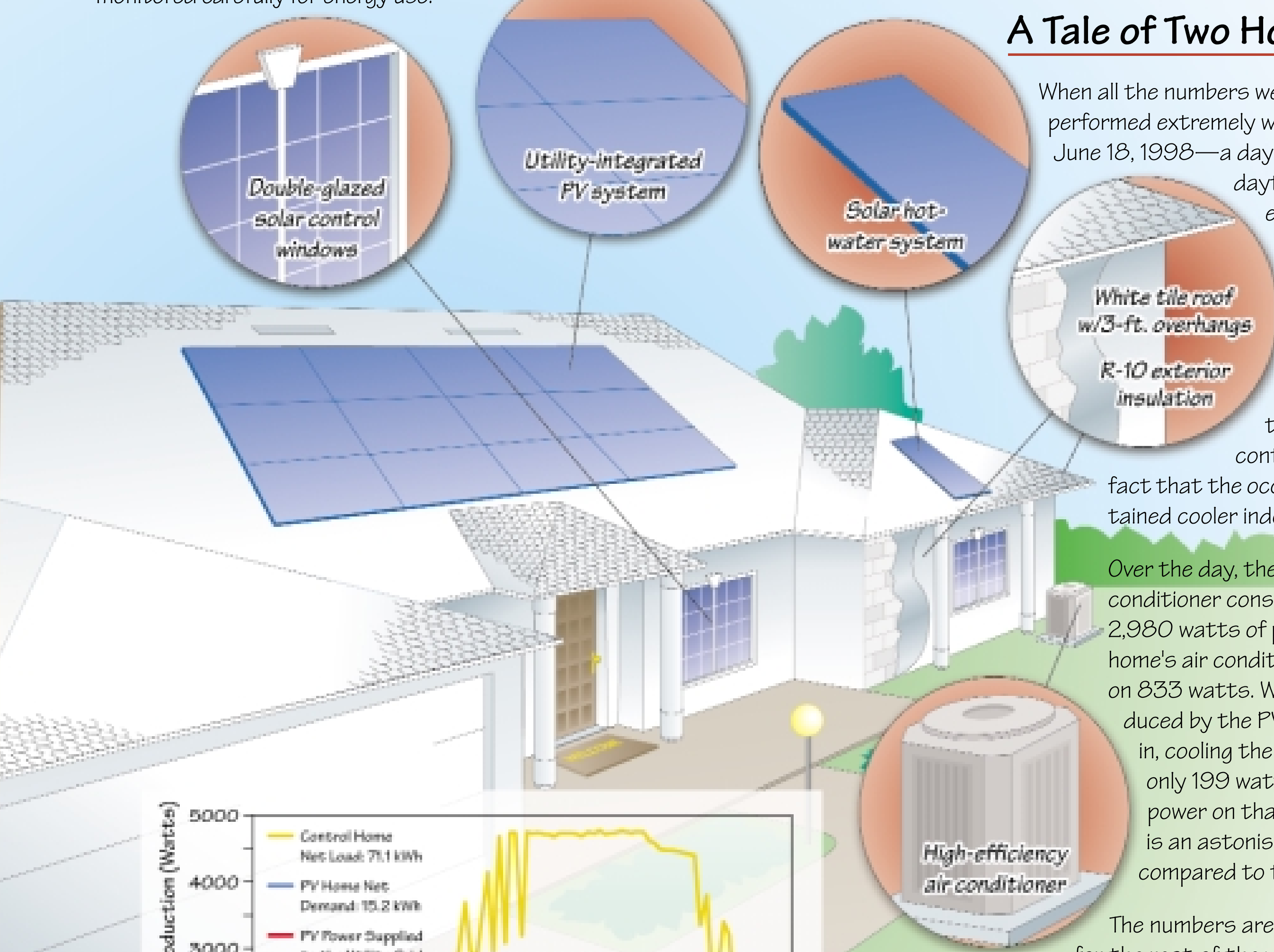
So air-conditioning is a necessity. But it's also a big energy drain, accounting for about 35% of all electricity used in a typical Florida house. As the largest single source of energy consumption in Florida, a home's air-conditioning load represents the biggest energy challenge.

The Florida Solar Energy Center (FSEC) designed a project to answer this challenge. Two homes were built with the same floor plan on near-by lots. The difference was that one (the "control home") conformed to local residential building practices, and the other (the "PV home") was designed with energy efficiency in mind and a PV system on the roof. The homes were then monitored carefully for energy use.

The project's designers were looking to answer two important questions: Could a home in a climate such as central Florida's be engineered and built so efficiently that a relatively small PV system would serve the majority of its cooling needs—and even some of its daytime electrical needs? And, would that home be as comfortable and appealing as the conventional model built alongside it?

The answer to both questions turned out to be a resounding "yes!" And the test was especially rigorous, because it was conducted in the summer of 1998—one of the hottest summers on record in Florida.

This news is important for city planners, architects, builders, and homeowners not only in the Sunshine State, but elsewhere, too. The PV/energy efficiency combo worked so well in Florida that it can—and should—be tried in other parts of the country.

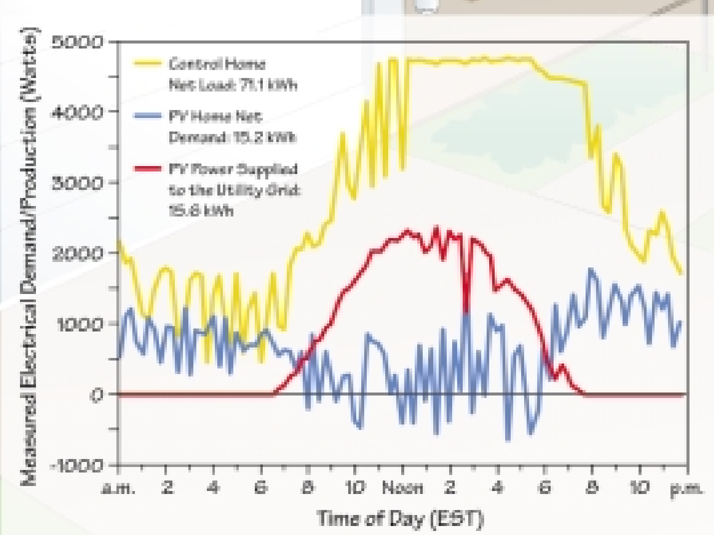



## A Tale of Two Houses

When all the numbers were in, the PV home performed extremely well. The results for June 18, 1998—a day with the hottest daytime temperatures ever recorded in Lakeland, Florida—tell the story. During a 24-hour period, the PV home used 72% less power from air-conditioning than did the control home, despite the fact that the occupied PV home maintained cooler indoor temperatures.

Over the day, the control home's air conditioner consumed an average of 2,980 watts of power, while the PV home's air conditioner breezed along on 833 watts. When the power produced by the PV system is factored in, cooling the PV home required only 199 watts of utility-supplied power on that hot day in June. This is an astonishing 93% reduction compared to the control home.

The numbers are equally impressive for the rest of the year. So efficient was the PV home that its relatively small PV system (4 kW) provided 65% of the power required for all electrical loads. These results need to be taken seriously by anyone looking to save energy... and the environment.



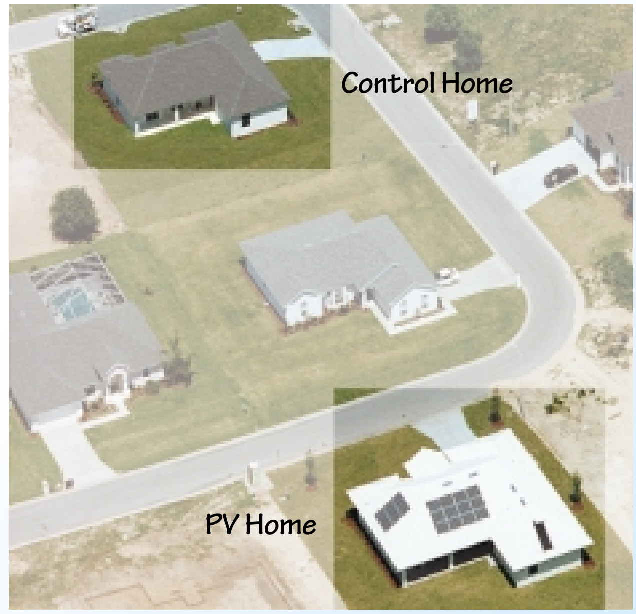

**Peak Day in June**

This graph shows the difference between the energy demand of the control and PV homes on June 18, 1998. The local utility experienced its annual summer peak demand at 5:00 p.m. on this day. The spikes that dip below the zero line indicate the times when the PV home produced more power than it required and supplied the excess to the utility grid.

# Conducting the Test

The two homes were built in Lakeland, Florida, in the spring of 1998. They were constructed by the same builder and had identical compass orientations and floor plans (of 2,425 square feet). The energy use of both homes was monitored for more than a month.

The objective was to test the feasibility of constructing a new single-family residence that was engineered to reduce air-conditioning loads to an absolute minimum so most of the cooling and other daytime electrical needs could be accomplished by the PV component. The PV home included a number of features and engineering elements designed to minimize cooling loads, especially in late afternoon during the utility's peak period of electrical demand. As a research project, the goal was to see how much energy could be saved without factoring in the cost of the efficiency features. Now that the energy efficiency and PV production have been demonstrated, the next step is to evaluate the most cost-effective elements.




**A Bird's-Eye View of Both Homes**
The completed control and photovoltaic (PV) homes in the Windwood Hills development of Lakeland, Florida.

# Breaking Out the Savings

The traditional wide roof overhang of old-style Florida homes is seldom used these days, on the assumption that air-conditioning takes care of cooling needs. But why make the air conditioner work harder—and cost more to operate—than it should? The PV home's **3-foot roof overhang** (versus 1.5 feet for the control) produces twice as much shade, which is especially beneficial for controlling solar gain (heat buildup) on walls and windows.

Another innovative feature is the **reflective white-tile roof** on the PV home versus the locally popular gray/brown asphalt shingles on the control home. Both homes have R-30 fiberglass insulation in the attic. But records from that peak utility day of June 18, 1998, point up the differences. The attic temperature in the control house rose quickly in the afternoon to reach a maximum of 138°F, while the PV home's attic reached only 100°F—about the same as the outside air temperature.

**Exterior insulation (R-10 value)** thermally encases the PV home. This allows the masonry to be precooled during daytime hours when the sun is shining brightly and the PV system output is at maximum power. The precooled concrete walls help maintain indoor comfort into the late afternoon and evening.

| Site Description | Power Use (kWh) | PV Array Output (AC kWh) | Net Power Use (kWh) | Monthly Cost of Power | PV Output % of Total Loads |
|---|---|---|---|---|---|
| PV Home | 837 | 502 | 335 | $27 | 60% |
| Control | 1,839* | 0 | 1,839* | $147 | 0% |

*Air-conditioning only

**Energy Bottom Line for June 1998**
During the month of June, the occupied PV home consumed only 335 kilowatt-hours (kWh) of utility-grid power for all its electrical needs. This compares to 1,839 kWh used by the unoccupied control home for air-conditioning only! The monthly power cost in the PV home was only 18% of the control home's power cost.

The PV home's windows, accounting for almost one-fifth of the energy savings (for cooling), were selected carefully for both appearance and thermal effectiveness. The **advanced solar control windows** are spectrally selective, which means that they transmit much of the light in the visible portion of the solar spectrum, but limit transmission in the infrared and ultraviolet portions (which causes overheating and fading of interior materials).

**Interior-mounted, oversized ducts**—positioned within the air-conditioned space as opposed to the hot attic—are used in the PV home to great

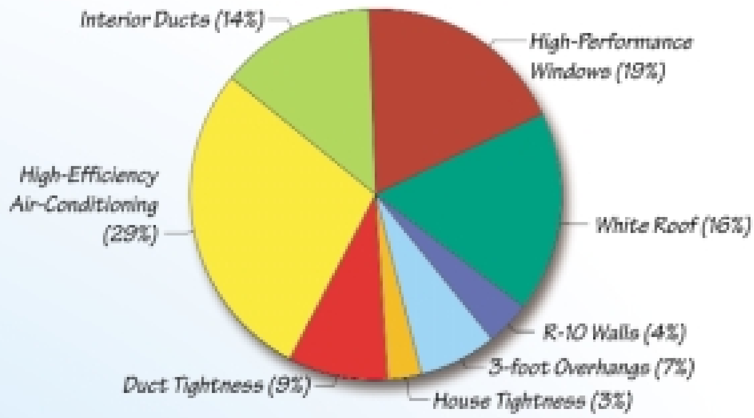
### Control Home Features

- Gray/brown asphalt shingle roof with 1.5-foot overhangs
- R-30 attic insulation
- R-4 wall insulation on interior of concrete block walls
- Single-glazed windows with aluminum frames
- R-6 ducts located in attic
- Standard appliances (electric range, refrigerator, and electric dryer)
- Standard incandescent lighting (30 recessed-can lights)
- Standard-efficiency, 4-ton, SEER 10 (seasonal energy efficiency ratio) heat pump (a typical air conditioner in Florida).

advantage. Tests at FSEC had shown that heat transfer to the duct system can rob the air conditioner of as much as one-third of its cooling capacity during the hottest hours. Oversizing the ducts allows high air flow and low friction loss (previously shown to provide as much as a 12% improvement in cooling efficiency at essentially no extra cost).

**High-efficiency appliances and lighting** further minimize the PV home's electrical load. These appliances and lighting also release less heat into the home while operating, which decreases the cooling load that must be met by the air-conditioning system. The smaller appliance, lighting, and air-conditioning loads result in less PV capacity required to meet the home's total electrical load.

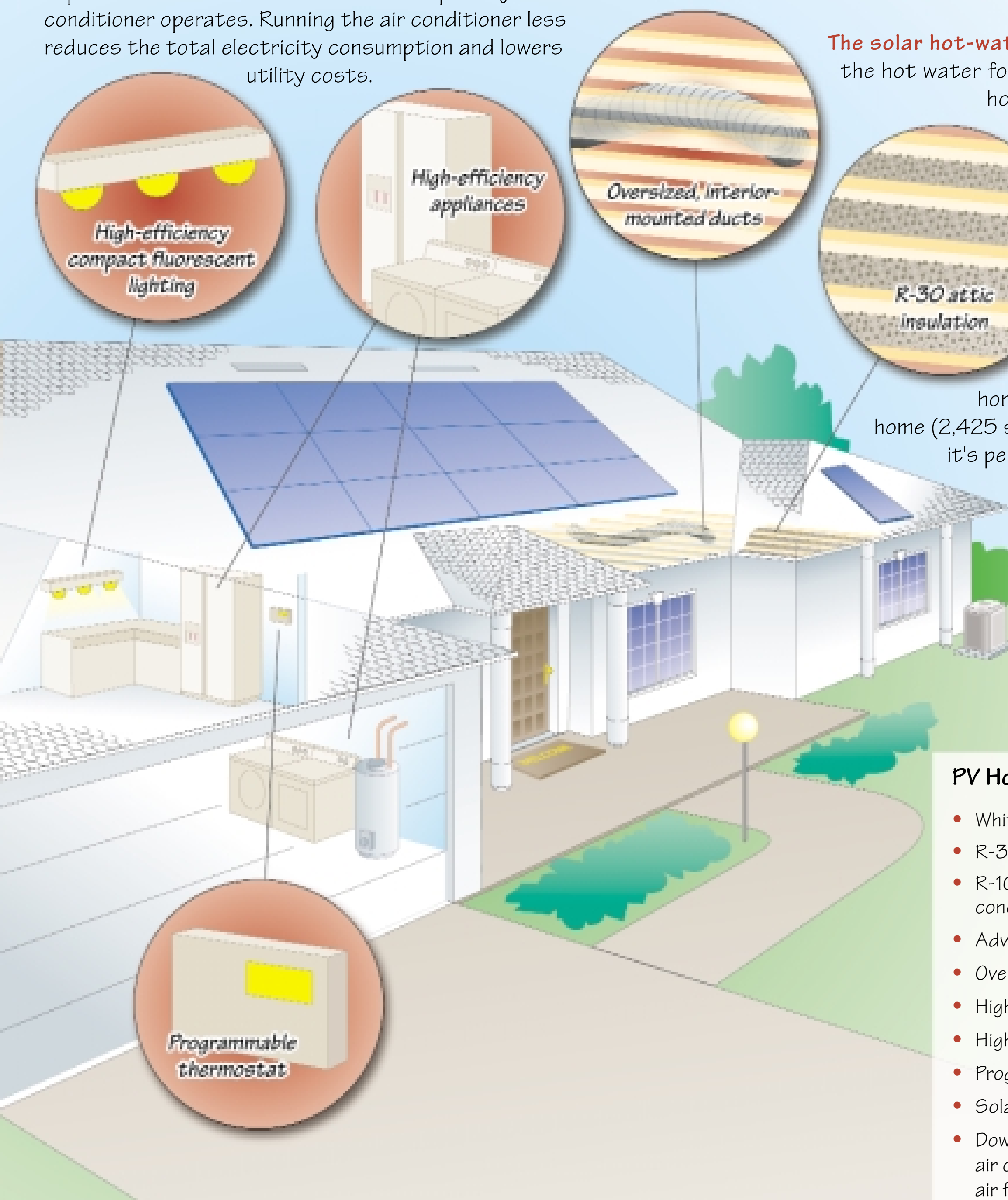
**A programmable thermostat**—set so that the indoor temperature is allowed to increase overnight and while the house is unoccupied—decreases the number of hours per day the air conditioner operates. Running the air conditioner less reduces the total electricity consumption and lowers utility costs.




**The Energy Savings Picture (for Cooling):** The estimated percentage of energy savings attributed to each measure used in the PV home.

**The solar hot-water system** supplies most (66%) of the hot water for occupant needs before the propane hot-water heater (used as a backup) is activated.

All told, the combination of efficiency features reduces the cooling loads so that a **downsized air conditioner** suffices—and, here too, FSEC chose a high-efficiency appliance. The small size of this system (half that of the control home) is highly unusual for such a large home (2,425 square feet) in Lakeland, Florida, but it's performing to expectations. In addition, the unit's **cooling coil air flow** was field-verified at the PV house, which involves using a flow hood to adjust the fan speed of the variable-speed air handler. Installers who neglect this crucial step commonly cost the system a 10% drop in actual operating efficiency.




For illustration purposes, some features of the PV home have been relocated (versus actual).

## PV Home Features

- White-tile roof with 3-foot overhangs
- R-30 attic insulation
- R-10 exterior insulation over concrete block system
- Advanced solar control double-glazed windows
- Oversized, interior-mounted ducts
- High-efficiency refrigerator
- High-efficiency compact fluorescent lighting
- Programmable thermostat
- Solar hot-water system
- Downsized SEER 15.0, variable-speed, 2-ton air conditioner with field-verified cooling-coil air flow
- 4-kW utility-interactive PV system.

## About the PV System

The PV system was sized to provide power that would offset as much of the household load as possible. Based on the predicted load for a peak day, a 4-kW PV array (split into two subarrays) was specified. One subarray was located on the south-facing roof, which is generally the preferred placement for a PV system. The other was located on the west-facing roof, because this orientation provides more PV power during the hot afternoons, when the utility experiences its peak demand period. Reducing demand at this time of day is particularly valuable to the utility. The PV system is grid-interactive, producing DC power that is converted to AC and then fed directly into the local utility distribution system. The City of Lakeland Department of Electric and Water Utilities, which owns and operates the PV system, allowed unprecedented connection of a residential PV system to the utility grid in Florida.

## Energy Efficiency Enhances PV Power

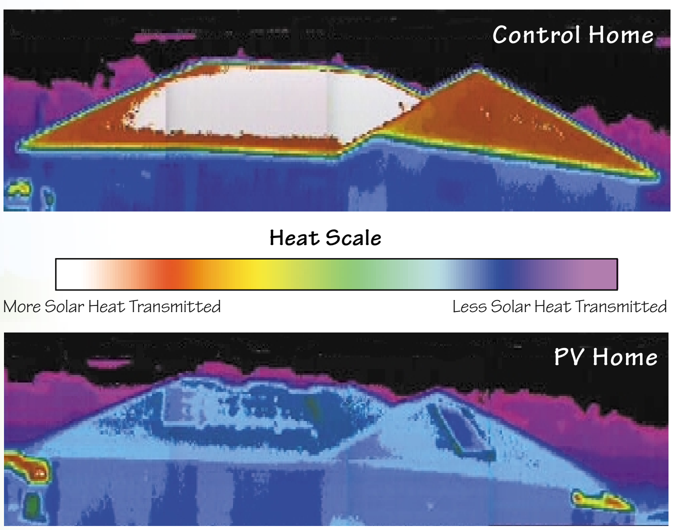
It's important to note that a PV system will not save energy. People invest in PV because it's an energy producer... one that releases no noxious gases into the air... one that can minimize or eliminate monthly utility bills. And, when PV technologies are combined with energy efficiency measures, PV's investment value is magnified.

Here's where energy efficiency factors in: as a home's energy efficiency increases, PV can offset more of the utility bill. This makes it a better investment, because the PV power stretches further. In the Florida case, building energy efficiency into the PV home—and sizing and locating the PV system correctly—resulted in the PV system offsetting about 65% of all grid-electricity needs on an annual basis.

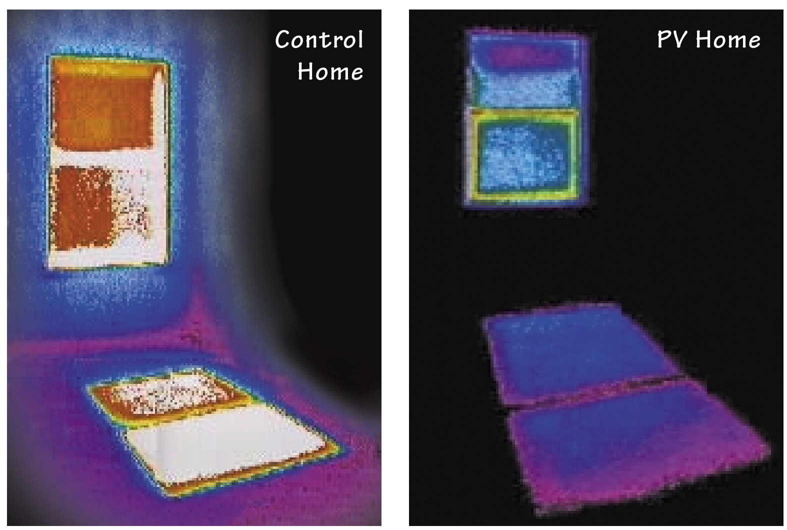
Of course, there are up-front costs incurred with purchasing the PV system and installing certain energy efficiency measures. But, in many cases, these costs can be recouped over time by the savings on the monthly energy bill.

What works in Florida can work just as well in other parts of the country. The appropriate energy efficiency measures and PV configurations will vary locally, but energy efficiency can improve the value of the PV resource anywhere.

### PV Home's Roof and Windows Beat the Heat




Thermographic images of the roofs in both homes. Note the lower roof and attic heat gain into the PV home, thus reducing the demand for cooling.




Comparison of the infrared appearance of west-facing windows of both homes in the afternoon. The PV home's windows accounted for almost one-fifth of the energy savings (for cooling).

## What If?

The demand for electrical energy in Florida is increasing continually as a quarter-million people move to the state each year, building more than 100,000 new homes. Imagine the scenario if all those new homes were built like the PV home (rather than the control home). How big a difference would this make?

Figuring that each home would save about 18,000 kWh/year, the total savings for the 100,000 homes is 1.8 billion kWh. Based on Florida's average cost of residential electricity (8¢/kWh), this would save about $144 million a year in utility bills. Multiply these figures by all 50 states, and it's clear that the energy and air pollution savings in the United States would be astronomical. So dramatic, in fact, that it just doesn't make sense to build a new home without, at minimum, incorporating energy efficiency features.

Homeowners may want to check out an Internet Web site called the "Home Energy Saver" (at http://hes.lbl.gov). Here, you'll find estimates of how energy efficiency measures can shave dollars off an energy bill in your geographic area. By providing some information about your house, the Web site will generate a custom report detailing which efficiency measures would save you the most.

## Project Participants

Florida Solar Energy Center (FSEC)—Coordinated and implemented the project.

Sandia National Laboratories—paid for the PV system and FSEC's technical support resources.

Florida Energy Office/Department of Community Affairs—Funded the energy efficiency improvements for the building.

City of Lakeland Department of Electric and Water Utilities—PV system owner and operator.

Siemens/Hutton Communications—Module supplier/system integrator.

The National Renewable Energy Laboratory produced this brochure as part of a series describing and promoting the use of solar energy technologies in a variety of applications.

**Source Document:** "Field Evaluation of Efficient Building Technology with Photovoltaic Power Production in New Florida Residential Housing," by Danny S. Parker et al. The entire document is available on-line at http://www.fsec.ucf.edu/~bdac/pvres_intro.htm

Also see, "Priorities for Energy Efficient New Residential Construction in Florida," available on-line at http://www.fsec.ucf.edu/~bdac/pubs/PRIORITY/Priority.htm

## Related Documents and Web Sites

"A Consumer's Guide to Buying a Solar Electric System," http://www.nrel.gov/ncpv/pdfs/26591.pdf

"Consumer Guide to Home Energy Savings," http://www.aceee.org/consumerguide/index.htm

DOE Building America Program, http://www.eren.doe.gov/buildings/building_america

DOE/NREL Photovoltaics in Buildings (site under development at press time), http://www.nrel.gov/buildings/PV

Energy Savers: "Tips on Saving Energy & Money at Home," http://www.eren.doe.gov/consumerinfo/energy_savers

Million Solar Roofs Initiative, http://www.eren.doe.gov/millionroofs

NREL High-Performance Buildings Research, http://www.nrel.gov/buildings/highperformance

U.S. EPA Energy Star Homes Program, http://yosemite.epa.gov/appd/eshomes/ESHomes.nsf

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