Solar Weatherization Assistance Program

Program Final Report

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ACKNOWLEGEMENTS

The Solar Weatherization Assistance Program (SWAP) has consumed the better part of four years for many of us. Overall, the program has been a success and shows that solar is, as has always been argued, a viable water heating option. This success could not have been accomplished without the help of many, many individuals. We wish to acknowledge and thank the United States Department of Energy (DOE) and Florida Department of Community Affairs (DCA) personnel who not only administered the overall program, but also provided the funding that made all this possible. Mr. Jim Tait of the Department of Community Affairs had the vision and a commitment to solar that helped make this program a reality. It has been a pleasure working with the DCA staff in Tallahassee. This includes Earl Billings, Hilda Frazier, Jim Smith, Jim Austin, and Diana Gregory. We thank them for allowing us the freedom to accomplish this program.

Participating local agency WAP staff also made this program accomplishable. They were the ones who identified the clients and procured the solar systems. Special acknowledgement must go to all of them.

Primary among those that helped with the FSEC tasks in this program were our colleagues at the Florida Solar Energy Center, especially Patrick Robinson and Tom Tiedemann. Patrick was responsible for procuring, assembling, calibrating, and installing 35 sets of field monitoring equipment. His dedication, faith in the program and willingness to spend many days in the field away from his family are greatly appreciated.

Tom Tiedemann provided professional advice and, as Patrick did, participated in the installation of the monitoring equipment and inspection of over 200 SWAP systems throughout Florida. Tom’s practical knowledge of solar components and systems and his impeccable troubleshooting were invaluable.

Teresa Johnson’ and Sue Blum’ assistance with the various administrative functions made our jobs that much easier. Their positive attitude, patience and pleasant demeanor were an added bonus.

Other FSEC staff members also contributed greatly to this program. These include Carlos Colon, Carol Emrich, Mary Freen, Bill Guiney, Jim Huggins, Safvat Kalaghchy, Tim Merrigan, Jim Roland, and Yayi Rickling. We are especially grateful to these people, and any we may have inadvertently omitted.

Many members of the Florida solar industry participated in this program. Thanks and acknowledgements are made to Ben Bentley, David Burrows, Griff Carrison, David Eddington, Tom and Shirley Lane, Richard Lavigne, David Marsh, Mike Newman, Robert Zrallack and to all those who we have failed to mention.

Acknowledgement must also be made to all the participating low-income families, especially those who participated in the instrumented monitoring phase of this program. We have met many wonderful people over the past three years that encompassed the monitoring phases of this contract. Sadly, several of them have passed on, but they nevertheless made an impression on us in the brief time that we knew them. We have learned much more than just about technical issues. This program has also taught us about the humanity, dignity and needs of all persons, no matter their social or economic circumstances.

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SOLAR WEATHERIZATION ASSISTANCE PROGRAM

The Solar Weatherization Assistance Program (SWAP) was a joint effort of the U.S. Department of Energy (DOE), the Florida Department of Community Affairs (DCA) and the Florida Solar Energy Center (FSEC) to provide solar water heating systems for low-income residents in Florida.

Raising families, incurring everyday bills and purchasing common necessities are all part of daily life that can rapidly drain a family's budget. This is especially burdensome for low-income and elderly residents on a fixed income. A major part of the budgetary concerns are the recurrent and unavoidable electric bills.

In northern colder climates, weatherization programs assist low-income clients in reducing their energy costs by conducting weatherization on existing homes.

Very often many northern weatherization measures such as caulking and weatherstripping are not cost-effective in warmer climates. Therefore, it only makes sense to take advantage of Florida's abundant and everlasting solar energy resource to help reduce energy costs in low-income residences.

Mrs. Roundtree and her three children are quite happy with the solar heated water they get from their SWAP solar system. They have more hot water than before the solar water heater was installed and reduced electric bills.

The SWAP program's major objectives included:

- ✓ **reducing energy consumption and power bills for low-income residents**
- ✓ **calculating the savings-to-investment ratio from the DOE NEAT audit procedures**
- ✓ **Evaluating the feasibility of solar systems as a WAP program measure**
- ✓ **provide a niche market for the solar industry**
- ✓ **reducing LIHEAP expenditures**

DCA provided grants to local Weatherization Assistance Program agencies and other non-profit agencies to operate the program, while SWAP-certified solar contractors provided installations.

The program was widely administered in rural and urban communities by non-profit organizations and governmental agencies in cooperation with local volunteer groups.

FSEC established an extensive database to compile and store information obtained by site inspections, surveys, utility bill analysis and computerized data acquisition at over 30 selected sites, where such variables as water temperature, water consumption, and power consumption are monitored.

FSEC developed all technical guidelines and provided on-going technical assistance, training, and program support to DCA and all participating local agencies and installers.

SWAP participating agencies throughout Florida

Solar collectors mounted on low-income residences in Miami.

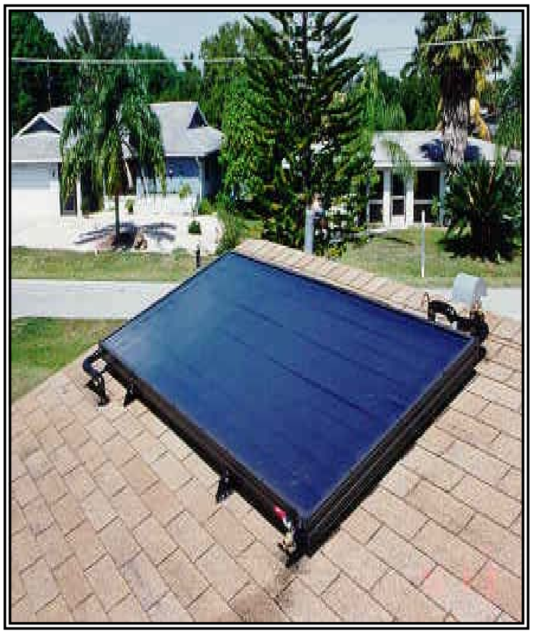
Solar system installed on country home in rural North Florida.

SWAP INSTALLED SYSTEMS

Several types of solar systems were installed under the SWAP program. The primary ones were the Integral Collector Storage (ICS) and the direct pumped systems.

In the ICS unit pictured below, one can clearly see the large tubes in which water is heated and stored. ICS systems combine both the heat collection and storage in one unit. Water is heated in the ICS tubes and flows to the back-up water heater when the client uses hot water.

Of course, both ICS and pumped systems include a back-up electric water heater for use during inclement weather.



The flat-plate solar collector, above, is mounted on a residence in Miami. This collector uses a pump to help circulate water through the small tubes in the collector.

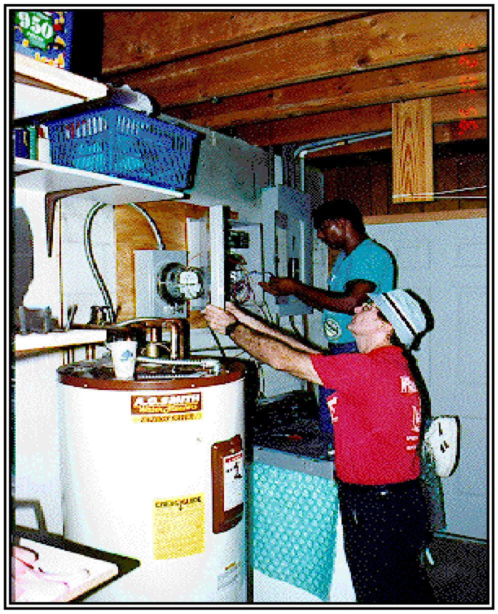
Direct pumped systems include a pump and some type of controller that determines when the pump should be on. The pump then forces water through the solar collector, where it is heated and returned to the water heater in the house.

Listing of SWAP Systems installed throughout Florida

Florida Location	Agency	System	Total installed Systems	Average System Cost
North	Central	ICS	45	$1,641
	Suwannee	ICS	90	$1,631
	Suwannee	Pumped	1	$1,690
	Tri-County	ICS	48	$1,641
Central	Citrus	ICS	25	$1,516
	Citrus	Pumped	4	$1,388
	Citrus	Thermo	1	$1,690
	Mid-Florida	ICS	162	$1,497
	Mid-Florida	Pumped	28	$1,384
	Pinellas	Pumped	5	$1,535
	Pinellas	Thermo	1	$1,750
South	Metro-Dade	Pumped	307	$1,501
	Centro	ICS	4	$1,540
	Centro	Pumped	30	$1,423
	Lee County	ICS	19	$1,641
	Lee County	Pumped	31	$1,414
		Total Installed Systems	801	
			Average Cost	$1,555

SWAP INSTRUMENTED MONITORING

In order to assess the viability of solar systems as well as low-income hot water use characteristics, FSEC conducted detailed instrumented monitoring at over 30 SWAP sites.



FSEC staff members Tom Tiedemann, right, and Patrick Robinson installing monitoring equipment at one of the SWAP sites.

The following were monitored at the instrumented sites:

- ✓ Cold and hot water temperatures
- ✓ Collector feed and return line temperatures
- ✓ Flow to and energy usage of water heater
- ✓ Horizontal solar radiation
- ✓ One-time measurement of pump and controller power usage
- ✓ Scanned data every 15 seconds - stored average - totals every 15 minutes.
- ✓ Ambient temperatures during pre-solar monitoring

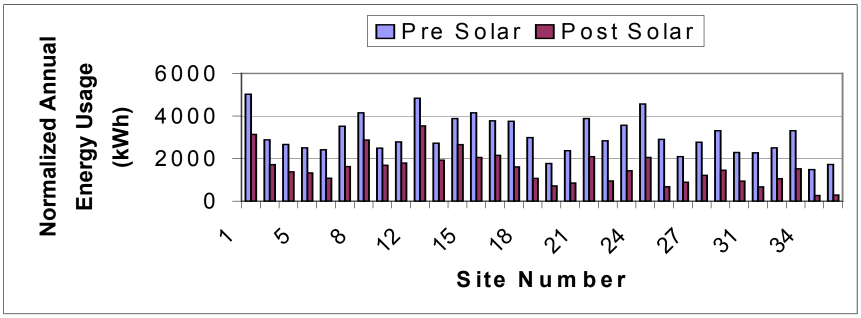
SWAP Monitoring Program Results

Parameter	**Pre Solar**	**Post Solar**
Average family size	4.7	4.4
Average water heating energy consumption (kWh per system, per year)	3,100	1,500
Water heating costs per year ($.08 kWh)	$250	$120
NEAT Savings-to-Investment Ratio (at $.08 per kWh)	N/A	1.0
Solar Fraction (Percentage of hot water heated by solar)	N/A	0.53
Average system Coefficient of Performance	0.73	1.4
Average SWAP solar system installed cost	N/A	$1,550
Gallons used – Family per day	63.8	62.5
Gallons used – Per person per day	13.6	14.2
Average hot water temperature (^{0}F)	119	119

SWAP INSTRUMENTED MONITORING RESULTS

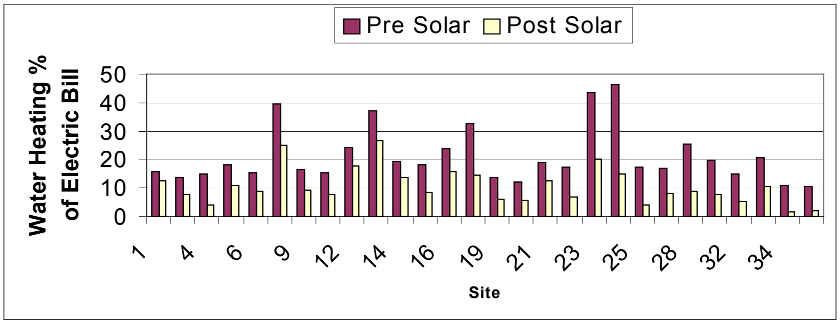
The following charts are based on instrumented monitoring data from 32 SWAP sites.

SWAP Hard Monitoring Annual Energy Usage



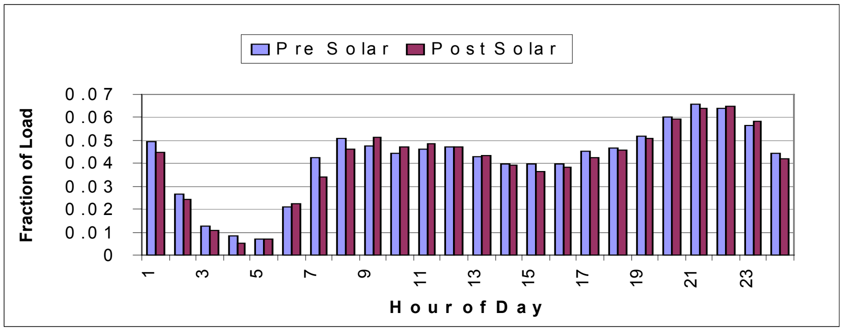
Pre solar energy usage and energy costs are greatly affected by factors such as water usage, and existing water heater and water heater thermostat settings. Post solar system usage and savings are affected by the above as well as timing of loads, solar radiation, and solar system performance.

SWAP Hard Monitored Systems Water Heating Ratio



This chart indicates the percentage of electrical energy devoted to heating water. The amount varies by site and is typically a very substantial portion of the utility bill. Solar systems reduce this percentage dramatically.

SWAP Hard Monitored Systems Water Usage Profile



This water usage pattern is very favorable for solar water heating since usage peak is in the evening.

SYSTEM OWNER SURVEYS

Surveys were sent to over 800 clients that had received a solar system. Over 35% responded to the survey. Overall, the survey indicated that:

- ✓ most participants were satisfied with their systems
- ✓ participants were aware of the weather-sensitive nature of the solar systems
- ✓ participants need more information and education regarding system operation, maintenance, etc.

SYSTEM INSPECTIONS

FSEC staff inspected over 200 of the installed systems, looking at the quality of the installations as well as system/component problems. In general, the inspections revealed:

- ✓ Few component failures
- ✓ Most installation discrepancies are easily fixed
- ✓ Most discrepancies are related to workmanship versus equipment problems
- ✓ Post-installation inspections are critical.

LOCAL AGENCY PARTICIPATION

Brenda Mobley, SWAP Program Manager for the Mid Florida Community Services Agency, believes that ". . . a solar water system doesn't just help with the energy bill, it also relieves other financial stress."

Brenda goes on to state, "For a program that reduces your energy bill and doesn't cost you a penny, the solar heater is the way to go. This program has proven itself to many low-income clients in Hernando and Sumter Counties. Several clients have made a point of telling me personally that the solar water heaters have cut their electric bill in half and have advised anyone to take advantage of this worthwhile program. The SWAP program has been very worthwhile in meeting Mid Florida's primary mission of reducing the energy costs of low-income clients."

Brenda Mobley, SWAP Program Manager for the Mid Florida Community Services Agency discusses a local installation with FSEC SWAP Program Manager John Harrison (right), and FSEC's Patrick Robinson (left).

THE CLIENTS' STORIES

The Sims Family – Brooksville, Florida

Although it's easy to get lost in the technicalities of this program, the end product is that these solar systems are affecting people's lives in a positive manner. They are helping low-income people better support themselves. At this point, let's allow a few clients to speak for themselves on the impact of their solar water heating systems.

Take the example of Mrs. Sims and her family. As a single mother with three children, Mrs. Sims provides a stable family environment, maintains two jobs and is currently attending medical radiologist school.

According to Mrs. Sims, the ICS solar system that was installed on her residence has become one of her favorite appliances. It works quite well; she doesn't have to do anything with it. It's just there, silently creating hot water from a free energy source.

The monthly savings accrued from the solar system provide her with additional income that can be used for her family's unavoidable expenses.

Mrs. Sims is shown conferring with FSEC SWAP program staff members. Her ICS solar system is conveniently mounted facing south. Note the solar collector's unobstructive look, similar to that of a standard skylight.

And, Mrs. Sims states: "I also feel like I'm doing my part in preserving natural resources as well as helping save energy and the environment. But most of all, I really appreciate the savings and extra hot water that I have enjoyed since the solar system has been installed."

Sims System monitoring results

Category	Pre Solar	Post Solar
Installed system	N/A	ICS
Installed system cost	N/A	$1,500
Water heating energy usage (kWh per year)	2367	846
Water heating costs per year ($.08 kWh)	$189	$68
Water usage (Gals per day)	59	44
Solar Fraction	N/A	.64
NEAT Saving-to-Investment Ratio	N/A	1.03

The Ahmadi Family – Miami, Florida

Behind Mrs. Ahmadi and her two children is the water heater. Above the tank is the solar system pump and piping going up to the solar collector.

“Since my solar system has an on/off switch that turns the electricity to the water heater off, during sunny days, we always keep the switch off. This way, all the hot water that I use is made by the sun. This really cuts my utility bill. I’m getting free hot water.”

Mrs. Ahmadi received her solar system through the Metro-Dade Community Action Agency in 1996 and has been quite satisfied with it since. “What took you so long in providing me a solar system?” she wonders. “I’ve had neighbors ask about the collector on the roof and after I’ve told them of how great the system was, they also want one.”

The system consists of a flat-plate pumped solar collector retrofitted to a 50-gallon water heater. Sensors at the collector and pump tell an electronic controller when there is sufficient solar energy available to heat the water. At that time, the pump comes on and circulates the water from the tank through the solar collector where it is heated.

Ahmadi system monitoring results

Category	Pre Solar	Post Solar
Installed system	N/A	Active Pumped
Installed system cost	N/A	$1,550
Water heating energy usage (kWh per year)	2902	679
Water heating costs per year ($.08 kWh)	$232	$54
Water usage (Gals per day)	78	79
Solar Fraction	N/A	.77
NEAT Saving-to-Investment Ratio	N/A	1.4

1.0 PROGRAM DESCRIPTION

The Solar Weatherization Assistance Program (SWAP) program is a pilot program that provides grants to local agencies that participate in the Weatherization Assistance Program (WAP) to install low-cost, low maintenance solar water heater systems in low-income residences. It is a collaborative effort between the U.S. Department of Energy, the Department of Community Affairs, the Florida Energy Office (FEO), the Florida Solar Energy Center (FSEC), participating statewide local WAP agencies, utility companies, and the Florida solar industry.

The program's objectives included the following:

1. Reduce energy bills for low-income residents.
2. Reduce consumption of non-renewable energy resources statewide.
3. Stimulate and encourage manufacturers and installers of solar water heating systems to produce, market and install low-cost, energy-efficient solar water heating systems for low and moderate income consumers.
4. Quantify electrical energy savings that will encourage the increased usage of solar water heating systems in low-income housing.
5. Evaluate the feasibility of incorporating solar water heating as a WAP option.
6. Reduce pollution/CO_2 emissions.
7. Reduce Low Income Home Energy Assistance Program (LIHEAP) expenditures.
8. Increase energy efficiency and economic security for low-income individuals.

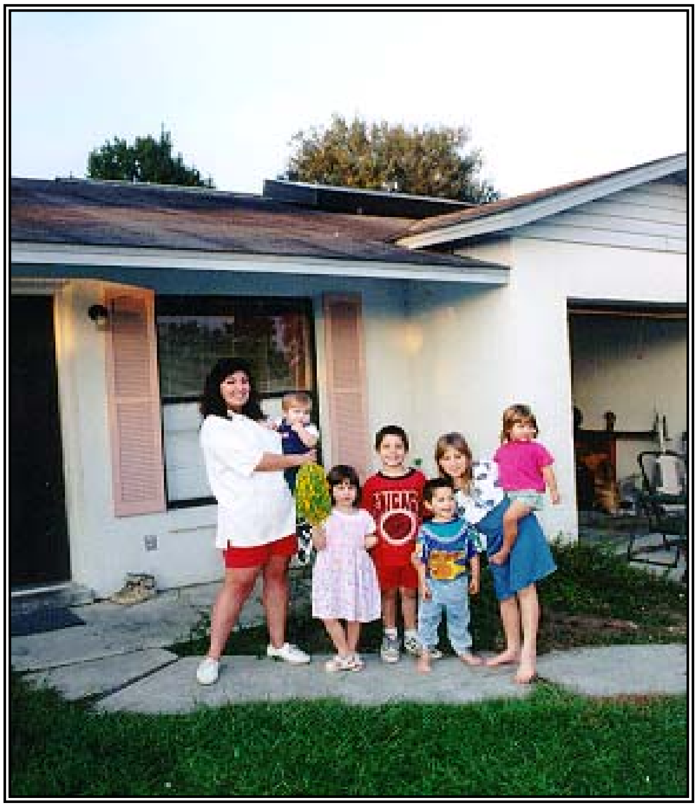


Figure1.0-1. Central Florida family with their solar system.

Secondary benefits that can be derived from the SWAP program are:

1. Provide the framework for enhanced recognition by government, the solar industry, and consumers that affordable solar water heating installations are a viable tool that creates jobs, enhances the quality of life for low-income consumers, and provides a marketable product.
2. Provide a program model that utilizes partnerships between government, the private sector, non-profit community based organizations and local volunteer groups that can be replicated in other states.
3. Increase the value of low-income houses through the addition of solar systems.

The SWAP program was targeted to benefit low-income clients with household incomes meeting federal Office of Management and Budget poverty guidelines. Three or more low-income persons were required to reside in each household before a solar water unit could be installed. In a few exceptional cases a solar installation was permitted where less than three low-income residents occupied a home if one or more of the residents were elderly, handicapped or infirm. Installations were geographically distributed in the north, central and southern climate zones of the state. The program was widely administered in rural and urban communities throughout Florida by nonprofit organizations and governmental agencies.

FSEC has established an extensive database to store and compile data obtained from the local agencies on installed systems and by FSEC from onsite inspections, surveys, utility bill analysis and computerized data acquisition at selected sites that monitor water temperatures, water flow and power consumption.

Why was Florida chosen to conduct the pilot SWAP program for DOE? Florida has always been at the forefront of developing a stable state solar infrastructure. It is primarily for this reason that Florida was chosen. This infrastructure includes:

1. Adequate solar resource
2. Substantial low-income housing
3. Large amounts of electrical water heating
4. Solar contractors licensing program administered by the Florida Board of Professional Regulations
5. The Florida Solar Energy Center's capabilities and experience
6. A history of solar development in the Sunshine State
7. An industry base of national collector manufacturers and local solar system installers

The SWAP program merges Florida's unique solar energy potential with the needs of its low-income clients. By providing solar systems that heat water with solar energy instead of conventional energy sources, the savings accrued from these systems provide low-income population with additional income that, as Mr. Oscar Harris of Gainesville's Central Florida Community Action Agency states, " . . allows the money [for electric bills] to go to other needs such as health care, transportation, and shelter."

1.1 PROGRAM IMPLEMENTATION

The program was initiated by the development of program criteria and guidelines established by FSEC and DCA. These criteria included site selection, system types, sizing and performance requirements, and solar contractor qualification requirements. Solar site and system inspection tools and training were also provided to the local participating WAP agencies. Of course, the ability of local agencies to identify clients and sites that would benefit from the solar systems was, in the end, an important element in the success of this program.

Following is a detailed description of the SWAP program implementation activities.

1.2 SYSTEM TYPE REQUIREMENTS

The introduction of solar water heating systems in low-income residences provided many challenges and special requirements. These challenges were compounded by the necessity of keeping installed costs at a minimum in order to achieve overall system cost effectiveness. It was important that the system design be kept simple. Basic operation principles had to be understood by both the local participating agency staff and the low-income residents.

The reliability of the installed systems was also important. Once installed and out of warranty, it was unlikely that the majority of low-income clients could or would want to spend limited income on system maintenance or repairs. Since all SWAP systems were installed with a back-up electric water heater, electric heated water was always available. Therefore, in the event of system failure, many clients would undoubtedly delay or ignore required repairs to the solar system.

Installations were limited to the following system types according to the climate areas defined in the "Florida Energy Efficiency Code for Building Construction" (State of Florida, 1993). The primary purpose of these criteria was to ensure that systems installed in North and Central Florida areas that encountered periodic freezes during winter months would be protected by the particular system's freeze prevention design strategy. Detailed investigation was conducted by FSEC to determine areas most susceptible to annual freeze conditions. This included the review of weather maps providing long term temperatures for the Florida peninsula (USDA, 1475). The use of a variety of systems that were available in the Florida marketplace was also considered during the selection of applicable systems.

Listed below is the breakdown of systems specified for use in the various Florida geographical regions.

Central & South Florida	North Florida (& Certain Areas of North Central Florida)
Direct Active	Indirect Active
Integral Collector Storage	Integral Collector Storage
Thermosiphon (Direct and Indirect)	Thermosiphon (Indirect)
Indirect Active	Direct Active Photovoltaic Automatic Draindown

Following is a detailed description of the types of systems that are mentioned in the table listed above and installed throughout Florida as part of this program.

Specific systems were selected for each Florida climatic zone. This ensured that systems were compatible with the various climatic conditions, such as frequency and duration of freeze conditions. As previously stated, systems were also selected for their simplicity and convenience to low-income clients.

The primary systems used in North and Central Florida were the Integral Collector Storage (ICS) systems.

The systems installed in South Florida were pumped solar systems using a conventional flat-plate collector and a variety of control methods. These systems have been the workhorse of solar systems throughout Florida during the past decades. Some ICS systems were installed by several agencies in South Florida, but were not used in the large Metro-Dade area due to excessively costly Dade County Product Approval requirements for the manufacturer.

All installed solar systems were retrofited to existing electric water heaters. This included 40- or 50-gallon water heaters for ICS and pumped systems. Initial site inspections determined whether the water heaters had to be replaced. If so, the new water heaters were sized for the particular system. Flat-plate collector systems were retrofited with new or existing 40- or 50-gallon water heaters, while ICS systems could be installed with any size or existing water heater due to the storage design and total volumetric capacity of this system. Storage capacities followed the guidelines outlined in Table 1.5-2 of this report.

Standard solar systems, sold primarily to middle-income clients, usually require 80-to 120-gallon water heaters, but for SWAP, it was determined that the use of conventional smaller sized water heaters would be more beneficial. Smaller heaters reduced the cost of the overall systems, plus allowed future tank replacement by the client to be more affordable.

The installed solar collector area was also downsized by approximately 20%. This downsizing of the collectors and the water heaters provided a lower initial system cost and compatibility between the collector area and the tank volume.

1.3 SYSTEM DESCRIPTIONS

PASSIVE SYSTEMS

Integral Collector Storage (ICS) systems

This is an ideal system for low-income clients. Its combines both simplicity and reliability. The system provides pre-heated solar water to the existing auxiliary tank. The ICS system has been installed in close to 50% of all the residences in the SWAP program. It is unique in that the hot water storage system is the collector. On demand, cold water flows through the collector where it is heated by the sun. Hot water is drawn from the top, which is the hottest part of the collector. During draws, the hot water from the collector flows to a standard hot water auxiliary tank within the house, eliminating much of the electricity required to heat water. During inclement weather when there is little solar radiation, hot water is still available through the use of the conventional water heater.

Thermal mass of the large tubes within the ICS unit serve as positive freeze resistance in Florida. In addition, and as a secondary back-up, a flush type freeze protection valve is often installed. Both 30- and 40-gallon versions of the ICS system were used in the SWAP program.

Figure 1.3-1. ICS System in North Florida.

Figure 1.3-2. Water heater and plumbing from ICS system.

Thermosiphon systems

Thermosiphon systems, like ICS systems, are considered passive systems since no pump is used to circulate water to the collector. Thermosiphon systems use flat-plate collectors to solar heat water. As the sun shines on the collector, the water inside the collector flow-tubes is heated. As it is heated, this water expands slightly and becomes lighter than the cold water in the solar storage tank mounted above the collector. Gravity then pulls heavier, cold water down from the tank and into the collector inlet. The cold water pushes the heated water through the collector outlet and into the top of the tank, thus heating the water in the tank.

A thermosiphon system requires neither a pump nor a controller. Cold water from the city water line flows directly to the tank on the roof. Solar heated water flows from the rooftop tank to the auxiliary tank installed at ground level whenever water is used within the residence.

These systems are quite popular throughout the world and, due to their simplicity, would also be quite feasible for the SWAP program. They do take a bit more installation time since both the solar storage tank and collector must be mounted on the roof with a proper sloping of the pipes.

Because of the great weight of the thermosiphon and ICS units, the structural integrity of the roof must be verified before both thermosiphon and ICS systems are mounted on the roof. In many cases, the weight of a 40-gallon ICS or thermosiphon unit can easily exceed 500 pounds. Therefore the truss and roof sheathing must be strong enough to take this load. Of course, the units are usually mounted so that the weight of the unit is placed in four locations. As was the case in several SWAP installations of the ICS units, if the roof is not suitable for the mounting of these units, they are ground mounted.

Figure 1.3-3. Thermosiphon system in Central Florida.

Indirect thermosiphon systems work in the same manner except a freeze-proof glycol solution is used in the collector loop. A heat exchanger transfers heat gained by the heat transfer solution to the potable water in the solar storage tank.

ACTIVE SYSTEMS

Pumped system using a flat-plate collector and differential controller

The direct pumped system has a flat-plate solar collector installed on the roof and plumbed to a standard electrical storage tank. A pump circulates the water from the tank up to the solar collector and back to the tank. The sun's heat is transferred directly to the potable water circulating through the collector tubing and storage tank. This system uses a differential controller that senses temperature differences between water leaving the collector and the coldest water in the storage tank. When the water in the collector is about 12-20^0 F warmer than the water in the tank, the controller turns on the pump. When the temperature difference drops to about 3-5^0 F, the pump is turned off. Simply put, the sensors and controller determine when there is enough solar heat available to turn the pump on.

Figure 1.3-4. Flat-plate collector mounted flush to roof.

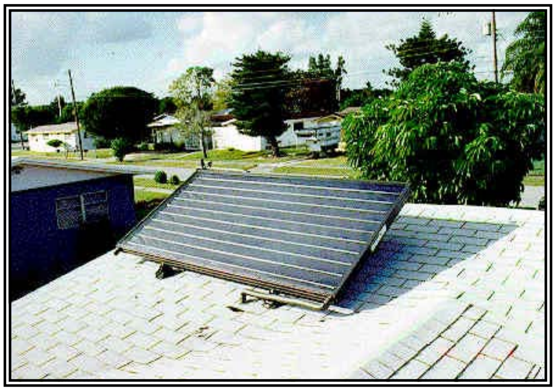


Figure 1.3-5. Flat-plate collector mounted at an angle.

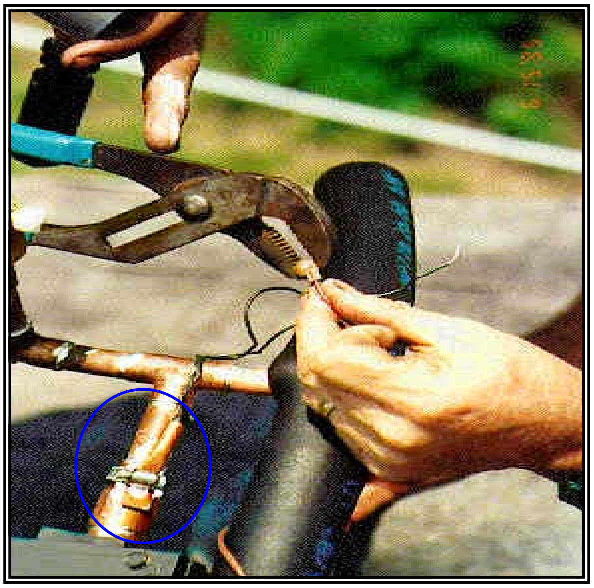


Figure 1.3-6. Sensor being attached to collector.

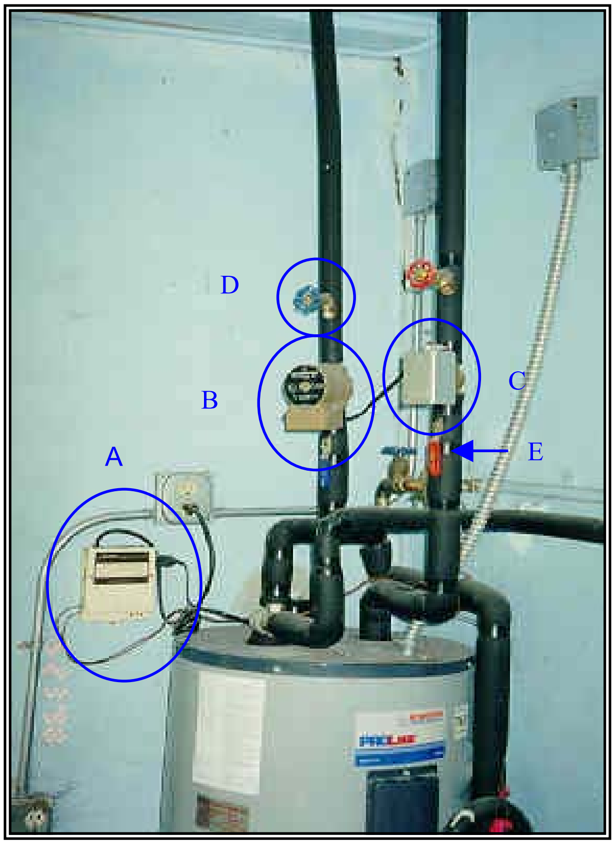


Figure 1.3-7. Differential control system. Note controller (A) at left of tank, pump (B) on collector feed piping, motorized check valve (C) on collector return piping, and ancillary drain (D) and isolation valves (E).

These systems also incorporate a freeze protection valve. Whenever temperatures approach freezing, the valve opens to let warm water through the collector - much like allowing water to flow through house piping to prevent the piping from freezing. Once the valve senses the warm water it shuts off. This process is repeated numerous times during freezing conditions. A minimal amount of water is used – a total of approximately 1 gallon or less per day, depending on the severity of the freeze.

Figure 1.3-8. Freeze valve jutting from collector return line.

Another method of freeze protection is achieved by water recirculation in those systems that use a differential controller. When the temperature drops below 40^0 F, the collector sensor activates the pump to circulate warm water through the collector.

The majority of pumped systems installed under the SWAP program incorporated differential controller methods. Differential control systems are also the most commonly installed control in conventional Florida solar water heating systems.

Although quite popular and efficient, and generally quite reliable, these systems include many more components than the ICS systems, which could increase the likelihood of future maintenance and service requirements.

Pumped system using a flat-plate collector and timer controller

This system differs from the differential controlled system in two ways. First, a timer is used to control the operation of the pump. A conventional timer with battery back-up (in the event of power failure) is used in conjunction with a standard solar pump. The timer is set to operate the pump during hours of the day when solar radiation is available to heat the potable water. In order to avoid loss of energy from the tank during overcast days, the collector feed and return lines are both connected at the bottom of the storage tank with a special valve. During normal operation, natural convection allows the warmer water to rise to the top of the tank. During cloudy weather, the pump only circulates water that is in the very bottom of the tank, thereby preventing most heat loss of the energy being dumped from the collector. This type of system requires that the homeowner replace the timer battery (common AA type) annually.

Figure 1.3-9. Tank bottom feed/return valve used in timer controlled systems.

Figure 1.3-10. Tank bottom feed, bottom return valve installed at drain of water heater. Note timer attached to wall at right.

Pumped system using a flat-plate collector and photovoltaic controller

This type of system differs from the differential controlled and timer controlled systems in that the energy to power the pump is provided by a photovoltaic (PV) panel. Unlike the AC-powered systems, there is no separate controller in this system. This PV panel converts sunlight into electricity, which in turn drives a direct-current (DC) pump. In this way, water flows through the collector only when the sun is shining. The DC pump and PV module must be suitably matched to ensure proper performance. The pump starts when there is sufficient solar radiation available to heat the solar collector. It shuts off later in the day when the available solar energy diminishes. The pump flow varies throughout the day in proportion to the sun falling on the PV panel. The compatibility of the PV panel and the DC pump are determined during the FSEC system approval process.

Figure 1.3-11. PV modules installed in plane of flat-plate collector.

The PV controlled system is ideal for use in residences where there is no readily accessible electric receptacle for AC powered pumps and controllers. As with the differential and timer controlled systems, a freeze valve is also incorporated into the system design as a freeze protection mechanism. One maintenance item on some DC pumps is the periodic replacement of the pump motor brushes.

Figure 1.3-12. Freeze valve attached to collector return line. The long non-insulated pipe stub to the freeze valve allows the valve to obtain better ambient temperature readings. It also provides heat release in the summer. Note the foil tape used as protective covering for the pipe insulation.

Pumped system using DC pump, photovoltaic panel and automatic draindown valve

This system is also ideal for areas in which freezes can occur. It uses no house electricity to power the pump since a PV panel wired to a DC pump provides electricity whenever there is sufficient solar energy. An automatic draindown valve is also incorporated in the system design to provide fail-safe freeze protection by draining the water from the collector every day. After sufficient solar energy has been received from the PV panel, the draindown valve is actuated. At this point, the pressurized city water is allowed to flow into the collector and the pump takes over and circulates water from the storage tank to the collector. When there is insufficient solar radiation, the draindown valve is no longer energized and at this time, the collector will drain water out of a drain port located at the tank. The drain line is run to a suitable drain location, usually outdoors.

Active systems electric water heater on/off switch.

A water heater on/off switch, with which the client could regulate the power to the electric water heater, was installed on the majority of active pumped systems. The logic behind the addition of this component was to turn the electricity to the water heater off during days when there was sufficient solar radiation to heat the water. The use of this switch increases system efficiency and reduces electrical consumption.

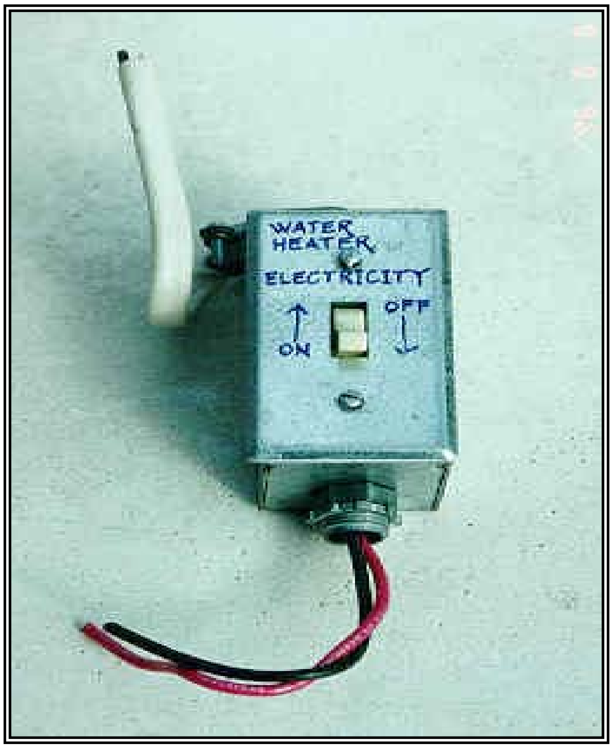


Figure 1.3-13. Electric on/off switch being installed on water heater.

Figure 1.3-14. Close-up of on/off switch.

In the first few installed pumped systems, the top thermostat in the water heater was set at approximately 125 to 140 F^0 while the bottom thermostat was disconnected to improve performance. Unfortunately this strategy did not provide the clients with enough hot water during inclement periods. After this, the top thermostats were set at 125-130 ^{0}F and the bottom thermostats were set at their lowest settings (90 to 110 ^{0}F).

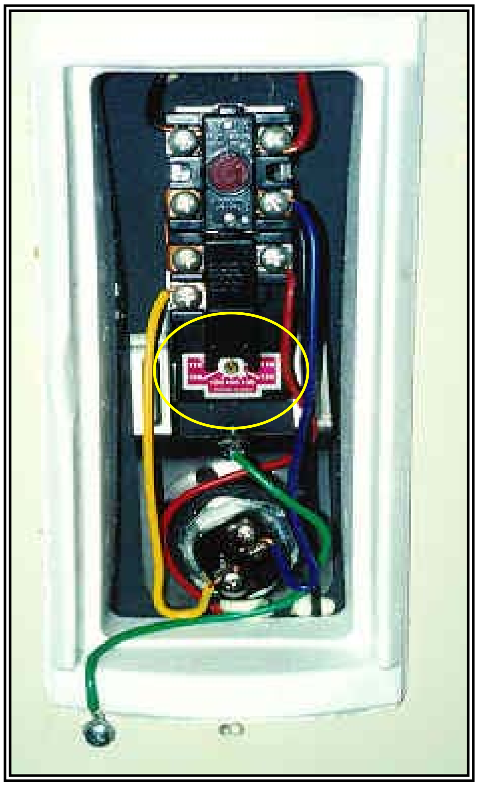


Figure 1.3-15. Water heater thermostat.

Since a secondary goal of this program was to help create a niche market for the solar industry in Florida, FSEC and the local agencies initially attempted to equally distribute the installations to several installers in each geographical area. Many agencies had several installers to choose from and each installer was provided with a listing of installations. As the program progressed, some installers became more efficient with an increased number of installations, their installed costs remained stable, and they developed a good working rapport with the local agencies. Because of this, many agencies became accustomed to working with only one or two installers during the remainder of the program. Also, some agencies felt more comfortable procuring specific system types as long as they were approved for their area.

1.4 SYSTEMS NOT USED IN THE SWAP PROGRAM IN FLORIDA

Several common systems were not used in the SWAP program. Florida's warm sub-tropical climate presented opportunities for using systems that could not be used in other climates where freeze protection is a major and routine problem. Therefore, the systems used in Florida are basically those intended (and restricted) for use in warm climate states. Most of the SWAP systems used in the Florida SWAP program could not be used in, for example, Wisconsin, unless the systems were deactivated during the cold winter months.

Several systems could be used in Northern climates, but they each have specific characteristics that make them less than ideal for low-income residents. These include indirect pumped systems and drainback systems. Indirect pumped systems are more common in colder climates, where freezing weather occurs more frequently. These systems use heat exchangers and antifreeze solutions to protect the collector and other components from freeze damage. There were several reasons for not including these systems in the SWAP program. These include:

1. A possible candidate system manufactured in Florida that was designed to use an external heat exchanger (ideal for retrofits to conventional electric water heaters) was not available until the majority of SWAP systems had been installed.

2. A thermosiphon system incorporating a heat exchanger at the tank, which is currently manufactured in Australia, was considered for the SWAP program. Since the contract between DOE and DCA stipulated that systems used in the SWAP program had to meet "Buy U.S.A." requirements, this system was excluded from the program.

3. Most important, indirect systems require periodic maintenance and the checking of the heat transfer fluid chemical (pH, etc.) makeup. This, it was felt by program principals, would be a financial burden to low-income clients. In addition, it was presumed that most clients would not have this service conducted. This service is strictly required on systems using heat transfer fluids.

Other types of systems such as drain back were not used due to the complexity of the systems, as well as the markedly increased initial installation costs.

1.5 SYSTEM SIZING

The primary goal was to provide systems that were inexpensive, reliable, provided reasonable savings, and would provide an FSEC Florida Energy Factor of at least 2.0. (The energy factors represent the ratio of the hot water energy made available by each approved system divided by the electric energy used by the system.) SWAP performance requirements for the solar water heating systems were based on the Florida Energy Factor listed in the document "FSEC Approved Solar Energy Systems: Domestic Hot Water and Pool Heating," (FSEC-GP-15-81, Revised January 1993).

For a four (4) person or larger residence, the Florida Energy Factor listed in FSEC-GP-15-81 was applicable.

For three (3) person residences, an adjusted Florida Energy Factor had to be multiplied by 1.4.

Listed below are examples of the procedures used for calculating the adjusted Energy Factor.

For three (3) person residences:

Table 1.5-1. Solar Energy Factor Adjustment Procedure

System selected for installation on a three (3) person Residence	Florida Energy Factor listed in FSEC-GP-15-81	Multiplier used to Obtain adjusted Florida Energy Factor for three (3) person residence	Calculation to be performed	Adjusted Florida Energy Factor for three (3) person residence
Solar Florida, Inc. Model: Solar Ray	1.7	1.4	1.7 x 1.4 = 2.4	2.4

As per FSEC-15-81, different energy factors applied for Central/South and North Florida climate zones.
It was stipulated that the majority of systems installed would be retrofit applications to existing 30-, 40- or 52-gallon tanks. The use of existing water heaters would keep costs down and would also enable the low-income resident to replace the conventionally sized water heater in the future without incurring high replacement costs as would be the case if large solar storage tanks were used.

Table 1.5-2. System Sizing

Number of People	Estimated Gallons Per Day Usage	Energy Factor: 2.0 - 2.9 Minimum Storage Volume (Gallons)*	Energy Factor : 3.0 and up Minimum Storage Volume (Gallons)*
3	55	40	40
4	70	40	66
5	85	52	80
6+	100+	52	80
*For Integral Collector Storage (ICS) and Thermosiphon systems, the tank size includes both the solar and auxiliary storage volumes. The initial gallons per day consumption levels were based on those outlined in the "FSEC Simplified Sizing Procedure for Solar Domestic Hot Water Systems." (FSEC-GP-10-83, Revised April 1992)			

All solar domestic water heating systems installed under SWAP were approved by the Florida Solar Energy Center (FSEC), per guidelines outlined in the FSEC document "Florida Standard Practice for Design and Installation of Solar Domestic Water and Pool Heating Systems," (FSEC-GP-7-80) and "Operation of the Florida Standards Program for Solar Domestic Water and Pool Heating Systems," FSEC-GP-8-80, January 1985).

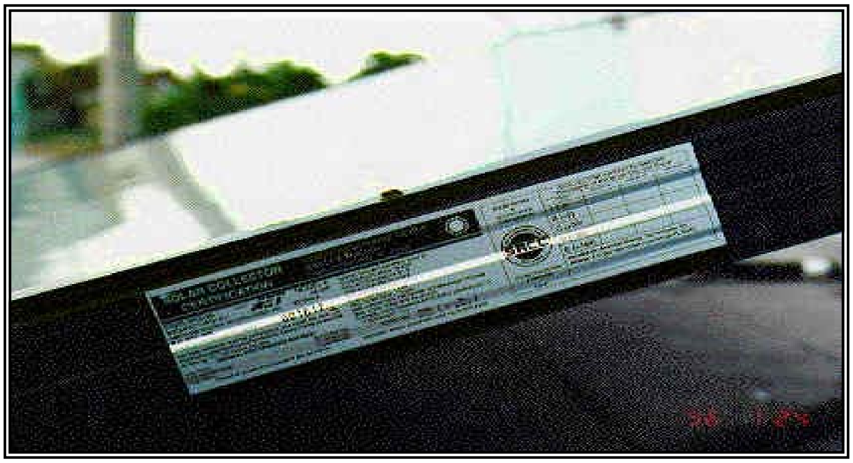


Figure 1.5-1. FSEC collector certification label.

1.6 SYSTEM INSTALLATION REQUIREMENTS

Additional SWAP program system criteria not previously listed in FSEC-GP-7-80, January 1985, were also required for system installations. These included the following:

1. Installed collectors had to be oriented within 45^0 west or east of due south and mounted at an angle plus or minus 15^0 from local latitude.

2. Except when required by system design or constrained by safety considerations, water heaters were to have a minimum insulation rating of R-12. An exterior insulation blanket could also be used to satisfy this requirement.

3. Insulation rated at R-2.4 or greater was to be installed on all interconnecting hot and cold water piping installed in attics, unconditioned garages other unconditioned indoor spaces, as well as all conditioned spaces.

4. Contractors submitting integral collector storage (ICS) systems for use in central and North Florida had to submit collector feed and return pipe size information and the type and thickness of the pipe insulation. This information was used to determine the freeze prevention capabilities of the ICS system and its external piping components.

5. Temperature control of the potable water used by the clients was of concern due to the installation of systems in residences where there were unsupervised young children and/or elderly clients that could get scalded if faucet temperatures were not adjusted correctly. Due to this, it was determined that anti-scald valves had to be used in residences where active systems were installed. The scald preventative valve provided a means of limiting the temperature of the hot water at the fixtures to a selectable temperature. It was also stipulated that the Scald preventative valves used must meet A.S.S.E. Standard 1017, *Temperature Actuated Mixing Valves for Primary Domestic Use*. The major intent of this criterion was for active pumped systems. However, some of the ICS installers also used this valve.

Specific installation requirements followed the criteria set forth in Chapter VII of the FSEC document "Florida Standard Practice for Design and Installation of Solar Domestic Water and Pool Heating Systems" (FSEC-GP-7-80). The installation requirements were also detailed in FSEC's solar system inspection checklist forms provided in the SWAP Training Manual. (See Appendix 1.)

1.7 INSTALLATION CONTRACTOR QUALIFICATIONS

Requirements were also established for SWAP program participating solar installers. The following guidelines had to be met before a solar installer was allowed to install systems under the SWAP program.

1. License: Contractors had to be Florida licensed contractors, in accordance with Chapter 489 Part I, Florida Statutes. Contractors' license was to be in a category that was authorized to install residential solar water heating systems.

2. Experience: Installers had to demonstrate capabilities to install residential solar water heating systems. Past experience was critical in meeting this requirement.

3. Place of Business: Installers were required to provide continuous post-installation service to the areas in which they installed SWAP solar water heating systems. Initial requirements stated that the solar vendor had to be within a 100 mile radius of the installation sites. This was changed to accommodate the installers and installations in North Florida that exceeded the 100-mile radius.

4. State and Local Codes and Ordinances: Contractors had to comply with all applicable state and local codes and ordinances. Appropriate city or county building permits to be obtained for each system installation.

Warranty requirements for the installation and the installed equipment was also established. The requirements were as follows:

1. Collector :
   The Contractor was required to provide a full ten (10) year written warranty on the collector. The warranty covered the full costs of field inspection, parts and labor required to remedy the defects, including, if necessary, replacement at the site.

The warranty did not cover defects of any kind resulting from exposure to harmful materials, fire, flood, lightning, hurricane, tornado, hailstorm, windstorm, earthquake or other acts of nature, vandalism, explosions, harmful chemicals, acidic or caustic water, other fluids, fumes or vapors, operation of the collector under excessive flow rates, misuse, abuse, negligence, accident, alteration, falling objects or any other causes beyond the control of the Contractor.

2. Systems:
The Contractor had to provide a full one (1) year warranty on the system. The warranty covered failure of the installed solar system, including any component or assembly where such failure was caused by a defect in materials, manufacture, or installation.

The warranty also covered damage resulting from freeze and over-temperature. This included the full cost of all parts, labor, shipping and handling necessary to remedy the defect, including, and if necessary, replacement at the site.

In those installations in which the SWH systems were retrofitted to the existing conventional electric water heater and the existing water heater failed due to normal circumstances during the one (1) year warranty period, the system warranty excluded the replacement of the water tank.

The system warranty did not cover defects of any kind resulting from exposure to harmful materials, fire, flood, lightning, hurricane, tornado, hailstorm, windstorm, earthquake or other acts of nature, vandalism, explosions, harmful chemicals, acidic or caustic water, other fluids, fumes or vapors, operation of the collector under excessive flow rates, misuse, abuse, negligence, accident, alteration, falling objects or any other causes beyond the control of the Contractor.

The system warranty was effective at the date of installation.

The fulfillment of the warranty was the responsibility of the installation contractor.

3. Contractor Identification:
The Contractor's name, address and phone number had to conspicuously appear on all warranties.

A formal application packet was provided to any solar installer interested in becoming a SWAP authorized installer. The application documentation was completed by the vendor and returned for review and acceptance by DCA/FSEC. The following list outlines the documents in the packet and those required from the applicants.

1. Form 1 - Contractor Profile and License
2. Form 2 - Solar System Application
3. FSEC "Approved Solar Energy System" Form with SWAP system selected components marked
4. Anti-scald valve specification documentation
5. System and collector warranties
6. Copy of the collector and system warranties that will be given to clients
7. Solar system Homeowner's Manual and Freeze Information Label
8. Copy of the System Homeowner's Manual and Freeze Information Label for each system submitted

FSEC and DCA published a listing of SWAP participating solar installers and disseminated that list to all SWAP agencies. During the initial phases of the program, FSEC assisted the local WAP agencies in developing their bid requirements for local installers. Many agencies used the bid forms developed by

FSEC and listed in the SWAP Training Manual in Appendix 1. Other agencies used procedures they had developed as part of the standard WAP program. Nevertheless, FSEC initially assisted all agencies in identifying and selecting both the installers and the system types to be installed in the specific WAP geographical areas.

1.8 PROGRAM IMPLEMENTATION - TRAINING

FSEC provided local WAP agencies an in-depth solar program that emphasized both in-house lecture and hands-on field solar training. FSEC Training included field activities that were repeated during numerous sessions in order to ensure that all parties participating with this program were familiar and confident with site and solar system inspections. (See training presentation in Appendix 2.)

Figure 1.8-1. FSEC staff providing system inspection training for local staff. Lesson learned here - photovoltaic module (on lower right corner of flat-plate collector) is not to be affixed to the face of the flat-plate collector.

A SWAP Solar Manual was developed to provide training guidance and program implementation assistance to all participating agencies. This manual included an overview of solar water heating principles and basic information, as well as detailed site and system inspection instructions and the use of system inspection forms. The manual was intended as a reference guide for local SWAP participating agencies throughout the course of the SWAP program. A copy of the manual is included in Appendix 1.

Figure 1.8-2. Shawn Angell of the Metro-Dade Community Action Agency checking a collector sensor.

1.9 LOCAL PROGRAM IMPLEMENTATION

Implementation of the program was conducted through local Florida Weatherization Agencies. DCA provided grants to local Weatherization Assistance Programs and other non-profit agencies to operate the program while SWAP-certified solar contractors provided installations.

The initial SWAP agencies were selected by DCA based on the selected agency's previous weatherization performance records, their enthusiasm in adopting and working with new technologies, and of course, their willingness to participate in this novel solar energy pilot project.

Selection was also based on geographical location. Since the majority of low-income population in Florida was determined to be in Central and South Florida, with a smaller amount in North Florida, the agencies were selected accordingly. The total number of system installations was also guided by this criterion. The majority of systems were installed in Central and South Florida.

1.10 SITE SELECTION CRITERIA

Income qualification criteria followed that established by the standard Weatherization Assistance Program. Technical criteria were developed by FSEC for the local agencies to select SWAP participating residences:

1. The residence had to be located in one of the selected counties in the three climate zones in Florida as defined by Florida WAP and the Florida Energy Code.

2. At least three people had to be living in the residence. The occupants had to meet WAP program income requirements. Recently completed weatherized housing was acceptable for inclusion in the monitoring program.

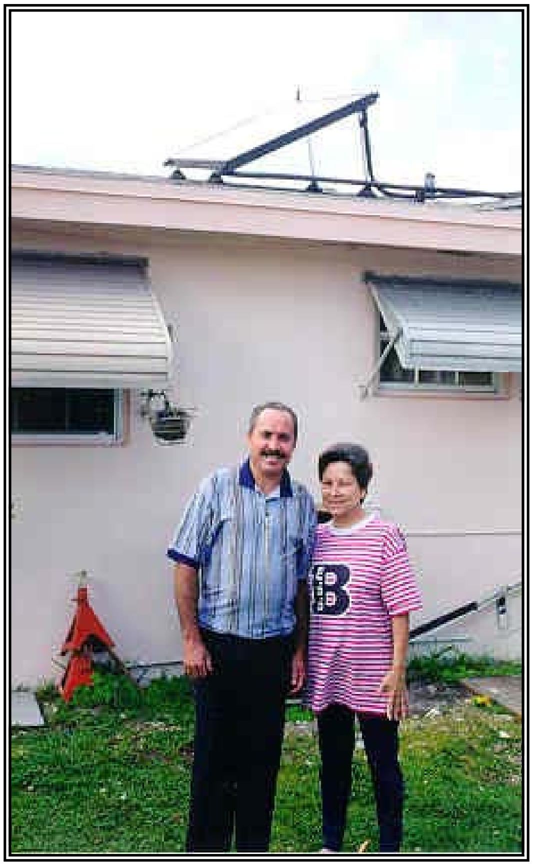


Figure 1.10-1. South Florida system installation at the Matos' residence. The solar system serves both Mr. and Mrs. Matos', as well as their two children. In the summer, they have learned to keep the water heater electricity off and allow the solar system to heat all the water.

Solar access had to be suitable to provide uninterrupted winter and summer season solar radiation at the potential collector mounting location between approximately 9 AM and 4 PM. There was to be no shading from trees, bushes, and fences (if the collector was ground mounted), etc., on the collector during this time period.

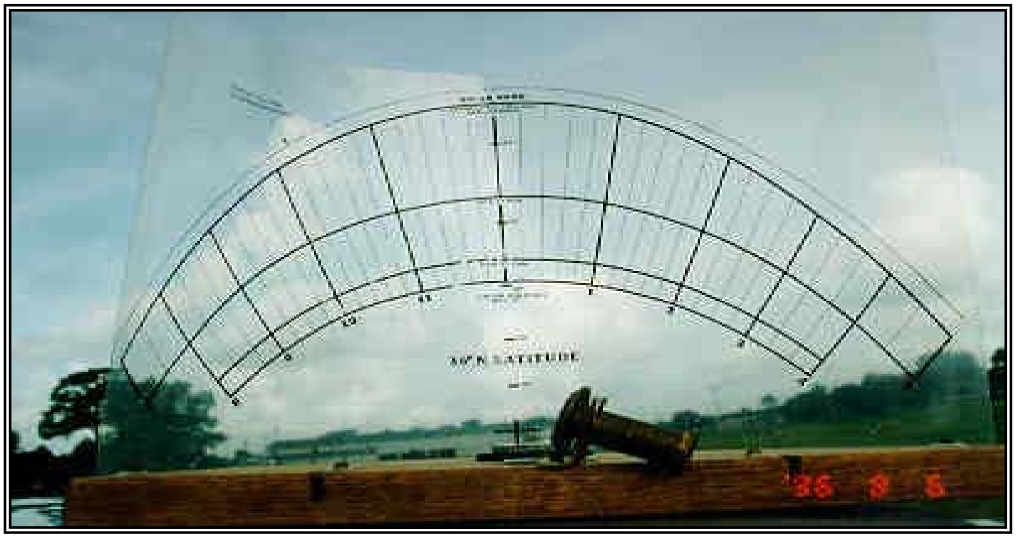


Figure 1.10-2. Solar site locator indicating that shade will not be a problem at this site.

4. In accordance with WAP requirements, the residence had to be a single-family detached structure. Mobile homes were not allowed due to WAP requirements.

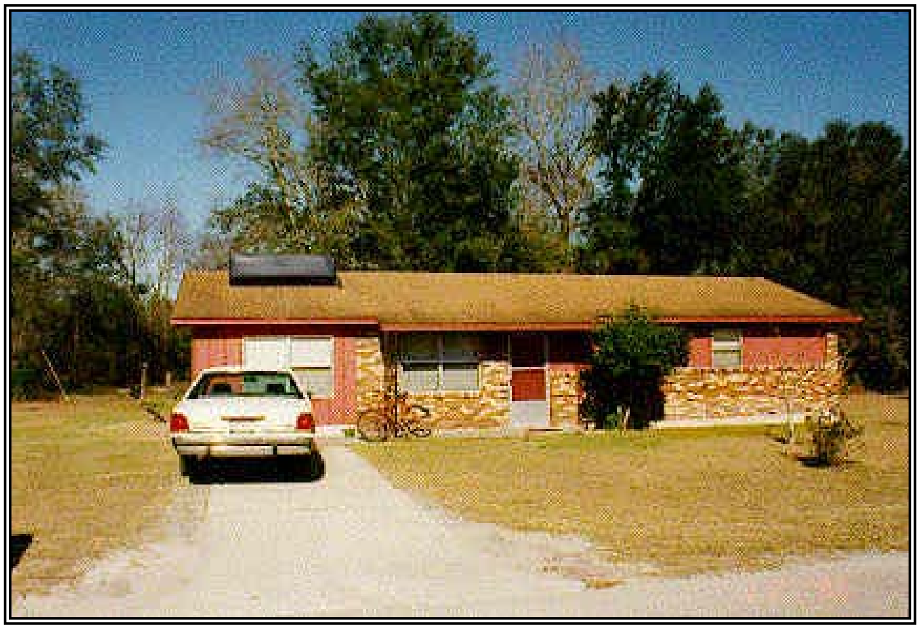


Figure 1.10-3. ICS on single-family detached residence.

5. The occupants' potable water had to initially be heated with electricity. This is the most common type of water heating system in Florida, so it is more representative of the majority of the population.

6. The house was to be owner-occupied.

7. The house and collector mounting location had to be such that the probability of vandalism to the solar collector was low

3.0 SWAP PROGRAM EVALUATION

In order to quantify the value of the SWAP program, four separate methods were implemented to assess measured energy savings, quality of system installation and operation, and general perceptions of the users of solar domestic hot water (SDHW) systems. This collected information is intended for the following applications:

- As the basis for the implementation of this pilot program as a standard weatherization option (Department of Energy, 1993).
- To study the water usage characteristics of low-income owner-occupied housing.
- To evaluate the short-term reliability of solar water heating systems, and to collect data for future long-term reliability evaluation.
- As a study on the perceptions of the operation of SDHW systems.

Two methods were used to evaluate energy savings from the SDHW systems: "Hard Monitoring" and "Soft Monitoring." The hard monitoring method consists of a detailed monitoring of 35 systems for two years (pre and post solar), while the soft monitoring consists of the analysis of two years worth of utility bills for 275 households. The soft monitoring was performed in order to verify if the measured energy savings from the hard monitoring could be evaluated through the statistical analysis of household utility bills (which are sensitive to weather and many other things, including the solar system). The advantage of the soft monitoring is that it does not require the use of any additional monitoring equipment.

Two methods were used to evaluate the quality of installation and operation: inspections and surveys. Over 25% of the sites were inspected by FSEC staff after the installation of the SDHW system to ensure quality of installation and to field verify components used in the installation process. The surveys were mailed to all SWAP clients. Approximately 1/3 of the surveys were returned. Although the primary intent of the surveys was to gain information about the occupants and their perceptions about SDHW, there were also indications of installation issues as well.

3.1 SITE SELECTION CRITERIA FOR INSTRUMENTED AND SOFT MONITORING

In addition to the requirements for the solar weatherization sites, five additional requirements were imposed for the hard and soft monitoring sites in order to ensure that the data collected before and after the solar installation was as consistent as possible:

The occupants must not have been planning an extended (greater than two weeks) stay away from their house during the monitoring period. A decrease in energy consumption during such a period might be erroneously attributed to conservation rather than lack of occupancy. Likewise an anticipated increase in occupants was also not anticipated during this monitoring period.

During the two year SWAP monitoring period, the house must not have been scheduled to receive housing modifications under any other weatherization or housing rehabilitation program. This was to help ensure that the only change made to the house during the monitoring period was the installation of a solar system. This was done to ensure consistency in the house energy use characteristics for utility bill analysis.

A required site inspection of the residence was conducted by FSEC staff prior to selection to ensure that the residence was suitable for the hard monitoring phase (this was not performed for all soft monitoring). Upon completion of the solar system installation, FSEC staff conducted an inspection to determine that the solar system was installed properly and that both the system and the monitoring equipment were functioning correctly. Installation and operation deficiencies were corrected before formal solar system monitoring for phase two (post solar) was initiated.

Selected homeowners were required to sign an agreement form stating that they were willing to participate in the SWAP monitoring program (for soft and/or hard) and authorizing FSEC to obtain past and present utility bills. This agreement also provides FSEC and solar installers permission to access the site as required for monitoring (hard monitoring only), installation, and maintenance purposes. All hard monitoring sites were also incorporated into the soft-monitoring program so that monitored and predicted savings could be compared.

The monitored sites were selected so that the regional (North, Central, and South) number and system type were roughly proportional to the number and type of installed systems.

Although efforts were made to enforce these additional requirements to maintain a high quality of measured data, feedback from the homeowners indicated that in some cases, these rules were not maintained. One of these (discussed in the soft monitoring section) is that some WAP measures besides solar were implemented in these homes during the two year moratorium on these modifications, possibly affecting the quality of the soft monitoring data.

3.2 OVERVIEW OF COLLECTED DATA

A variety of data were collected in order to satisfy the requirements of the program evaluation.

Table 3.2-1 summarizes the types of data which were collected, the way in which each type was collected, and the phase(s) during which each was collected.

Table 3.2-1. Summary of Collected Data

Data Type	Phase One (Pre Solar)	Phase Two (Post Solar)
Total electric use	Electric bills	Electric bills
Occupancy	Surveys	Surveys
Solar system reliability	N/A	Site inspections, surveys
Hot water system operation	Monitored data	Monitored data, site inspections, surveys
Owner satisfaction	N/A	Surveys
Operation and maintenance	N/A	Surveys, site inspections
Local temperature (at location of water heater)	Monitored data	N/A
Pump and controller power measurements	N/A	Site measurement
Regional weather data	Local meteorological station	Local meteorological Station

Information was gathered through system inspections and surveys pertaining to system operation, owner satisfaction, repair requirements, failure rates and frequency, types of failures, criticality of failures, and general degradation of components. Survey data was used to document the number of occupants and their impacts on energy use, specifically for water heating. All of the survey and inspection data were summarized and incorporated into a database for analysis and future retrieval.

A separate database (in-house format) was used to store and analyze monitored data. The local meteorological data and utility billing data were stored in ASCII files used for analyzing this data.

4.0 HARD MONITORING

The primary purpose of the SWAP monitoring project was to determine the energy savings and cost effectiveness of low-cost solar water heating systems in low-income homes in Florida. This will determine the feasibility of incorporating solar water heating systems as a WAP program weatherization measure. Ancillary SWAP monitoring program purposes and issues also addressed include:

1. Determining the savings-to-investment ratio (SIR)
2. Evaluating the reliability of SWAP installed low-cost solar water heating systems
3. Comparing hot water usage and associated energy costs before and after solar system installations
4. Determining low-income hot water usage profiles

The purpose of this monitoring project was not to once again ask if solar water heating works, but instead to ask if it is cost effective for the WAP program and low-income families. With this in mind, the monitoring program was developed by FSEC in an attempt to provide statistically significant data necessary to answer this question while keeping costs of monitoring to a minimum.

The hard monitoring phase of the SWAP program was intended to provide quantitative evidence regarding the performance of a representative sample of installed SDHW systems. The results from this phase of the work indicate the viability of the systems both in terms of thermodynamic performance as defined by Coefficient of Performance (COP) and economic savings for the US Weatherization Program's National Energy Audit (NEAT) procedure as defined by the SIR (Gettings, 1990). Additional information, including water usage profiles, average water temperatures and monitoring-related issues have also been gleaned from the data.

A total of 35 systems were selected for the hard monitoring phase. Sample size was kept small to minimize costs. A sample size of thirty was considered to be sufficient for the purposes of this study. Therefore, a sample size of thirty-five was chosen to allow for unforeseen circumstances which could result in the elimination of test houses. Selection was based on the first thirty-five houses that met the criteria set forth previously. Two of the sites (#2 and #30) were dropped from all analysis due to unanticipated ownership changes. A third site (#10) was also dropped due to a fire that caused the house to be vacated during 6 summer months of the post solar monitoring period. A total of 32 sites were used for the overall hard monitoring analysis. As explained later, some of these 32 sites were not included with some of the comparisons (e.g., F-Chart) due to lesser problems that did not preclude them from the overall analysis.

Each test house was located in one of the three climate zones. While the North was represented in the total sample, the distribution of test houses was more consistent with population demographics. Specifically, the majority of the test houses were in Central and South Florida. Local WAP agencies in each of these regions were identified to assist in selection of these houses.

Southern Florida was represented by Dade County. Mid-Florida (Hernando County) and Citrus County represented Central Florida. Suwannee and its surrounding counties represented Northern Florida. (See Florida Map in Appendix 4.)

Because water usage and weather vary throughout the year and the efficiency of the solar system is a function of both the load and weather, a period of one year after the solar installation was selected as the second monitoring period. In this way typical annual extremes of load and weather would be accounted for. Although the existing electric auxiliary tanks are less sensitive to weather changes than the solar systems are, a period of one year was also selected for the pre-solar installation. This method, although considerably time consuming, gives the most credible indication of savings, assuming that the household has consistent water usage patterns.

4.1 HARD MONITORING: INSTRUMENTATION

The instrumentation for this project was designed to yield adequate information for calculating the COP, SIR of the SDHW systems and the water usage patterns of the households. To accomplish this, a moderate amount of hourly (or better) data is required, as indicated in DOE's Single-Family Building Retrofit Performance Monitoring Protocol (Ternes, 1987). Other information was also extracted in this process.

In order to calculate hot water energy delivery, the following measurements are required: inlet temperature, outlet temperature, and flow rate. To calculate efficiency of the existing electrical tank, the electrical energy input is also required. Additional information acquired during the pre-solar phase included the environmental temperature at the tank and the horizontal radiation gathered on the roof. Because the radiation value was only to be used for diagnostic purposes and the installed angle of the solar collector was not known at the time of sensor placement, a horizontal measurement was used.

During the post-solar phase, the collector feed and collector return temperatures were added and the ambient temperature was removed (due to lack of additional channel space on the datalogger). These two quantities, along with the solar radiation were used primarily to identify and resolve problems with the systems. For some of the active systems, these values were also used for predicting pump and electric valve operational times. Because no real-time pump and valve power were measured, a one-time site visit was made to measure the wattage of the pump and electric valve in all of the systems employing pumps and electric valves. Table 4.1-1 indicates the type of instrumentation used for the systems. Appendix 5 contains the specification for the instrumentation. Table 4.1-2 indicates the site-measured values for the pump/valves. Notice that sites #22 and #29 had significantly higher measured power consumption (for controller, pump, and electric valve) than did the other sites with similar equipment. Since the piping runs and equipment are similar, it is unclear why these values differ.

Table 4.1-1. Instrumentation

Measured Quantity	Device Type	Accuracy	Manufacturer and Model
Temperature	Thermocouple (Type T)	+/- 1.5 ° F	Any Copper-Constantan
Flow Rate	Positive Displacement Flow Meter	+/- 1.5 %	Kent Meters Model C-700
Electrical Energy	Watt-hour Meter	+/- 2 %	Hialeah Meter Model D4S
Radiation	Semiconductor-Based Pyranometer	+/- 5 %	Licor LI-200SB
Pump/Valve Electrical Power	Digital Power Analyzer	+/- 0.25% +/-6 counts	Valhalla Scientific Model 2101

Table 4.1-2. Measured Pump/Electric Valve Wattages

Site Number	Collector Pipe Run (Feet)	Pump	Controller	Electric Valve	Measured Wattage
22	17	Grundfos UP-15-18 B5	Goldline GL-30-LCO	Erie 5/8 SWT MOPD	89
24	14	Grundfos UP-15-10 B5	Goldline GL-30-LCO	Honeywell V4043A	43
25	17	Grundfos UP-15-18 SU	Goldline GL-30-LCO	Erie 5/8 SWT MOPD	56
26	18	March 809-2	Intermatic Timer	N/A	26
28	20	Laing SM 3CB BSW	Heliotrope Delta T	N/A	43
29	23	Grundfos UP-15-18 B5	Goldline GL-30-LCO	Erie 5/8 SWT MOPD	85

31	18	March 809-2	Intermatic Timer	N/A	27
32	20	Grundfos UP-15-18 B5	Goldline GL-30-LCO	Erie 5/8 SWT MOPD	56
33	24	Grundfos UP-15-18 B5	Goldline GL-30-LCO	Erie 5/8 SWT MOPD	57
35	36	Grundfos UP-15-18 SU	Goldline GL-30-LCO	Erie 5/8 SWT MOPD	57

Placement of the instrumentation is critical to the proper understanding of the systems' performance. The ideal placement of the sensors is indicated in Fgure 4.1-1. The placement of the inlet sensor (cold water) was the most difficult to make due to limited access. Due to conductive effects and unanticipated in-line thermosiphoning, it was necessary to relocate this sensor at several sites and adjust the data acquisition program accordingly. The other temperature sensors would also be affected by the same effects, although the collector feed and return could usually be located further from the tank and conduction in the hot water usually improved response time, as opposed to reducing it for the cold inlet.

Error! No topic specified. Figure 4.1-1. Placement of Instrumentation for Hard Monitoring – Timer System

The placement of the flow meter was made in the cold inlet directly before the tank for two reasons: the flow meter is not designed for temperatures in excess of 120° F, and the desired flow was into the tank, not into the system. In all installations, the flow meter was further protected by the use of a heat trap in the cold water piping. Because many of the SDHW systems use an anti-scald valve, the cold flow rate before the "T" to the valve may be higher than the flow through the tank. The tank flow was used to isolate the mixing valve effects from the measurements; however, this method necessitated the addition of a check valve before the anti-scald valve in the cold water line to eliminate the thermosiphoning in this loop that sometimes resulted.

4.2 HARD MONITORING: DATA COLLECTION

Because all of the sites are located at some distant from FSEC, a datalogger with remote data transfer capability was required. Additionally, the instrumentation outputs and a desire for data storage were initial considerations in choosing the data acquisition system (DAS). A Campbell CR10 datalogger was selected because of its reliability and capability to be easily used in remote applications. The DAS box consists of the datalogger, modem, battery, electrical connection, and phone connection. A diagram of the DAS box is included in Appendix 6. The datalogger has ample storage and battery capacity to operate without losing data for at least a week when no power or phone line connection is available. A separate phone line was installed at each site so that the data could be uploaded to the FSEC VAX computer system on a daily basis without the need for periodic visits.

Software developed at FSEC was used to poll each site on a daily basis to retrieve, store, and process the data. A co-current program, SWAPA, was developed to analyze the data from the sites on a daily basis. For each site, the program lists Inlet Temperature (CW), Outlet Temperature (HW), Feed Temperature (FD), Return Temperature (RT), Radiation (SOL), Total Flow (FLOW), Calculated Energy Delivered (Btu), Measured Input Energy to Tank (kWh), and Calculated COP. A status variable by each measurement is used to flag any problems. "O" =ok, "-" = Low, and "+" = High. Missing or calculations that can't be performed are flagged as 999.99. Table 4.2-1 indicates the bounds for flagging the data.

Table 4.2-1. Flagging of Data for Daily Quality Check

Quantity	Adjustments	Low ("-")	Okay ("0")	High ("+")
Cold Water Temp.	Average for flows > 1 gallon / 15 minutes	< 50° F	50-90° F	> 90° F
Hot Water Temp.	Average for flows > 1 gallon / 15 minutes	< 80° F	80-130° F	> 130° F
Feed and Return Temps. (Active	Average for flows > 1 gallon / 15 minutes	Return< Feed	Feed>= Return	N/A

Solar Systems)				
Feed and Return Temps. (Passive Solar Systems)	Average from 8 AM to 5 PM	Return< Feed	0°F< (Return-Feed) < 20° F	(Return-Feed)> 20° F
Flow	Sum all day	< 10 Gal.	10-150 Gal.	>150 Gal.
kWh (Element)	Sum all day	N/A	All others	KWh>15 kWh or kWh/Flow> 0.1
COP	Calculated (Sum Btu/ Sum kWh)	0.8	0.8-10.0	>10.0

Although many data errors were caught using the status variables indicated by this program, others were not clearly detected by daily calculations. Consequently, visual graphs of all system outputs on a site-by-site basis were also plotted on a daily basis to catch other problems. A sample of these graphs and the output of the daily quality check program are provided in Appendix 7.

4.3 HARD MONITORING: PROBLEMS WITH DATA COLLECTION

Although every effort was made to ensure the highest quality of collected data, there were several cases where the data was corrupted and/or problems with the system occurred. These discrepancies had to be cleaned up before the final analysis could be performed. The first step was the identification of problems in either the DAS or in the water heating system. As indicated in the previous section, this occurred on a daily basis. A log sheet was maintained for each site to track problems. Appendix 8 contains these log sheets for all sites.

Upon identification of problems, appropriate steps were taken to remedy problems. In many cases, the problems were obvious and the solution was clearly enacted; however, in some cases, the solution proved elusive, and the true cause of the problem was never really determined. Table 4.3-1 indicates some of the more significant monitoring related events that occurred.

Table 4.3-1.Significant Monitoring Related Events

Event	Affected (%)	System Type Affected	How Resolved
Major kitchen fire.	6	All	Data excluded, 1 site dropped.
Unanticipated occupancy changes.	20	All	Occupancy was adjusted, 2 sites dropped.
Temporary air entrainment in ICS systems at startup caused false flow indications.	80	ICS	Data excluded for the first 1-3 weeks of solar operation. The only effect upon the system operation is some initial turbidity in the delivered hot water.
Short circuiting of water through anti-scald valve.	67	All active 50% of ICS	Water mains temperatures from pre-solar operation used as required. Check valve installed to prevent this. The original system design did not include this feature.
Bottom feed/return on tanks crimped.	25	Timer controlled	Data excluded and bottom feed/return was replaced. Problem was due to poor installation.
Systematic loss of thermocouple data.	14	All	Data excluded and additional grounding installed.
Problems with datalogger phone line.	37	All	Phone line repaired.
Power turned off	9	All	Power turned back on.

unintentionally.			
Major household leak (> 4 gal/hour).	23	All	Data excluded and leaks fixed. These problems were not related to the solar system.
Cold water temperature increases with flow due to routing of cold water line through attic/exterior masonry walls, which preheats water.	14	All	No adjustment necessary - this is an actual usage condition that existed prior to monitoring.

Prior to the commencement of the data analysis, the third step of data clean up was performed. All of the bad data from the daily logs were flagged and a sample of the raw data was visually inspected (at times most likely to be bad) such as when monitoring started or the solar system was first installed) to locate any further problems. These bad times for data were used as input for the data analysis step.

4.4 HARD MONITORING: DATA REDUCTION AND ANALYSIS

With the completion of the monitoring phase of the project in April 1998, data had been collected for a period of approximately two and a half years. The final collection period was extended by several months to overcome some of the problems indicated in Table 4.3-1, which resulted in several months of lost data for sites #17, #26, and #31.

Based upon the problems gathered in the daily monitoring phase, the data were cleaned up to eliminate the following type of problems:

Missing data (flagged automatically by FSEC's data reduction software). These data were ignored.
Data that exceeded normal ranges (flagged automatically by FSEC's data reduction software). This would include thermocouple grounding problems. These data were ignored.
Abnormal occupant absence: data ignored.
Abnormal utility cessation: data ignored.
Initial monitoring and/or water heating installation errors: data ignored.
DAS failure and/or sensor failure: data ignored.
Small hot water leaks (< 4 gal/hr): These data were kept, as it was felt that small leaks would not be fixed on a routine basis due to limited funds/capability on the part of the homeowners.
Large hot water leaks (>=4 gal/hr): These data were ignored, as it was felt that that these size leaks would normally be fixed.
Misplaced sensors: data ignored.
Inaccurate cold water sensor: Pre-solar water temperatures used instead.
Dataloggers inadvertently programmed in both standard and daylight savings time: adjusted in software.

With consideration of the listed methods of eliminating some of the bad data, a program, FINAL, was written that interfaced with FSEC's GET V3.0 software. The GET software accesses the database created by the daily polling of the data. The FINAL program processes these data so that the desired output is created and unwanted/bad data are eliminated.

Additional processing of the data was also performed to clean up some of the values and to generate calculations not explicitly measured. Because of problems with mixing valves and the resulting unanticipated thermosiphoning, all of the active systems that had problems with cold water temperatures used averaged data from the pre solar operation for the time period preceding the addition of the check valve. Additionally, because most of the systems exhibited some problems (due to conduction from tank) with the cold water temperatures, an algorithm was incorporated that uses the most recent cold water temperature that occurred during flows of 1 gallon or more per fifteen minutes.

Although the measured flow temperature was used for energy calculations, the calculation of load profiles was complicated by the presence of the anti-scald valve. The anti-scald valve was assumed to be an ideal mixing valve set at approximately 122° F, which allowed for the determination of the total hot water load that was delivered to the household. This value was only used for the determination of water usage profiles and reporting of average water usage.

Because the DAS did not measure power use of the controller, electric valve (used in place of a manual check valve), and pump, the one time measurements were used, along with an algorithm to predict 15 minute energy usage. For passive systems, this number was equal to zero. For timer systems, this value was a fixed value for 9 hours per day, which was consistent with the settings. For the differential controlled active systems, the algorithm looked for several things to determine if the collector pump was operational (when off, the power draw was assumed to be 1.6 W):

> Can only operate from 7 AM to 8 PM.
> Return temperature-Feed temperature> 0.5.
>
> The change in feed temperature/time is > 6° F/hour and the change in feed temperature/time is > 6° F/hour if the pump is off.
> The change in feed temperature/time is > 2° F/hour and the change in feed temperature/time is 2° F/hour if the pump is on and flow =0 or flow>0.

Although an attempt was made to validate this algorithm by the use of a clip-on datalogger, it yielded no useful data. Comparison of this algorithm and visual temperature data yielded good agreement.

From the raw data, the FINAL program calculates several quantities that are used for further analysis. Calculation of energy delivered to the load is by the standard formula:

$$\text{Q Delivered} = M * C_p * (\text{T out} - \text{Tin})$$

Where Q Delivered is the water-heating load, M is the mass flow rate, Cp is the heat capacity of the water and Tout and Tin are the outlet and inlet temperatures of the storage tank. The figure-of-merit for solar water heating systems, like many other appliances is the COP:

$$\text{COP} = \frac{\text{Q Delivered}}{\text{Q Aux} + \text{Q Parasitic}}$$

Where Q Aux is the energy used by the electric element and Q Parasitic is the energy used to power the pumps, controllers and valves of the solar system. For passive and photovoltaic-pumped solar systems and all of the systems prior to the addition of the solar component, Q Parasitic = 0.

This program was used for the calculation of several quantities for both a monthly and time of operation basis. Appendix 9 includes a monthly summary of all systems during both the pre- and post-solar installation periods. The data in this appendix was used for monthly comparisons and for the comparison with F-Chart. The following list summarizes the information presented in the first page of each monthly table:

> Site: Site number
> Cold (F): Average cold water temperature.
> Hot (F): Average hot water temperature.
> Flow (Gal): Total flow.

Aflow (Gal): Adjusted flow (includes anti-scald valve flows).
Load (MMBTU): Water heating load.
Elem (MMBTU): Q Aux – Auxiliary energy used by electric element.
Par (MMBTU): Q Par – Calculated energy used by pumps, controllers, and electric valves.
Rad (kBTU/sf): Average amount of solar radiation per horizontal surface area.
COP: Coefficient of Performance
Eff (%): A rough measure of solar radiation converted to hot water energy. Used for diagnostic purposes only. This value is zero except during months in which solar was installed at the start of the month.
BTU/GAL-DT: A calculation determined by dividing load by flow and the difference between hot and cold.
Good %: Indicates percent of hours in month that data were good. The basis for 100% may be less than the number of hours in the month if the system monitoring was completed during the month.
Good (hr): Number of good hours. This excludes flagged, missing, bad and excluded data.

Note that missing data and/or invalid calculations are flagged with 999.99.

Appendix 10 contains a different summary of these data for each site. Each site has two listings, a pre solar listing and a post-solar listing. A spreadsheet was created from the data in Appendix 10 to create the overall evaluation of the program. The following calculations for SIR and Solar Fraction were also performed at this stage:

$$\mathrm{SIR} = \frac{\mathrm{Savings} * \sum \dfrac{\mathrm{Fuel\ Cost} * \mathrm{Fuel\ Price\ Index}_{\mathrm{I}}}{(1 + \mathrm{Discount\ Rate})^{\mathrm{I}}}}{\mathrm{Installation\ Cost}}$$

For the SIR calculations, the data in Table 4.4-1 were used. Note that energy costs were based upon an amount that the customer could save. In general, this will be less than the total cost of electricity because the customer charge (fixed) is not included. The current implementation of the SIR for the NEAT program does not include additional maintenance costs. These costs have not been included in the SIR calculation to allow the solar performance to be evaluated on an equal basis with other measures (some of which may also require maintenance). Estimated maintenance cost could well be $150 for each active system every 10 years and $100 for each passive system every 10 years. These average costs would include system service and one component replacement.

Table 4.4-1. SIR Calculation Assumptions

Parameter	Value	Source
Life Time	20 Years	General assumption
Fuel Price Index	Varies from 1.0 in year 1 to 0.93 in year 20	Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis-April 1997 (Fuller 1997)
Energy Savings	Varies by site	Measured SWAP data
Installation Costs	Varies by site	Actual Installation costs
Discount Rate	4.7%	Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis-April 1997 (Fuller 1997)
Fuel Cost	$0.08/kWh	Average of variable user electrical costs (energy, fuel, and taxes) for 94% of the Hard Monitoring sites.

The Solar Fraction (SF) compares the portion of the normalized pre-solar energy with the post-solar energy to deliver the water load and overcome standby losses.

$$\mathrm{SF} = 1 - \frac{\mathrm{Q\ Aux\ Post\ Solar} + \mathrm{Q\ Parasitic}}{\mathrm{Q\ Aux\ Pre\ Solar}}$$

4.5 HARD MONITORING: OVERALL RESULTS

Site-By-Site Calculations for the pre- and post-solar time periods were performed on measured values, energy flows, power demand, and water usage profiles. A spreadsheet was used to calculate and display the summary results from these data. Monthly comparative calculations were made on measured values, energy flows, and water usage profiles. A second spreadsheet was used to calculate and display monthly comparative results from these data.

For measured data, the adjusted values (as indicated previously) were averaged/totaled as appropriate.

For the energy calculations, the data were normalized to an annual time period (monthly for the comparative results) and to the actual number of systems operating. Because the delivered hot water load fell by approximately 7% between the pre- and post- monitoring phases, the energy calculations used to project energy savings and SIR were normalized to the average of the pre-and post- hot water loads. Note that the energy calculations used for the Soft Monitoring and the F-Chart comparison were not adjusted to the average pre and post solar load.

For water profile calculations, the 15-minute water consumption per site were summed together to create an hourly consumption per site. The data from all sites were summed together and binned on an hourly basis. The reported fractional profile was generated by dividing the hourly usage by the total usage for 24 hours.

A Comparative monthly illustration was performed on a subset of the final data to provide an illustrative example of the solar system performance. These calculations were performed one year apart on a monthly basis for all of the systems in operation at the time. The months of October through December were not included because most of the installations occurred during this period and the combination of start-up problems and relatively few number of systems in operation could have skewed the comparison.

Figure 4.5-1. indicates the monthly reduction in energy usage by the solar systems. The energy usage indicates a large energy reduction and illustrates that the water load falls by approximately 1/3 during the summer months.

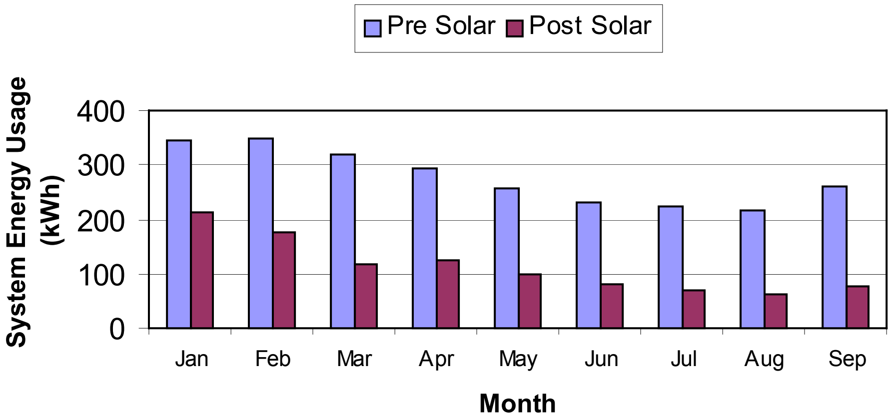


Figure 4.5-1. Monthly Pre and Post Solar Total Measured System Energy Usage

The following graphs and tables indicate annual calculations. Figure 4.5-2. indicates the measured annual water usage profile. In contrast to the "Florida Average" profile (Merrigan 1988), which has a dual peak in the morning and evening, this profile exhibits a relatively flat profile during the day with the main peak at night (rather than in the morning in Merrigan's work). Merrigan's profile is similar to the profile that generally is used for national consumption analysis (Becker and Stogsdill, 1990). What this indicates is that the home is usually occupied during the day with primary usage from 8-10 PM. From an application of solar water heating, this is a very favorable usage pattern, since the bulk of hot water is used soon after it is collected from the solar system.

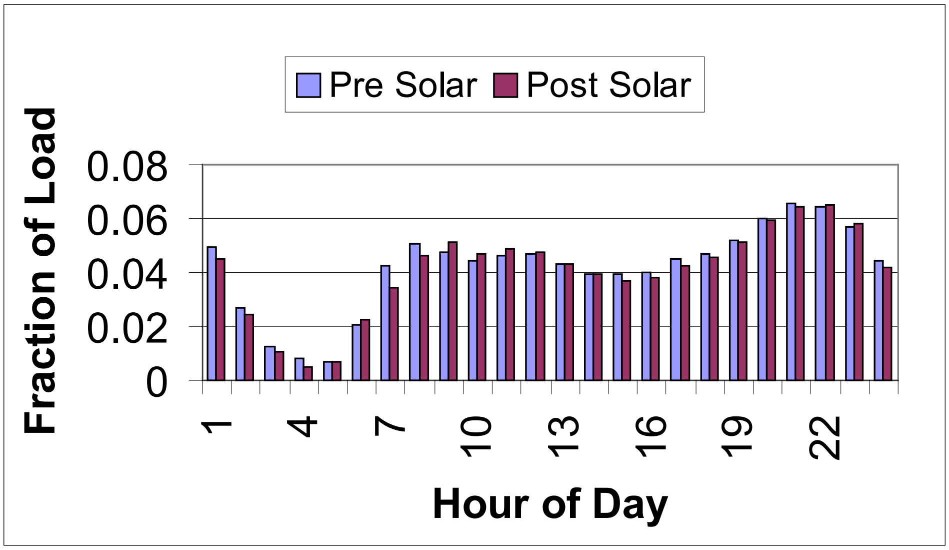


Figure 4.5-2. Annual Measured Water Usage Profile

Figure 4.5-3. indicates the variation in COP by site. One fact of interest is that the COP for the existing tanks is 0.73. Approximately 2/3 of these tanks were new with energy factors of 0.86 or higher. The Energy Factor is the COP under DOE (Federal Register 1990) test conditions of 135° F set point, 64.3 gallons/day, 58° F mains (inlet) temperature, and 67.5° F environmental temperature. Using Florida parameters, the COP would be slightly lower at 0.87. Because the measured values are lower than the required minimum energy factor, it is likely that site factors, including thermosiphoning in plumbing and non-ideal operating conditions (e.g. short draws), could result in a lower values. The post-solar COP does show sensitivity to region and system type. In general, the north (sites 8-14) has lower values than central (1-7 and 15-21), and the south (22-35) has the highest. Note that the southern values are highest for three reasons: warmer climate, active system type, and the use of on/off switches, which dramatically increase COP (in particular sites, 34 & 35).

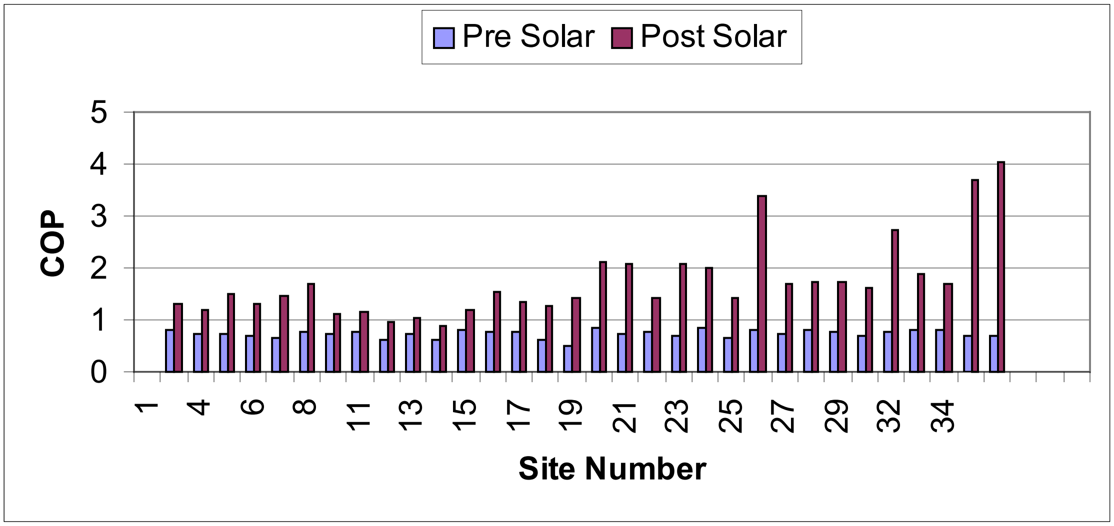


Figure 4.5-3. Pre- and Post-Solar Annual COP

Figure 4.5-4. indicates the pre- and post-energy usage for each site. One important thing to note is that low COPs do not necessarily imply low energy savings (the difference in pre- and post-solar usage). The pre-solar energy usage varies by site because of differences in water usage, set point, and existing water heater. Although these same factors also affect the post-solar energy use (and consequently the savings), other factors including the timing of load, radiation, and system performance are also important.

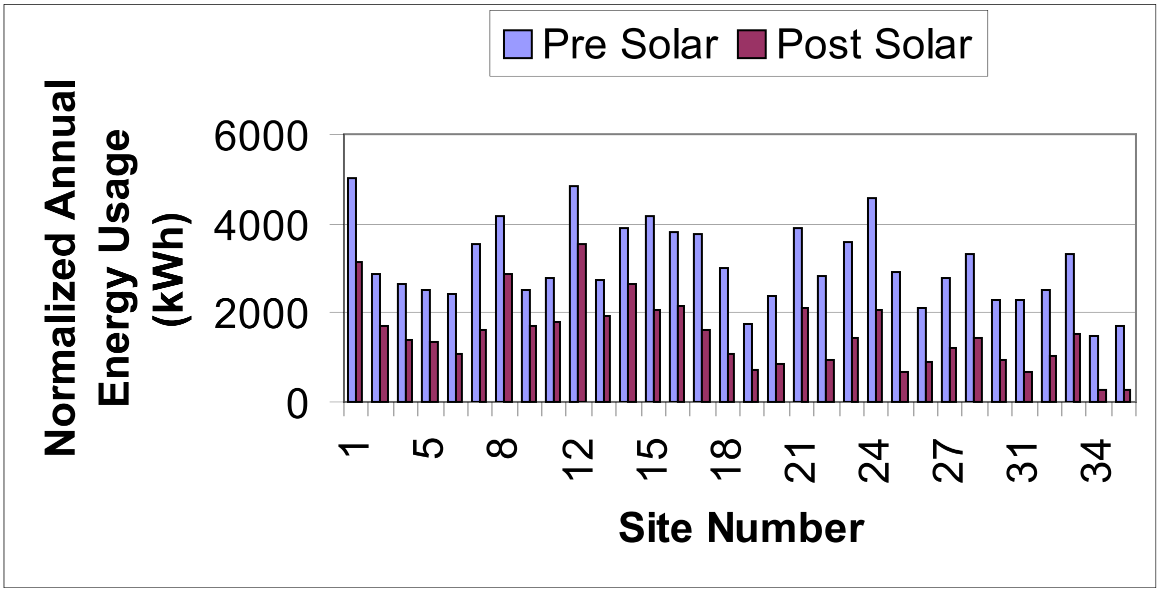


Figure 4.5-4. Pre- and Post -Solar Normalized Annual Energy Usage

One primary goal of this program is to evaluate the SIR of the systems. Figure 4.5-5. indicates the distribution of SIR's for monitored sites, given the assumptions for the SIR calculations. The break-even energy savings (SIR=1.0) is 1,540 kWh/yr (5.25 MBTU/yr) The average measured energy savings is 1600 kWh/yr (5.46 MBTU/yr). The distribution indicates that not all of the monitored systems have SIR's greater than 1.0.

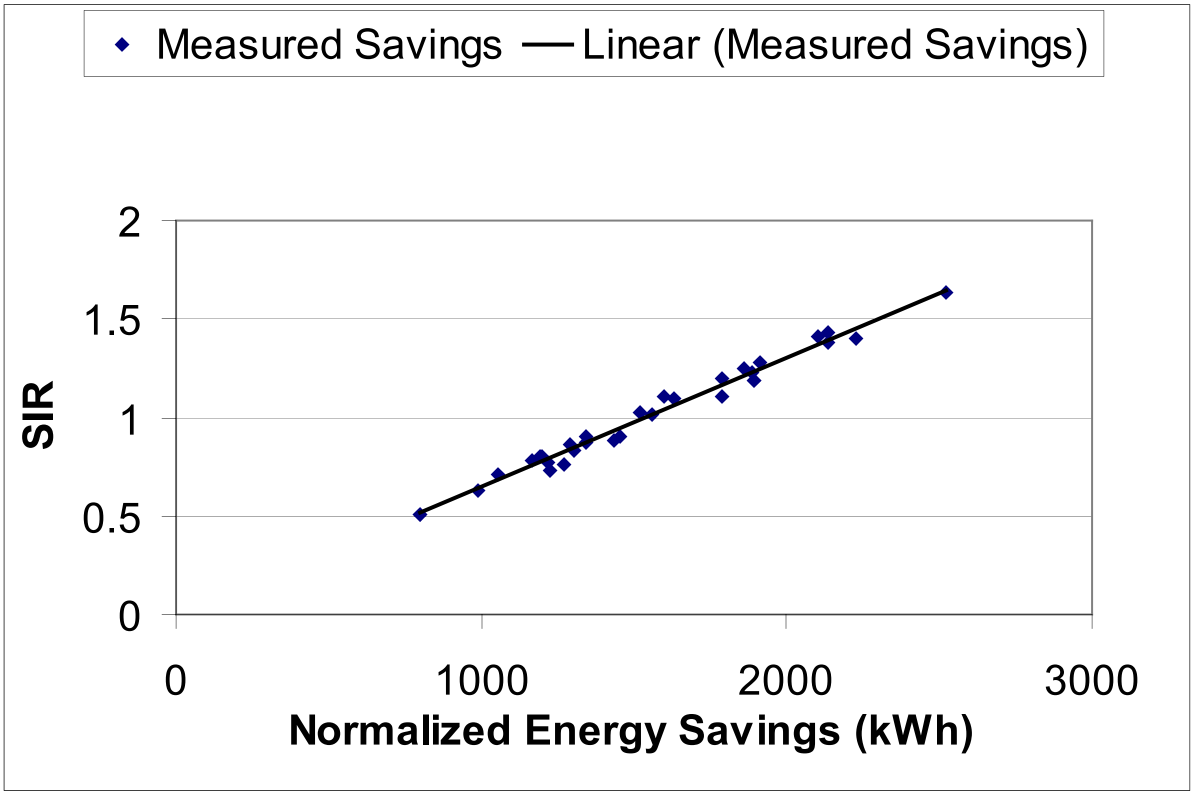


Figure 4.5-5. SIR vs. Normalized Energy Savings

A general summary of the hard monitoring is shown in Table 4.5-1. This table indicates that the two goals of an SIR of 1.0 and of a solar fraction of 0.50 have been met.

Table 4.5-1. General Hard Monitoring Summary

Parameter	Pre-Solar	Post-Solar
Average cold water temperature (° F)	76.7	76.7
Average hot water temperature (° F)	119.4	118.6
Average family size	4.6	4.4
Overall weighted COP	0.73	1.4
Flow/family-day (Gallons)	63.8	62.5
Flow/person-day (Gallons)	13.9	14.2
Average Installed System Cost ($)	N/A	1550
Average measured energy consumption (kWh /system)	3200	1500
Normalized solar fraction	0.0	0.53
Normalized SIR @ $0.08 /kWh	N/A	1.0
Normalized Energy Savings (kWh/year-system)	N/A	1600
Normalized Cost Savings ($/year)	N/A	130

Table 4.5-2 summarizes the individual data for each of the 32 monitored sites. This table is very important because it shows the direct comparison of one year's measured energy and usage data for hot water both before and after the installation of a solar system.

In the table, zone indicates the region of the state (N = north, C = central, S = south) where the system was installed. Type indicates the installed system type (ICS = Integral Collector Storage, A-DC= Active with differential control, and A-TC = Active with timer control). The number of occupants (# Ocp.) was figured as the average number of occupants during the time period. Average temperatures are based upon yearly averages. Flows are the flows delivered to the load (for post-solar, this includes the mixing valve effect). The pre and post energy usage is normalized to one year, but not normalized to average load. The post solar energy usage is broken down into the tank energy (Aux.) and the parasitic (Par.) energy (includes pumps, valves, and controllers for active systems). The Average COP is based upon the overall weighted energy usage (rather than an average of the COPs). The FEF (Florida Energy Factor) is calculated using a standard storage tank Energy Factor of 0.88 in place of the pre-solar COP. The summary values are normalized to the average delivered load. The important results of Table 4.5-2 are:

1. The pre-solar average COP of 0.73 is over 15% less than the standard Energy Factor of 0.88. Approximately 1/6 of the storage tanks were existing tanks.
2. The post-solar average COP of 1.43. The pre-solar COP for this system is implicitly included in this measurement.
3. The post-solar average FEF of 1.76. The standard tank Energy Factor of 0.88 was used for this calculation.

Determining why some sites saved more than others is useful for the future implementation of this type of program. In general, weatherization measures tend to best benefit the sites already using the most energy. This is illustrated for the SWAP sites by Figure 4.5-6. In this figure, the active systems show a better correlation than do the passive systems. Note that the straight-lines shown in Figures 4.5-6 and 4.5-7 are a best linear fit of the experimental data sets. The difference in the correlations is probably caused by two factors: the active systems offset some tank standby losses (and thus are easily correlated with the standby loss portion of the load), and the passive system performance is much more dependent on the profile of usage than are the active systems.

Figure 4.5-7 indicates that SIR does not correlate well with flow for either type of system. The passive fit is worse due to the reasons mentioned previously. Since the interest of this program is to ascertain which sites are best suited for solar weatherization, the sites were re-examined in term of factors that maximize energy savings. By examining the top performing systems (SIR>1.2), it is clear that high flow (given a relatively similar set of conditions and water heater set point) is critical to high savings, and thus high SIR. The average pre-and post flow for these systems (#15, #17, #21, #23, #24, #25, #28) is 80 gallons/day, which is approximately 30% higher than the mean for the group, although the reported occupancy (5) is approximately 10% higher than the mean for the group. Note that the pre-solar COP was identical to the whole group's value of 0.73, indicating that the pre-existing tank was not the significant factor in determining energy savings. Because there was significant scatter in the group, there is no clear cutoff for recommended sites; however, a pre-solar energy usage of 3,100 kWh/year (10.6 MBTU/year) or an average daily flow of 60 gallons/day or higher could be established as a minimum. As with other appliance specific weatherization measures, these values could be extrapolated from short-term monitoring of a given site and adjustment for seasonal usage.

The flow comparison also brings up another issue, the reliability of reported occupancy figures. The number of reported occupants in this group of 7 sites ranged from 3 to 9, indicating that flow, and thus energy savings is not ostensibly linked to occupancy. However, the variation in flow/ per person-day varied by a factor of 3, implying that the occupancy data may not have been too accurate, despite multiple attempts to get this information. Because of this factor, it is not clear that occupancy can be used as a means to select which sites receive this type of weatherization.

Table 4.5-2. Performance and Energy Summary by Site

			Pre Solar						**Post Solar**								**Summary** (Normalized)		
Site #	**Zone**	**Type**	**# Ocp.**	**Cold (F)**	**Hot (F)**	**Daily Flow (Gal.)**	**Aux. Usage (MBTU)**	**COP**	**# Ocp.**	**Cold (F)**	**Hot (F)**	**Daily Flow (Gal.)**	**Aux. Usage (MBTU)**	**Par. Usage (MBTU)**	**COP**	**FEF***	**Energy Saved (MBTU)**	**SIR**	**SF**
1	C	ICS	8	76.0	129.2	86.3	17.11	0.82	8	75.7	123.0	97	10.65	0.00	1.32	1.41	6.46	1.19	0.38
3	C	ICS	5.2	75.3	139.7	39.3	10.76	0.72	3	74.8	133.3	35.8	5.31	0.00	1.19	1.46	3.97	0.78	0.40
4	C	ICS	4	77.5	114.5	63.6	9.39	0.74	4	77.2	118.2	53.3	4.50	0.00	1.49	1.77	4.40	0.87	0.48
5	C	ICS	3	76.9	137.3	32.0	8.61	0.69	3	76.9	131.7	34.9	4.48	0.00	1.30	1.65	4.06	0.80	0.47
6	C	ICS	3	78.0	128.9	35.8	8.71	0.64	3	76.2	122.4	35.4	3.46	0.00	1.45	1.99	4.58	0.90	0.56
7	C	ICS	6	79.7	126.0	58.2	10.52	0.78	6	78.9	130.5	67.4	6.28	0.00	1.68	1.90	6.45	1.19	0.54
8	N	ICS	5	76.5	122.2	86.7	16.16	0.75	5	76.8	116.1	79.6	8.52	0.00	1.11	1.30	4.34	0.76	0.31
9	N	ICS	4	75.1	119.6	54.7	9.55	0.76	4	77.8	123.5	44.9	5.02	0.00	1.15	1.33	2.74	0.51	0.32
11	N	ICS	4	75.4	126.5	44.2	11.03	0.62	3.7	78.1	121.3	40.5	5.18	0.00	0.97	1.37	3.38	0.63	0.36
12	N	ICS	5	69.5	119.6	83.0	17.44	0.73	4	72.1	120.0	81.6	11.40	0.00	1.02	1.22	4.44	0.83	0.27
13	N	ICS	3	72.9	123.4	39.9	9.76	0.62	3	74.5	120.6	42.5	6.22	0.00	0.89	1.26	2.72	0.51	0.29
14	N	ICS	4	74.6	120.3	85.4	14.68	0.81	3.8	73.9	113.5	80.3	8.12	0.00	1.20	1.30	4.18	0.73	0.32
15	C	ICS	6	74.8	121.2	74.3	13.75	0.76	6	76.3	119.6	84.2	7.18	0.00	1.55	1.80	7.18	1.41	0.51
16	C	ICS	6	73.3	116.5	68.2	11.43	0.76	6	74.6	118.2	85.3	8.19	0.00	1.35	1.56	5.57	1.10	0.43
17	C	ICS	3.5	71.9	115.3	55.0	12.08	0.60	3.2	74.8	122.0	56.7	5.83	0.00	1.26	1.85	7.30	1.44	0.57
18	C	ICS	3	75.1	132.1	29.1	9.60	0.51	3	76.3	124.7	37.6	3.79	0.00	1.43	2.46	6.53	1.28	0.64
19	C	ICS	4	74.3	117.8	39.0	6.10	0.84	4	76.1	119.3	38.5	2.41	0.00	2.13	2.24	3.59	0.71	0.60
20	C	ICS	5.3	76.2	111.7	58.7	8.59	0.75	3	75.6	116.5	44.1	2.66	0.00	2.07	2.43	5.19	1.02	0.64
21	C	ICS	5	76.6	117.3	82.3	13.30	0.76	5	77.1	118.2	80.7	7.11	0.00	1.42	1.65	6.10	1.20	0.46
22	S	A-DC	4	79.4	113.9	64.9	9.38	0.71	5	79.9	112.0	78.3	2.71	0.62	2.06	2.44	6.43	1.22	0.66
23	S	A-DC	3	78.4	116.3	96.7	13.16	0.83	3	78.7	114.6	94	4.11	0.40	2.00	2.11	7.28	1.39	0.6
24	S	A-DC	9	79.5	118.2	100.8	17.67	0.66	9	79.9	120.0	82.8	5.72	0.30	1.43	1.87	8.60	1.64	0.55
25	S	A-DC	5	79.0	116.8	78.4	11.17	0.80	4.2	78.8	108.9	79	1.58	0.45	3.37	3.62	7.59	1.40	0.77
26	S	A-TC	4	77.3	111.9	42.5	6.16	0.73	4	76.5	115.9	53.8	3.18	0.32	1.68	1.99	4.09	0.80	0.57
27	S	A-DC	4	79.9	113.0	76.2	9.57	0.80	3.5	80.4	112.3	79.8	3.75	0.32	1.73	1.89	5.31	1.01	0.56
28	S	A-DC	4	78.5	111.6	98.2	13.09	0.76	3.5	77.1	109.0	76.2	3.83	0.35	1.73	1.98	6.36	1.25	0.56
29	S	A-DC	4	79.8	118.7	50.2	8.75	0.68	4	78.4	120.5	40.3	2.17	0.61	1.62	1.96	4.60	0.87	0.59
31	S	A-TC	5	78.2	103.8	87.3	8.26	0.76	5	78.6	108.8	65.2	1.73	0.33	2.75	3.10	5.46	1.11	0.71
32	S	A-DC	4	80.5	115.2	74.6	9.63	0.81	4	78.9	112.2	63.4	2.74	0.41	1.90	2.04	4.97	0.90	0.58
33	S	A-DC	5	79.7	115.8	81.9	10.99	0.80	5	81.8	113.0	106	4.93	0.32	1.71	1.87	6.11	1.11	0.54
34	S	A-TC	4	77.5	110.4	37.5	5.63	0.68	4	76.6	114.5	26.6	0.43	0.33	3.71	4.27	4.16	0.77	0.82
35	S	A-DC	6	77.2	117.5	35.2	6.17	0.71	6	77.8	120.8	34.7	0.58	0.35	4.04	4.57	4.89	0.89	0.83
Avg. / Sum			**4.6**	**76.7**	**119.4**	**63.8**	**348.23**	**0.73**	**4.4**	**77.1**	**118.6**	**62.5**	**153.77**	**5.12**	**1.43**	**1.76**	**169.02**	**1.0**	**0.53**

* FEF= Measured Florida Energy Factor calculated using a standard Energy Factor of 0.88 for auxiliary energy usage.

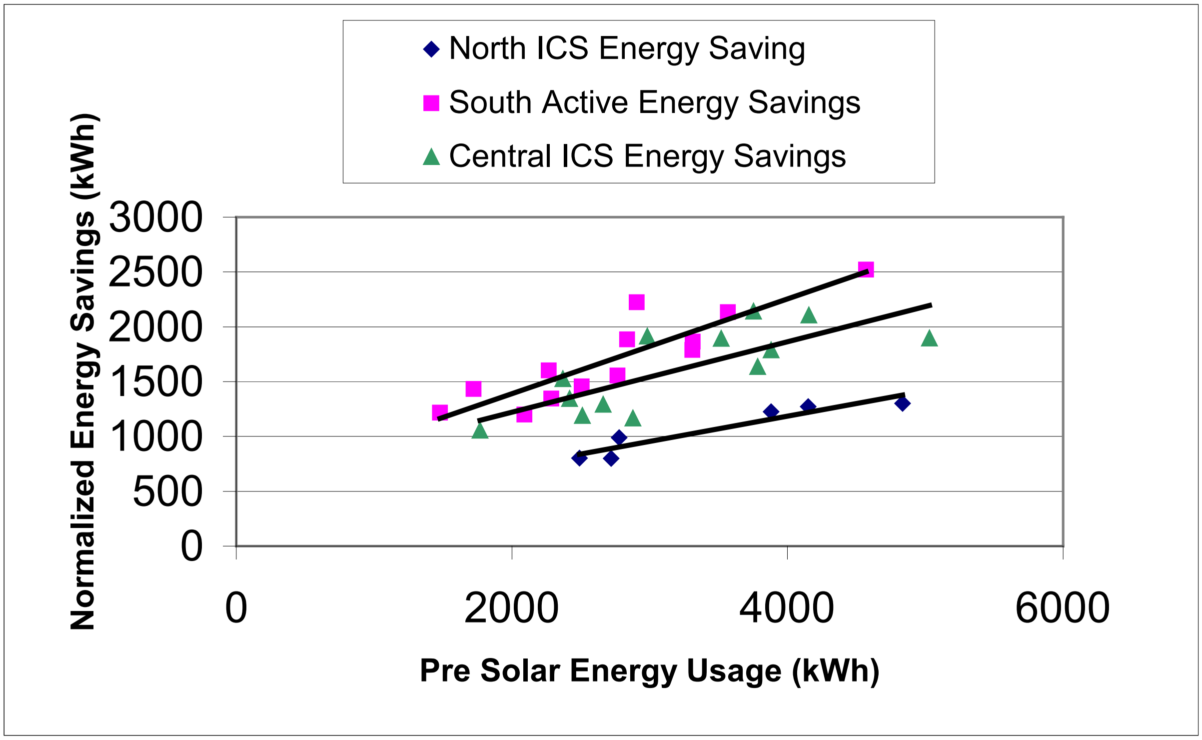


Figure 4.5-6. Energy Savings vs. Pre-Solar Energy Usage

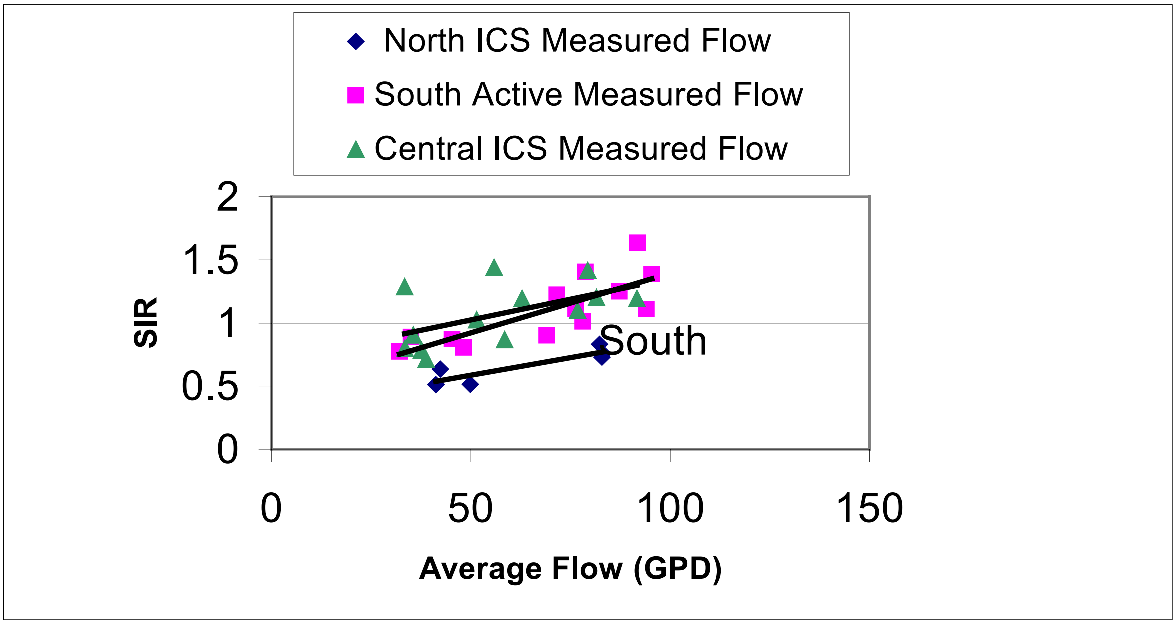


Figure 4.5-7. SIR vs. Flow

4.6 HARD MONITORING: COMPARISON WITH F-CHART PREDICTIONS

As part of the data analysis for the SWAP program, a comparison between the measured data and the predicted results from F-Chart (F-Chart 1993) simulation program was undertaken. There are several reasons for this comparison:

1. If the SWAP program is accepted as a standard weatherization option, F-Chart is one means by which solar system savings could be quantified in different climatic regions.
2. F-Chart is the basis for which Energy Factors for Florida are calculated.
3. The SWAP data provide a good basis for further validation of the F-Chart program.

F-Chart has been previously documented to reproduce experimental data to within 5% for active systems in the laboratory (Fanney and Klein, 1983) and to within 11% for systems from the National Solar Data Network (Duffie and Mitchell, 1983). An interest to the SWAP program is if F-Chart can predict field results to within +/-10% using field level (e.g., site and non-site measured meteorological) data.

In order to make a meaningful comparison between the measured and predicted values, it is necessary to obtain as much detailed information for all parameters as is possible. Because F-Chart uses monthly calculations, the monthly data for each of the selected sites are used. Several of the hard monitoring sites (#14, #15, #17, #19, #21, #24, #26, and # 31) were not used because large gaps (in excess of 1 month) existed in the data. This would have made F-Chart comparisons difficult to assess because F-Chart works with monthly intervals for one year.

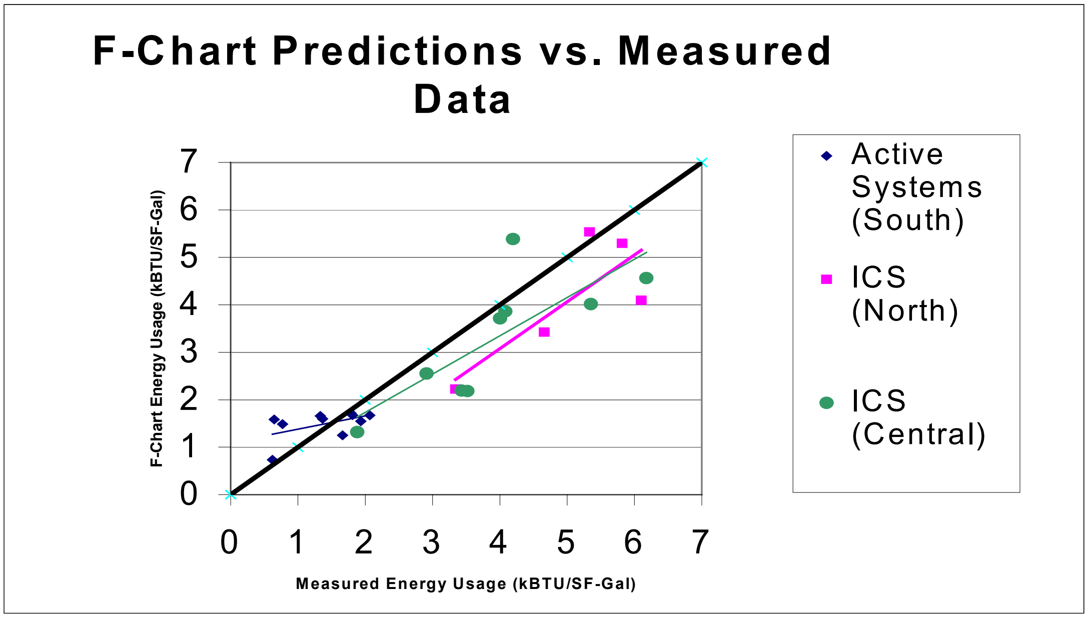
The data to drive the F-Chart program were entered from the monthly performance summaries, ambient temperatures from the adjacent meteorological stations, and system data from the inspections. Because the driving data for F-Chart is identical to that measured at the actual sites, this method should give an idea about how well F-Chart models the measured data. For ease of comparison, the month nearest the installation/completion dates were used as a basis for the comparison. In cases where this was not feasible, the site was dropped (sites #14, #15, #19, #24) from the comparison.

In doing the comparison, there is one piece of data that was not explicitly measured: the tank UA value. The UA value expresses the total amount of standby loss that the tank will have as a function of the temperature difference between the tank and its surroundings. The nominal value could be used, but this value is not typically the value experienced in actual installations (it may vary by a factor of 2). The pre-solar data were used to calculate the UA value for the F-Chart simulation. For the pre-solar phase, and the UA calculations, measured environmental temperatures were used. Because this information was not measured in the post-solar phase, it was assumed that the pre-solar and post-solar environmental temperatures were the same. This is one potential source of error, although the magnitude of error is probably not more than 3% of the total energy usage. For the post-solar phase, the pre-solar UA value was used as the basis of the calculations.

Table 4.6-1 indicates the comparison of predicted and measured energy usage for the selected sites. This data indicates two primary things:

1. The calculated energy usage compared to the measured usage for the ICS sites (#1-21) is under predicted in all but two cases (#11 & #18). F-Chart under predicts ICS energy usage by 19% for the group.

2. F-Chart over predicts the energy usage by 5% for the active systems group. For the active systems (sites #22-35) there is no clear trend: some cases are high and others are low. Note that the comparison for the active systems does not include parasitic energy usage.


F-Chart Predictions vs. Measured Data
F-Chart Energy Usage (kBTU/SF-Gal)
7
6
5
4
3
2
1
0
0
1
2
3
4
5
6
7
Measured Energy Usage (kBTU/SF-Gal)
Active Systems (South)
ICS (North)
ICS (Central)

2.0 OVERVIEW OF INSTALLED SYSTEMS

The following tables provide a detailed overview of the number, types, locations and costs of installed SWAP systems throughout Florida.

Table 2.0-1. SWAP Solar System Installations

Location	Agency	System Installed	Total Installed Systems	Average Cost ($) Per Installation
North Florida	Tri-County	ICS	48	$1,641
	Suwannee	ICS	90	$1,631
	Suwannee	Active Pumped	1	$1,690
	Central	ICS	45	$1,641
All North Total Systems/Costs			184	$1,650
Central Florida	Mid-Florida	ICS	162	$1,497
	Mid-Florida	Active pumped	28	$1,384
	Pinellas	Active pumped	5	$1,535
	Pinellas	Thermosiphon	1	$1,750
	Citrus	Active Pumped	4	$1,388
	Citrus	CS	25	$1,516
	Citrus	Thermosiphon	1	$1,690
All Central Total Systems/Costs			226	$1,537
South Florida	Dade	Active pumped	307	$1,501
	Lee	Active pumped	31	$1,414
	Lee	ICS	19	$1,641
	Centro	Active pumped	30	$1,423
	Centro	ICS	4	$1,540
All South Total Systems/Costs			391	$1,504
		TOTAL ALL SYSTEMS	801	
		TOTAL AVERAGE COST		$1,555

The following table outlines the types and sizes of collectors installed by total program participants:

Table 2.0-2. SWAP Installed Systems - Collector Types and Sizes

Collector	Size (Square footage for Flat-Plate and Square footage/ Gallons Capacity for ICS)	Total Installed	Percentage of Total
Flat -Plate	20	4	5
	21	3	4
	24	1	1
	25 (commonly identified as 26)	208	26
	32	157	20
	40	4	5
Thermosiphon	25	2	2
Integral Collector Storage	32/30	263	33
	40/40	131	16
Unknown*	-	28	3

*Note: Centro-Campesino did not report the size of the flat-plate collectors that were installed on active systems at numerous SWAP sites. From past installation inspections by FSEC staff of this installer's work in Lee County, it was noted that the collectors installed were either 26 or 32 square feet in size. Thereby, it is assumed that these would be in that same range.

Figure 2.0-1. Twenty-square-foot collector installed on tile roof.

As stated previously, a variety of systems were installed as part of the SWAP program. Table 2.0-3 provides an overview of the types and number of systems installed.

Table 2.0-3. Overall Summary of System Types Installed

System type	Total Installed	Percentage of total
Active Pumped Differential Controller	313	39
Active Pumped Timer Controller	70	9
Active Pumped Photovoltaic Controller	23	3
Integral Collector Storage	393	49
Thermosiphon	2	0.2

2.1 GENERAL COMMENTS ON NORTH FLORIDA INSTALLATIONS

North Florida installations were restricted to the use of ICS systems. As stated previously, more complex systems could have been used, but due to cost restraints, future maintenance, and criteria for system simplicity, they were not. The ICS systems in North Florida proved quite reliable. Local SWAP participating agency personnel found the system simplicity provided them with confidence in understanding and explaining to clients how the system worked. In addition, the rural nature and distances between clients and installers (as well as local SWAP agencies) necessitated the use of a simple system that would require very little service during its lifetime.

Three agencies participated in the SWAP program in North Florida. These agencies and the areas they served are as follows:

Table 2.1-1. SWAP Participating Agencies - North Florida

Agency	City	Region	Percent of total installed systems
Suwannee River Economic Council, Inc. (SREC)	Live Oak	Rural	11
Tri-County Community Council, Inc.	Bonifay	Rural	6
Central Florida Community Action Agency, Inc.	Gainesville	Urban	6

Both Suwannee and Tri-County served clients that lived, in large part, in rural areas. Central Florida encompassed an urban area, Gainesville, but also served numerous clients in outlying rural communities.

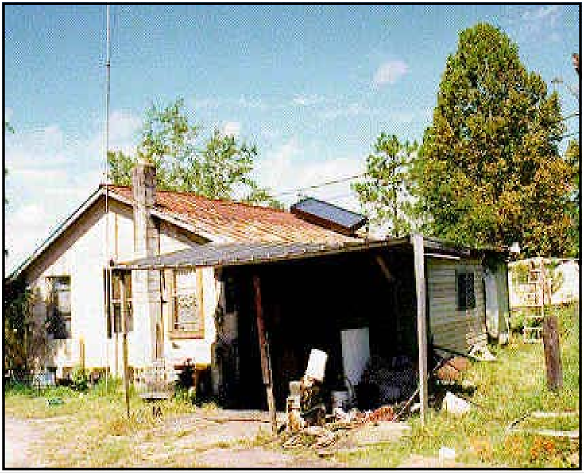


Figure 2.1-1. ICS system installed on a rural residence in North Florida.

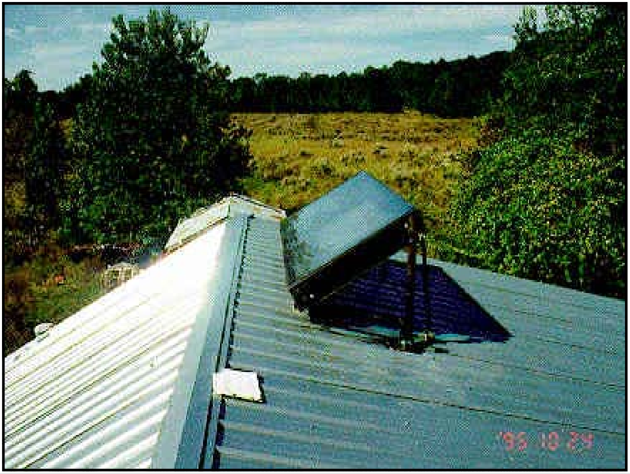


Figure 2.1-2. ICS collector installed on metal roof in rural area.

A major handicap in both Suwannee and Tri-County areas was that solar installers had to come from great distances (1 to 2 hour travel time) to install the SWAP solar systems. System installations were scheduled when more than one site was contracted for the installation of a solar system. Installers would often have to stay at area motels whenever numerous systems were to be installed. This of course affected the final installation cost of the systems, since logistics and costs involved with these distances had to be considered. Unfortunately, there were no installers closer than those selected for several of these agencies.

Suwannee did solve some of this problem by having FSEC train a local licensed plumber in the installation of the ICS unit. This provided the local agency with additional contractors from which to choose. Plumbers are, by Florida construction licensing regulations, allowed to install solar water heating systems. This will also serve to provide Suwannee with a local craftsman in the event of required service calls.

Figure 2.1-3. Local plumber installing ICS system.

Of special technical interest were specific instances where problems occurred in two North Florida areas (Suwannee and Tri County) where solar systems were installed. Interestingly, both problems were not the result of solar system discrepancies, but instead were caused by the quality of the local water.

Several systems installed in a specific neighborhood in Jasper, Florida, developed pinhole leaks in the absorber tubes. After detailed laboratory analysis, it was determined that the most probable cause of the leaking appeared to be localized pitting corrosion. This was the result of iron precipitation from the incoming city water supply. The severe iron content in the water supply was creating adverse galvanic corrosion in the copper tubing. This iron came from old iron pipes or/and pumps used in that specific neighborhood. A final report developed for FSEC on this problem is attached in Appendix 3.

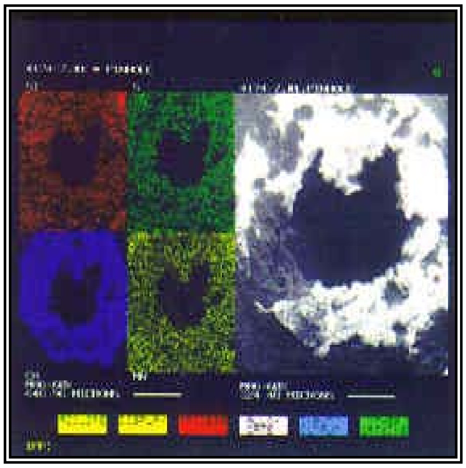


Figure 2.1-4. Analysis of pin holes with Energy Dispersive Spectroscopy analysis of pin holes.

The ICS units were repaired and whole-house water filters were installed. Since that time, there have been no further problems at the sites. The clients later remarked that their water was now much better with the filter. (Filters were purchased at a local hardware store that always stocks the filter replacement cartridges. Cost is $5 for 2 cartridges. An FSEC follow-up indicated that cartridges should be replaced every 4 to 6 months.)

Figure 2.1-5. Whole house filter being installed.

At two rural sites in the Tri-County area of North Florida, two clients started noticing that their tubs, shower curtains, and, at times, laundry had a blue color to it. FSEC investigation determined that these systems were installed on wells where the pH of the water was below 5.0. This very acidic water was leaching the copper, which in turn, caused the "blue water" syndrome. It was also noted that neither house had copper piping before the solar installation. The original piping was either short runs of metal pipe and/or PVC piping. Local plumbers must have known about this problem and therefore did not use copper in the potable water system.

Figure 2.1-6. Blue residue from copper leaching due to very acidic well water.

The problem was solved at one residence when the client decided to switch to the city water system. The other resident was not as fortunate. The system had to be removed and installed at another residence. The drilling of a new well may have provided better quality water, but this was cost prohibitive. In the end, FSEC sent the agency in that area a simple pH meter and instructed the agency to test the water prior to qualifying a site for a SWAP system. Sites with water pH levels less than 7.0 were excluded from the program.

Another water quality problem occurred in the active automatic draindown photovoltaic-powered system installed in North Florida. During instrumented monitoring of this system, it was noted that the draindown mechanism was not sealing completely during the draindown mode. Investigation revealed shell-like material stuck within the draindown valve mechanism. Flushing of the water heater also revealed large amounts of crushed shell material. FSEC staff conducted several trips to this site to clean the valve and completely flush out the system.

The above examples point out the problems that can occur due to water quality. This is a very important and troublesome issue for both solar systems and water heater manufacturers. Conversations with water heater industry representatives indicate that manufacturers at times have to modify warranties for water heaters in specific geographic areas due to the destructive quality of the water. (Sutherlin, 1994)

2.2 GENERAL NOTES ON CENTRAL FLORIDA INSTALLATIONS

The agencies listed in Table 2.2-1 were initially selected for participation in the SWAP program in Central Florida. Pinellas dropped out of the program after only six system installations. The remaining agencies, Citrus and Mid-Florida, and their clients participated in all phases of the SWAP program: system installations, instrumented monitoring, and utility bill analysis.

Table 2.2-1. SWAP Participating Agencies - Central Florida

Agency	City	Region	Percent of total installed systems
Mid Florida Community Services, Inc.	Brooksville	Urban/Rural	24
Citrus County Housing Division	Lecanto	Urban/Rural	4
Pinellas County Urban League	Gainesville	Urban	1

The outstanding feature of the installations in Central Florida was the efficiency with which the sites were identified and the systems installed by the Mid-Florida Community Services agency and their selected local installer. The SWAP coordinator in Mid-Florida (Brenda Mobley) was very instrumental in the success of the program by using every available means to procure clients for the SWAP program. This included working with the Mid-Florida database of low-income clients as well as through church groups, Habitat for Humanity, etc. The installer used in that area was also exceptional. Their professional attitude and craftsmanship greatly advanced the goals of the SWAP program in that area. The SWAP program greatly benefited from this special combination of SWAP program coordinator and particular solar installation firm.

Figure 2.2-1. Brenda Mobley of the Mid Florida Community Services discusses a ICS installation with FSEC's John Harrison and Patrick Robinson.

Pinellas County presented an initial administrative challenge to the SWAP program in that solar systems could not be installed on residences in St Petersburg without a separate professional engineer's certification for each proposed installation. This requirement would have greatly increased the installation cost of each system. FSEC staff and Henry Healey of Healey and Associates, a professional engineer familiar with structural requirements, met with St. Petersburg Building Department officials to resolve this problem. FSEC and Henry Healy presented the department staff with documentation, illustrating the various methods of attaching solar collectors to roof trusses. The building department officials were satisfied with one specific mounting method (spanner mounting) and agreed to allow a generic drawing of that mounting method to be submitted with each building permit, indicating that this type of mounting would be used for collector mounting. This precluded the requirement that a professional engineer had to develop a structural mounting analysis for each separate residence. Unfortunately, soon after this resolution was achieved, the Pinellas County Urban League dropped out of the SWAP program.

Figure 2.2-2. Spanner mounting of solar collector.

Although the above problem was encountered during the administration of the SWAP program, it is a very good example of the local barriers that are often faced statewide by solar installers.

As outlined previously, specific systems (and system sizes) were required in each area. The specifics of this criterion were revised periodically as lessons were learned. Initially, systems using flat-plate collectors were permitted for installations in Central Florida. This was revised after the first freeze in the area, in which one resident, whose system incorporated a flat-plate collector, decided to drain the system instead of allowing the automatic freeze protection mechanism to operate. The client properly shut the isolation valves in the collector feed and return lines, but did not continue the manual draining process by opening the drain valves and allowing the water to drain from the collectors. Therefore, water was still in the collector. The water froze, expanded and burst the copper tubing in the collector. After this incident, FSEC staff decided to end the use of flat-plate collector type systems in Central Florida, where periodic freezes are a common winter occurrence. Installations were restricted to the use of ICS systems, which have an inherent freeze protection method due to the collector tubes' thermal mass - and require no homeowner interaction.

Note that this applied strictly to specific areas in Central Florida (Citrus and Mid-Florida) since these areas tend to encounter colder weather during freeze conditions. (USDA, 1475) Pinellas County was not affected by this since it is located next to the Gulf Coast and does not register the extreme conditions noted in the other two areas.

Citrus County personnel brought up a specific situation that should be addressed for future low-income solar programs. Mobile homes are excluded from the Florida WAP program since the NEAT audit procedure does not apply to mobile homes. Unfortunately, a large number of low-income clients live in mobile homes in Citrus County. SWAP systems were not installed on these homes.

Figure 2.2-3. ICS system inadvertently installed on mobile home.

One must keep in mind that solar water heaters do one thing - heat water. they are not true weatherization measures. They are instead, water heating appliances. It does not matter whether the solar system is installed on tract houses, duplexes, mobile homes, etc. The system will work the same on any of these residences.

2.3 GENERAL COMMENTS ON SOUTH FLORIDA INSTALLATIONS

The majority of systems installed in South Florida were in urban areas. This includes a wide range of Dade County, from North Miami to Florida City. A tremendous amount of low-income housing stock was available. The majority of houses were quite suitable to the installation of solar systems. In the south part of Dade County, shading did not present a problem, since most of the trees and taller shrubbery had been destroyed by Hurricane Andrew. In addition, most of the houses in south Dade County had also received extensive renovation due to the hurricane, therefore providing housing stock with structurally sound roofing.

As stated previously, the ICS unit was not used in Dade County due to the cost the manufacturer would have to incur to obtain Metro Dade Product Approval on his collector. Fortunately, several flat-plate manufacturers did obtain approval and therefore all systems installed in Dade County incorporated the flat-plate collector.

In general, the installations in Dade County went in without a great deal of administrative problems. Nevertheless, since there are numerous cities within the greater Miami area, the installers very often had to deal with a variety of local code and building department requirements.

One problem that was encountered by local installers centered around the use of pitch pans that are used to seal roof penetrations. System inspections in the Dade County area indicated that the primary installer there was forced by local building code officials to use pitch pans instead of the standard copper flashing and cap method for sloped shingled roofing. Although the pitch pan method is often used, especially for flat roofs, this method requires maintenance and inspection over the life of the system to ensure that the pitch seal remains stable. FSEC contacted and provided documentation to the Metro Dade Product Approval Official specifying that the solar industry and FSEC recommended copper flashing was best for solar installations on sloped roofs. Unfortunately, Metro-Dade officials responded by stating that the copper flashing would not be approved and that pitch pans had to be used. After consultation with DCA, it was decided that system installations would continue in Dade County with the use of pitch pans.

Therefore, the majority of systems installed in the Metro-Dade area incorporated the pitch pan methods for roof sealing of penetrations. The installers did a very adequate installation of these pitch pans. Holes were drilled in the roof, the copper piping was wrapped with sealant tape and passed through the pitch pan, which was affixed to the roof. In turn, the pitch pans were filled with bitumen sealing material. A well-sealed pitch pan should not result in any problems, although pitch pans do require maintenance and inspections over the life of the system. Over time, the pitch material could dry and crack. If severe enough, these cracks could, in some instances, provide avenues for minute amounts of water to filter through.

FSEC recommended the use of copper flashing and coolie caps, but since this was not allowed in Metro-Dade, the use of pitch pans was a second, although not highly recommended, option. Periodic inspection of the pitch material is recommended.

FSEC closely monitored many of these systems. As suspected, several problems did occur with the use of pitch pans. These were quickly brought to the attention of the installers and corrected. During periodic inspections, FSEC staff inspect the pitch pans and added bitumen as required.

Having stated the above, it must be noted that pitch pans have been in use for many years without an appreciable number of problems, and in the case of flat roofs, are the recommended method.

Figure 2.3-1. Pitch pan filled with bitumen.

Figure 2.3-2. FSEC's Tom Tiedemann adding bitumen to pitch pan during routine FSEC inspection.

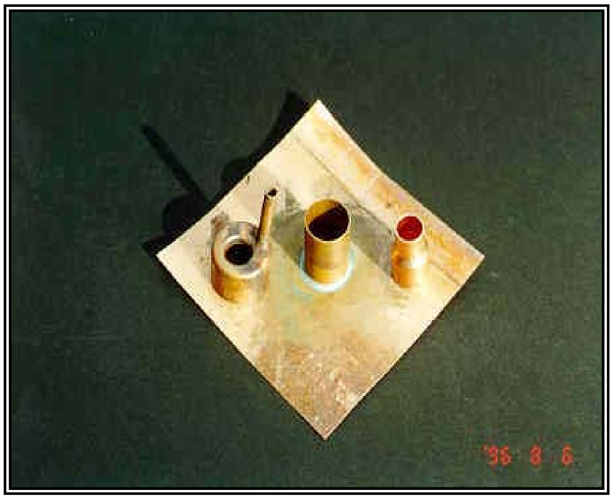


Figure 2.3-3. Standard solar industry flashing.

Figure 2.3-4. Ideal roof flashing using copper flashing shown in Figure 2.3-3.

Lee County did not enter the SWAP program until quite late. An agreement between DCA and a local distributor/installer provided very reasonable installation costs for the active systems installed in that area. Unfortunately, the majority of the systems revealed many discrepancies during inspection by FSEC. These discrepancies were pointed out to local WAP staff, who in turn contacted the installer for corrections. Most of the discrepancies were due to poor installation workmanship rather than solar equipment failure, as is usually the case.

A second installer in Lee County installed ICS units in that area. Unfortunately, since Lee County entered the program at a late date, it was too late to monitor some of these ICS units. The second installer did outstanding work.

Of special note is the hope that some form of low-income solar program will be initiated in many of the agencies that participated in the SWAP program. Many local staff members are now very qualified and knowledgeable in the installation and inspection of solar systems. It would be a shame to let this experience go to waste. For example, Shawn Angell of the Metro-Dade Community Action Agency has become very adept at solar system issues. Not only has he done a commendable job in procuring and supervising the installations in Dade County, but in turn, has also reached a high level of competency in maintaining and troubleshooting any and all types of active solar systems installed in his jurisdiction.

Table 2.3-1. SWAP Participating Agencies - South Florida

Agency	City	Region	Percent of total installed systems
Metro-Dade Community Action Agency	Miami	Urban	38
Lee County Community Improvement Division	Lecanto	Urban	6
Centro Campesino / Farmworkers Center, Inc.	Immokalee	Rural	4

Due to its urban location and vast number of residences ideal for solar systems, the largest numbers of installations were in Dade County (Miami area). All installed systems in Dade County used flat-plate collectors and various control strategies. The most common control strategy was the differential controller, followed by the timer and photovoltaic controller methods.

Figure 2.3-5. Low-income residential area in Dade County using SWAP solar systems.

The photovoltaic control method proved ideal at those residences where there were no electrical receptacles in close proximity to the water heater. Unfortunately, the cost of the photovoltaic system was several hundred dollars more than the standard differential or timer controlled system, thus precluding its use at more sites. Yet, this was often cheaper than contracting with an electrician to provide power for AC pumps and controllers. One advantage of the photovoltaic- powered, pumped systems is that they can operate during periods of power failure.

The differential control system was the most common system used due to the system's lower cost and common use in South Florida solar system installations.

The majority of the systems were retrofitted to 50-gallon water heaters that, in most cases, replaced the old conventional electric water heaters. LIHEAP funds were used to replace the majority of these water heaters.

Initially, both 20 ft^2 and 32 ft^2 flat-plate collectors were installed on the active systems in Central and South Florida. The 20 ft^2 collector was incorporated in a low-cost timer-operated system that had previously been granted a low-cost system development award by the Florida Governor's Energy Office. This system was installed on residences with three occupants.

Until the collector manufacturers were able to provide mid-size collectors, the 32 ft^2 collectors were initially used on large occupancy residences. These were replaced, in time, by 25 ft^2 units. This is an ideal sized collector for retrofitting to 40- and 50-gallon water heaters in residences where there are four or more occupants. This intermediate size has several advantages. The cost is somewhat less than the larger 32 ft^2 unit and not much more than the 20 ft^2 collector. In addition, the use of this intermediate size collector tends to reduce the possibility of overheating with oversized collectors.

Figure 2.3-6. Twenty-five-square-foot collector installed on Miami site.

5.0 SOFT MONITORING

A great deal has been learned regarding retrofit performance through analysis of monthly billing data collected from sample houses. While this type of data was insufficient for the objectives of the SWAP Program Hard Monitoring Plan, it may provide an estimate of energy saved by solar water heating. To test this hypothesis a soft monitoring project was conducted on a sample including 275 SWH systems. Soft monitoring included monthly electric bill analysis, site inspections and surveys. The instrumented (hard monitored) homes from the SWAP Program Field Monitoring Program were also part of this sample.

The soft monitored samples were chosen from the same geographical and climatic locations as the thirty-five hard monitored homes. Electric bills from homes meeting the selection criteria were obtained for the nine-to-twelve month period prior to installation of the solar system. The length of time was sufficient to include one summer and one winter season so the extremes in temperature were represented.

Local solar contractors installed solar water heating (SWH) systems in selected homes. Electric bills from these homes were collected for a second nine-to-twelve month post solar period. As before, this period included a summer and winter season. Each house served as its own control with monthly electricity costs being compared before and after installation of the solar water heating systems.

The soft monitoring phase of the SWAP program was instituted to evaluate if the use of utility bill data could be used as a simplified method for the evaluation of energy savings from the addition of the solar systems. Unlike the hard monitoring, there is no additional equipment that needs to be installed. This level of detail for monitoring is typically used for the evaluation of other types of weatherization options.

Unlike standard weatherization options, which are usually focused on reducing heating and cooling costs, the SWAP program will affect only the water heating energy use. This becomes an issue in evaluating the usefulness of utility bill analysis because the heating and cooling loads typically dominate the electricity bill, followed by water heating/refrigeration costs. The evaluation of utility bills is a statistical method that predicts a “typical” normalized annual energy use for a specific residence given weather data and utility billing data before a retrofit is made. Savings can then be calculated from the difference between the typical energy use before the retrofit and the normalized energy use after the retrofit. Normalization to typical weather is made assuming that the energy usage consists of a base load, a cooling component, and heating component.

A goal of 200 houses for the soft monitoring phase was established in order to give a precision of total electrical use of approximately +/- 1000 kWh/year at a 90% confidence interval. In order to obtain this figure, approximately 300 of the 801 installed sites were selected for utility bill analysis, assuming that approximately 1/3 of the sites would have unusable billing data for the following reasons: missing billing data, inadequate amount of billing data, occupancy changes, and problems with the solar system.

5.1 SOFT MONITORING: DATA COLLECTION

Unlike the process of electronically obtaining data for the hard monitoring, the soft monitoring energy data acquisition is all done through the various utility companies that serve the monitored systems. This entails getting the proper approvals for releasing utility company records prior to receiving any data. The procurement of the data receipt was timed so that both pre and post-solar data could be received. Because most utilities maintain data for a period of approximately 2 years, in many cases it was necessary to obtain data at several separate times, so that the required period before the solar installation and after the solar installation was satisfied. At least 9 months, and preferably one year’s data is required for both periods, so that summer and winter electrical usage is measured. The data of interest consists of two parts, the billing date and the measured electrical use in kWh.

The data were put into a spreadsheet form that was easily importable into the PRISM program (Fels et al., 1995) that was used for the data analysis. The month in which the retrofit occurred was excluded from the data so that partial days of retrofit and start up problems were resolved before the data were compared. Unlike the experimental data that can be flagged and cleaned up electronically, much of the utility bill data were transcribed by hand in at least one step. Therefore, it is likely that some errors may have occurred in the recording of data. The first step in the data collection was to examine it visually, looking for obvious errors and missing data. Sites with missing or inadequate amounts of data were discarded at this stage. Obvious transcription errors were fixed. Other sites with known problems, including solar systems that had failed for extended periods of time and sites with no utility usage (e.g. power shutoff) were also discarded at this stage. At this stage in the process, no data were available regarding occupancy and/or HVAC changes. The remaining data cleanup was handled by using the PRISM program, which identified other problems using statistical methods.

In addition to obtaining utility billing data, daily temperature data for the sites of interest were also obtained. All of the selected sites were divided into three geographical regions: North, Central, and South, corresponding to their proximity to the following weather stations: Tallahassee, Tampa, and Miami. To obtain accurate estimates of the building response to climate, the PRISM program recommends that a minimum of 12 years worth of weather data be used for analysis, including the years during the experimental phase. The year 1984 was selected as the starting year, because the data format has been consistent since then. This selection yielded 13 years of data.

The weather data were obtained from the National Climactic Data Center (NCDC) in Asheville, NC. The first 12 years worth of data had been previously digitized and was contained on 2 CDs (data set TD3200). The parameters of interest were the daily maximum and minimum temperatures that are used by PRISM to determine an estimated number of heating and cooling degree-days as a function of the reference temperature. The reference temperature is assumed to be the outdoor temperature below which heating is needed (or above which cooling is required). In general, this temperature is related to the indoor temperature, but with an offset which implicitly includes internal loads, shading, and solar gain. A separate program was written to extract the digitized weather data in the required columnar format, because the available format of the data did not match the processing input in PRISM. The last year of data for the three sites was input manually.

Because the digitized data from the NCDC had been previously cleaned up, there was no need to further clean up these data. The data entered manually were re-examined and cleaned up to remove transcription errors.

5.2 SOFT MONITORING: DATA ANALYSIS

As previously indicated, the analysis of the data was conducted with the PRISM program. This program uses statistical methods to predict the building energy response as a function of outdoor temperature. Because the program can normalize electrical heating/cooling energy use to weather, the baseline energy use (which includes water heating) can then be compared before and after the solar system has been installed to evaluate savings, independent of the weather. There is one primary formula that describes the PRISM evaluation method:

$$\mathrm{NAC} = 365\alpha + \gamma_{H} \mathrm{B}_{H} \mathrm{Ho}\,(\tau_{h}) + \gamma_{c} \mathrm{B}_{c} \mathrm{Co}\,(\tau_{c})$$

Where $\gamma_{H, C}$ are model selection parameters and are equal to zero or one. $B_{H, C}$ are the slopes of the cooling and heating load as fitted by the regression. The $Ho(\tau)$ and $Co(\tau)$ functions are the approximate reference temperature equations and are based upon a least squares fit of a building's utility billing data to the weather data (or they can be fixed). α is the baseline energy load that consists of all loads except the heating and cooling (the second term is the heating expression and the last is the cooling expression). The result of this equation, the NAC (Net Annualized Consumption) is used for the computation of energy usage before and after the solar has been installed.

The primary assumptions of the PRISM method are:

1. Building heating/cooling loads can be expressed as a direct function of the dry bulb temperature difference (in degree-days) between the building space and the outdoor temperature. This assumption is that other effects including radiation, wind speed, and humidity are all proportional to this term, even though they are not explicitly calculated.
2. Building temperature is constant during the heating/cooling season (although PRISM predicts the reference temperature to create the best fit from the data).
3. Efficiency of the heating/cooling equipment is inversely proportional with respect to the driving force in #2.
4. The baseline energy load is independent of weather effects and is relatively constant throughout the year.
5. Heating/cooling systems are run in accordance with the dry bulb temperature difference in #2.
6. Occupancy and use of the building is relatively constant.

The first step of the PRISM analysis is the processing of the weather data. In the first stage, the columnar format data are converted into a format PRISM uses for further analysis. At this stage, PRISM will also indicate if there are any problems that it detects with the data, aiding the manual clean-up process. In the next step, all of the weather data for a location are read in and two normalization files are generated. Each of these expresses the number of degree-days (heating and cooling) as a function of the optimized reference point. This point is used to minimize R^2 after the base energy use and heating/cooling slopes have been determined from a regression of the data.

Processing of the utility billing data also occurs in a multi-step process; the data are converted from a columnar format to a format that PRISM uses (the meter file). In this process, obvious errors are flagged and reported.

When the final processing is ready to begin, the user selects a weather site, a meter file, and run parameters to process. The run parameters are used to refine the model used for each specific building to predict energy usage. Among the refinements to this process are if cooling and/or heating are to be considered, and if outliers are to be weighted less. An option (used for this study) is to let PRISM automatically select these parameters. PRISM does the automated selection by evaluating the fit generated with several operational modes and selects the one that most appropriately fits the data.

The first step of this process was repeated several times to clean up errors not found previously in visual inspections or in the original file conversion. PRISM uses several methods to identify common problems with utility billing data:

1. Identification of estimated readings. The identification is done by flagging consecutive data that has a high and low deviation with respect to the normalized monthly energy consumption.
2. Identification of mis-ordered data. This usually entails flagging data with incorrect date stamps.
3. Identification of outliers. PRISM flags this value by noting a high deviation from the expected monthly energy usage.

Even after correcting errors, the PRISM program still detected errors that fell into categories #1 and #3. The recommendations from the PRISM program were used to run the program with the corrected estimated readings and the robust calculations for the outliers. In general, outliers reflect occupancy changes that have a large impact on energy usage. Estimated readings are as indicated, even if the utility does not flag them as such (Marean, 1998). After the determination of the NAC for each site, the PRISM program calculates several statistics for each site, including both the pre- and post-solar cases:

R^2: this parameter identifies how good the overall fit is. A value near 1.0 is desired.
CV (NAC): this is the relative standard error in %. This is the standard error. A low value for this parameter is desired.
FI: this is the flatness index. This value indicates how well the building's response is to temperature difference. A low value of the FI, combined with a low CV can indicate a building with a good NAC, even if the R^2 value is low (the fit is poor because the heating and/or cooling is not too temperature dependent).

The calculated savings are based upon the cutoffs selected by the three criteria listed above. The default values are : $R^2 > 0.7$, CV <= 7 %, and FI<0.12 with CV<0.57* CV cutoff. Acceptance of these values is used for calculation of energy savings. Energy savings is simply the difference in NAC before and after the installation of the solar system for the systems that meet the reliability criteria.

5.3 SOFT MONITORING: RESULTS

A preliminary analysis of the data is included in Appendix 11. This analysis was performed because the early indications were that the data were not well predicted by the PRISM model as indicated by the three performance indices for all three regions. Although the data did not agree well with the listed criteria, the distribution of the data appeared to be in a bell shape, indicating that there was not a particular bias in the data. This is reaffirmed by the generally good agreement between the mean and median values. In order to address possible shortcomings in the data, the stability of the population used for generating the data, and the model used to evaluate the data, a series of runs were made with the PRISM program.

Several different criteria were evaluated to assess the model results:

Model selection
Savings criteria cutoff
Use of a data set with no occupancy change
Variances by region
Correlation of predicted models with surveyed air-conditioning usage

The likely causes for the poor fits are:

Large changes in occupancy
Intermittent usage of air-conditioning
Air conditioning usage is not constantly proportional to cooling degree-days. This might be caused by change in wet bulb temperatures that do not have a large impact on the dry bulb temperature.
All baseline loads are not weather independent (seasonality of non-heating/air conditioning loads).
Change/addition of heating and cooling during the analysis period.

To evaluate the impact of model selection, a series of three models were run for all three regions. The following models were used:

Automated Selection (cannot select temperature bounds for models)
Heating and Cooling (reference point from 70-85° F in summer and 60-75° F in winter)
Cooling Only (reference from 70-85° F)

Where appropriate, all flagged estimated readings were combined and all outliers were evaluated with the “robust” version that de-weights the outlier points for making the analysis. For the south and central regions, the impact upon predicted energy usage averaged 30% or less, although one case varied from 533 kWh to 1,886 median savings. In the north, the results were poor, in particular, the use of the Cooling Only model generated a negative mean energy savings of –864 kWh, while the use of the automated model generated a mean energy savings of up to 2,068 kWh. In context, these results make sense because they indicate that the cooling only model does not work well in the north. This is expected from the climate. Therefore, for the final analysis, the automated model selection, which screens the various models for cooling/heating trends in utility bill usage was used.

In addition to the selection of the modeling criteria, the selection of the savings criteria can have a significant impact on the results. Although the savings criteria affect the final results, this selection does not affect how the models fits the weather data, as this step occurs prior to the calculation of savings. For all of the runs, four combinations of criteria were used:

Accept all sites
R^2> 0.7, CV<7%
R^2>0.7, CV<7%, FI (Recommended method)
R^2>0.6,CV<10%,FI

For the most part, the results from this process were fairly predictable. The first option, which excludes all criteria, has the poorest fit but the lowest standard error (because the most sites were used). In general, this approach has little merit due to normal errors/problems with the data.

The second criteria proved to be too stringent for this data set. In most cases, only about 10% of the data would have been used. Consequently, the R^2 values are the highest of the group, but the magnitude of the standard error is often the same as the predicted savings. This indicates that many of the buildings' temperatures/energy use have a low dependence on ambient temperature. This method was also rejected.

The third criteria is the default method and is intended to catch buildings that are not particularly climate sensitive ("flat"). This method yielded approximately twice the number of data points as the second method, with correspondingly lower R^2 values and lower standard errors.

A fourth set of criteria was modeled after the third, but with larger ranges to accommodate more of the data. Sharp (1994) also modified these values for their cooling data, which showed many of the same problems as this data set does. In particular, their cooling data showed R^2 values on the order of 0.1. His conclusion was that the air-conditioning usage was driven by factors other than just outdoor temperature. Although the aim of these data is to examine hot water heating savings from the solar system, the impact and understanding of the usage of the air-conditioning becomes critical as it typically is a larger electrical load than the water heating. The use of these criteria improves the size of the "acceptable" data for savings, but also reduces the overall R^2 value. For all of the criteria, the point at which the error becomes large, or larger than the predicted savings, indicates that an inadequate number of data points exists and/or the fit is poor. This is the case which exists with the north set when the criteria are applied. This criterion was selected for projecting savings.

The third objective to evaluate was if a better-conditioned data set, that had no reported occupancy changes (from the surveys), would yield better fits and a smaller proportion of "unacceptable" data points than the entire set had. To do this, the surveyed sites with no reported occupancy changes and appropriate billing data were re-run in the south and central regions. Only about 25% of the original data sets fell into this category. Note that this does not imply that 75% had occupancy changes, because only about 37% of the surveys were returned. These sites were run using the automated model selection and the various savings criteria described previously. When these results were compared with the full sets, the R^2 values were similar (+/- 0.1), and the percentage of buildings found "acceptable" by the various savings criteria was similar (+/-10%). If the reported occupancy changes were accurate, this finding would imply that the poor model agreement was not primarily due to occupancy changes. Another source of discrepancy in occupancy could be the "Friend Factor." This factor is a non-documentable change in occupancy that may occur on a regular or irregular basis. A follow-up survey was performed to answer this and other questions. Of the 39 respondents, 56% indicated that they have friends/relatives over for at least 4 hours/day. This occupancy could have a major impact if it does not occur as a regular pattern and involves significant energy use.

Another area of model evaluation is the geographical location of the sites. In general, all three areas show similar problems with disagreement. The northern region shows problems with higher relative errors, but this problem can be explained by the relatively few number of sites located in the North (approximately 40% of the other two regions). The previous discussion regarding modeling differences explains only the climate sensitive effect (cooling model not appropriate in the North). It is expected that the actual savings could vary by region.

To address the final question, the ability of the model to predict reported air conditioning use, the final analysis is used. Figures 5.3-1 to 5.3-3. indicate the normalized energy savings for all of the sites with utility billing data by region that passed the savings criteria. Note that the saving site numbers are not the same numbers used to identify these sites elsewhere.

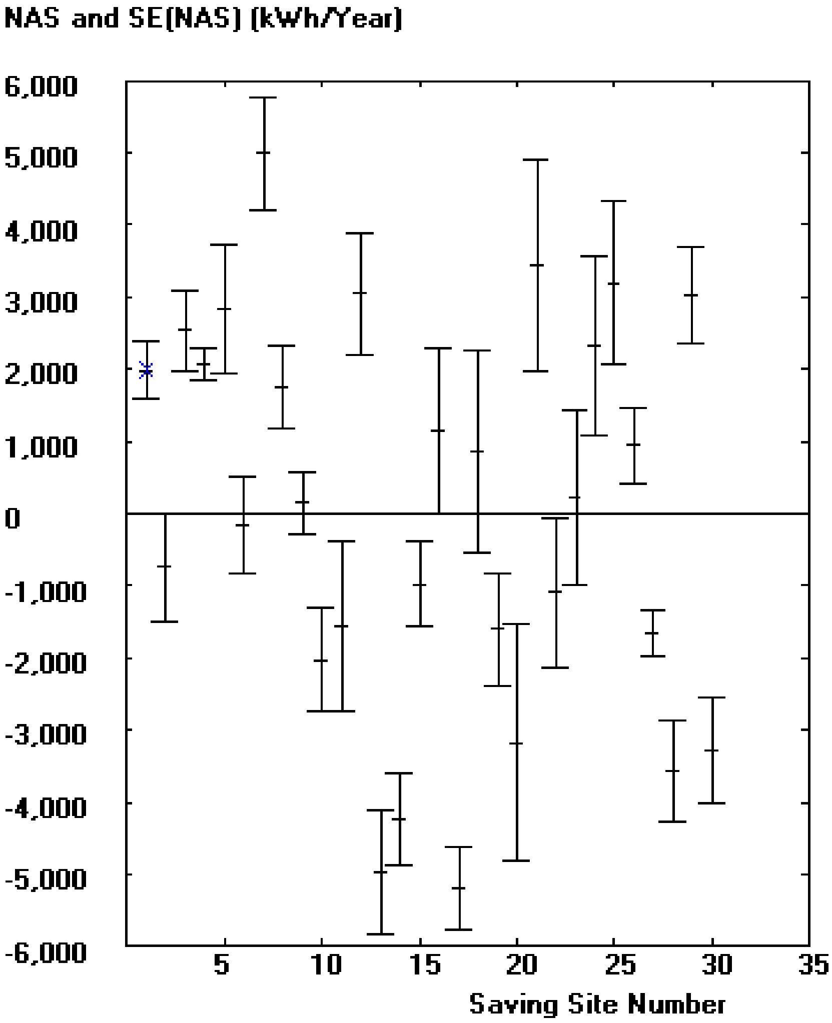


Figure 5.3-1. Normalized Annual Savings by Site for North Florida

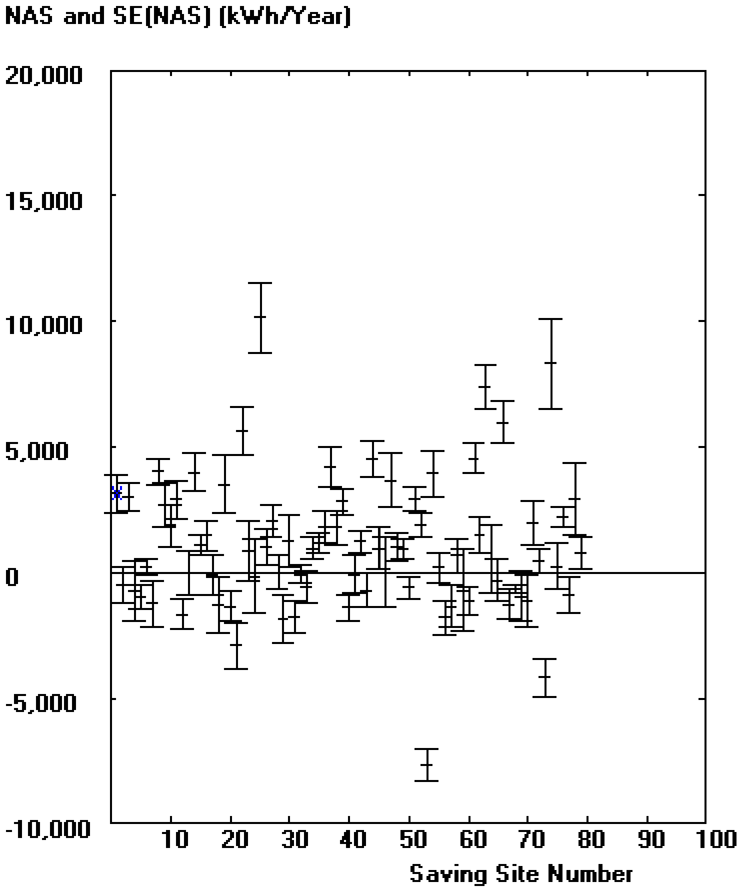


Figure 5.3-2. Normalized Annual Savings by Site for Central Florida

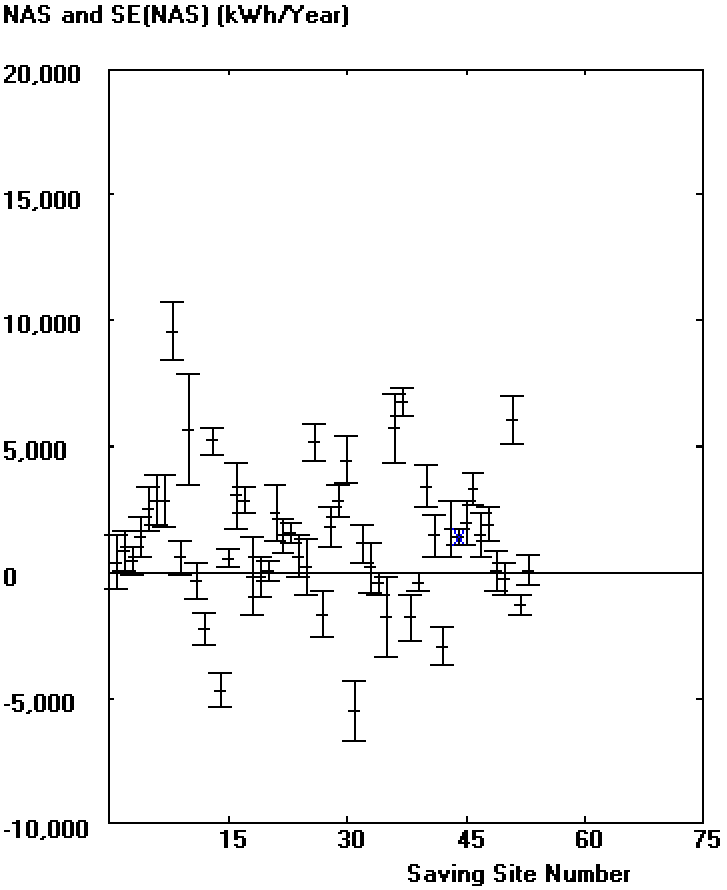


Figure 5.3-3. Normalized Annual Savings by Site for South Florida

These figures indicate many cases with unrealistically high savings and/or negative savings that cannot be attributed to the solar system operation. Appendix 12 indicates more detailed information for all of the utility billing data (by location) as modeled with the PRISM program. The appendix tables indicate the following information for the three zones:

Site: Site Number (different from the diagrams!)
Period: Pre/Post Solar
Model: Modeling used (C = cooling, H = heat, O = Only, R = robust, MVD = Automated selection, with outlier detection)
Data: # of data points used
FI: Flatness index. A low value indicates a temperature-independent electric load.
R^2: Least squares fit quality
T(heat/cool): Calculated reference temperature in degrees F
SE (heat/cool/base/NAC): Standard error of portion of parameter in kWh.
Base: Base load, which includes water heating in kWh.
NAC: Normalized annual energy consumption, which is the predicted energy use in kWh.
A/C and Heat: Yes/No survey result of air conditioning/heat in the home
A/C Use: Survey result of standard usage of air conditioning/heat
Occupancy Change: Reported occupancy change during monitoring period. Reported in %, only reported for whole period.
Friends: Yes/No question indicating if friends/relatives are in house more than 4 hours/day.

Blank survey information indicates that no information was available, blank PRISM indicates that a particular model type was de-selected. One item of particular interest in these tables is the determination of the reference temperature at which heating and/or cooling is used for calculating the normalized heating and cooling loads. Blocks shaded in light gray indicate physically unlikely values. Although the manual model selection allows for the selection of a reasonable range for these values, the automated model does not allow for unrealistic values to be eliminated. Although many of these cases result in correspondingly low R^2 values, there are many that have high fits, indicating that PRISM will use these for savings calculations. However, in many cases, these errors are small because the problems leading to these low values indicate poor correlation with either heating or cooling (and consequently a small load). This limitation of the automated model selection leads to some of the errors observed.

These data also indicate discrepancies with houses moving from HO (Heating only model) to CO (Cooling only model) in one year. Corresponding values of Tau Heat and Tau Cool also vary significantly. Although this may yield a “best” statistical fit, it is unlikely that this is physically occurring. One of the survey questions was to determine changes in heating/cooling equipment during the monitoring period. As indicated in the darker gray bands, a few cases of this did occur, although this does not explain the bulk number of modeling changes. This leads to the thought that some of the modeling problems may be caused by the improper assumption of heating and/or cooling model(s). Ideally, this type of data is useful for making utility bill comparisons. However, getting the equipment change information for all of the sites is not always feasible. Overall, the impacts of these data points were thought to be minor and were not deleted from the data set.

One item that could impact the results significantly is the intermittent use of heating and cooling. As part of the follow-up survey, this question was raised. Contrary to common thought, most residences indicate that they use their air conditioning continually during the summer (64%). Twenty-three percent used it on only hot days, and the rest used it at night (3%), during the day (5%) or never use/don’t have air conditioning (5%). For heating, the results were more evenly distributed, with 26% using it continually, 37% using it only on cold days, 8% using it at night, and 24% did not use or have any heating. Clearly, the heating, if used, was used more intermittently than the air conditioning. This could result in some impact on the results. However, because the heating is a lesser load than the cooling, the heating results affect the NAC by a lesser amount.

Another potential source of error is the ability of a degree day model to accurately model cooling energy in a humid climate. This issue has been explored previously for Houston (Fels and Reynolds 1993). Their analysis indicates that the daily average comfort index can be reasonably correlated to the dry bulb temperature in Houston. A corresponding relationship can also be found between wet and dry bulb temperatures. By comparing the fit with dry bulb temperature and comfort index, they showed that the NAC in Houston is similar for both methods, although the R^2 is always higher when the dry bulb temperature is used. Although they used the heat index as a relative comparison of performance, it should be noted that this value indicates the effect of heat on the body (primarily though limiting perspiration) rather than the effect of heat on a building, which entails both latent and sensible loads and cooling methods. It appears that the reliability of fitting Houston’s data should also apply to Florida’s climate, indicating that this issue is not the primary problem factor.

Another potential source of variance in the data is the assumption that all non-heating/cooling loads are constant throughout the year. The monitored data clearly indicate that the water-heating load varies by approximately 30% between August and January. A study by Fels et al. (1985) addressed this very issue, including a variance in the water-heating load of 41%. As applied to PRISM, their results indicate that the errors in the seasonality of loads were not significant enough in comparison with the standard error to affect the NAC for individual homes. However, it should be noted that their analysis was with heating in Denver. Some of the seasonality effects evaluated in this study may tend to cancel themselves out in a cooler climate than Florida (Lights vs. Refrigeration). Consequently the effect of the seasonality would be reduced.

An additional possibility is the effect the seasonality has on the summer/winter fits. In the winter, the seasonality (5% above mean in the Denver study) is reflected as an additional heating load (reducing the reference temperature) and in the summer, the seasonality (12% below the mean in the Denver study) is reflected as a lowered cooling load (increasing the reference temperature). However, in the "swing" seasons, there is no way of attributing seasonal loads to heating and/or cooling, although they are presumably at their minimum during these times. This swing season lasts approximately 4-6 months and may be significant enough to affect the baseline load and consequently the NAC, especially if there is a seasonal bias.

Table 5.3-1 indicates an overall summary of the PRISM results by zone. A comparison with the monitored sites has also been included. Although the relative distribution of system types is similar for both the monitored and PRISM sites, the monitored sites represented are not a large population sample, so it is possible that other effects other than the aforementioned modeling issues may have impacted the discrepancy in the results. The overall results for the state (weighted by # of buildings per zone for PRISM), indicate no agreement within the limits of error.

Table 5.3-1. Zonal Comparison of Prism and Monitored Sites

Climate	Measured		PRISM				
Zone	Savings (kWh +/- 60	# Buildings Used	R^2 Pre Solar	R^2 Post Solar	# Total Buildings	# Buildings Used	Mean Savings (kWh)
North	1,700	6	.754	.779	44	30	185 +/- 752
Central	1,500	13	.804	.790	117	79	766 +/- 386
South	1,850	13	.643	.796	114	53	1437 +/- 416
State	1,700	32	N/A	N/A	275	162	878 +/ - 464

It is unclear why the results between the monitored sites and utility bill monitored sites disagree. It is also unclear as to why many of the sites did not fit well with the PRISM data. The following list indicates some of the likely possibilities for these discrepancies:

Undocumented occupancy changes
Intermittent heating use
Summer biased seasonality effects
Mis-selection of models/reference temperatures in automated PRISM
Undocumented change of heating and/or cooling equipment

5.4 SOFT MONITORING: RESULTS COMPARISON WITH INDIVIDUAL HARD MONITORING DATA

As indicated in Figure 5.4-1. The utility-bill-predicted energy savings agree poorly with the measured energy savings from the solar systems. Thirty-one of the thirty-two monitored sites were used for this comparison. Site # 17 was dropped due to missing utility bill data. Of the remaining sites, only 1 site (#21) (3%) is predicted within the range of experimental and statistical errors and passes PRISM's criteria for "good" data. Two of the sites (#24 and #28) fell into the category of having air conditioning added, but they did not indicate large discrepancies with the measured data. A rough estimate would have been more useful than this one "good" prediction. Only 45 % of the hard monitoring sites passed PRISM's criteria for "good" data. However, 32% of the sites fell within the range of experimental and statistical error, but did not pass PRISM's criteria for "good" data. It is clear from some of the sites that magnitudes of energy savings (positive and negative) were larger than the total potential of water heating. It is expected that some noise will occur in a single sample, but these results show that the data and analysis used with the existing PRISM model were inadequate to accurately predict energy savings from the individual solar water heating systems in Florida.

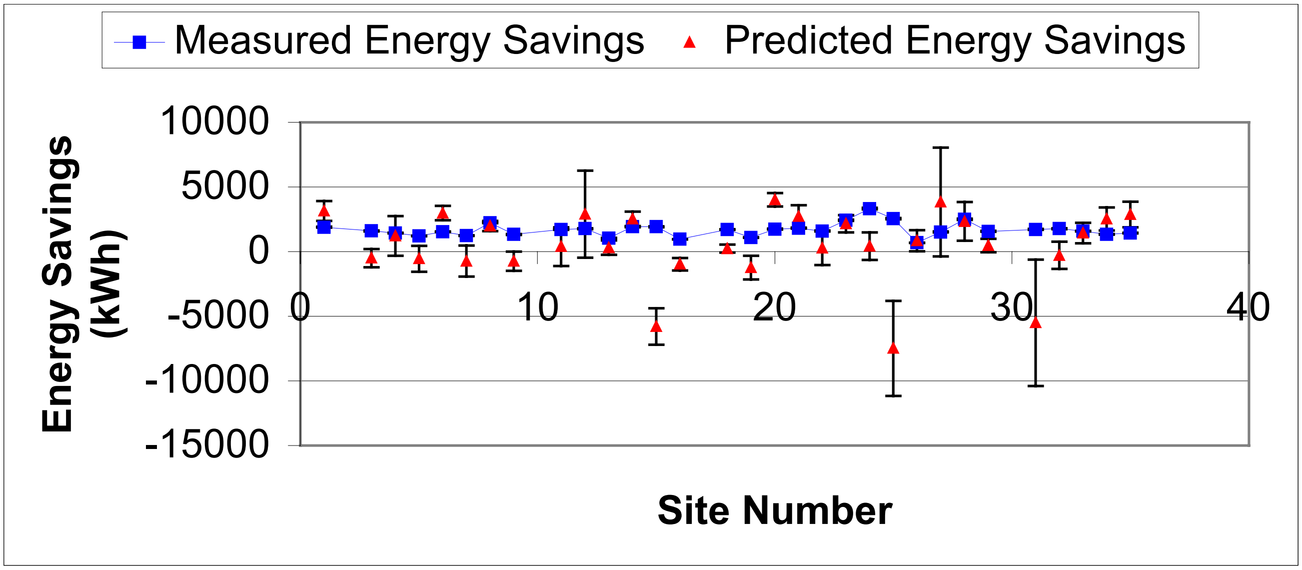


Figure 5.4-1. Comparison of Measured and Utility Bill Predicted Energy Savings

5.5 SOFT MONITORING: DETERMINATION OF WATER HEATING PERCENTAGES FROM UTILITY BILLS

For the hard monitored sites with adequate utility billing data and stable operation of the monitoring equipment/solar system, additional analysis was done to compare water-heating percentages of the electrical bill. Sites #7,#17, #26, and #31 were not evaluated in this comparison. For this analysis, the actual utility bills and actual monitored data were compared. No adjustments were required for weather, so the PRISM analysis was not used. Figures 5.5-1. and 5.5-2. indicate the percent of the electrical bill devoted to water heating both before and after the addition of the solar system.

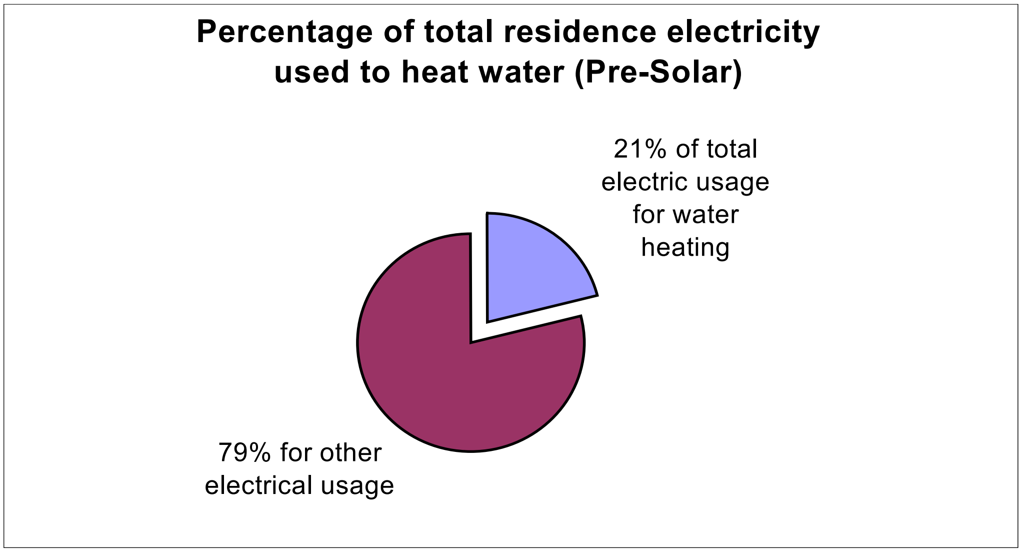


Figure 5.5-1. Percentage of Electricity Used to Heat Water – Pre-Solar

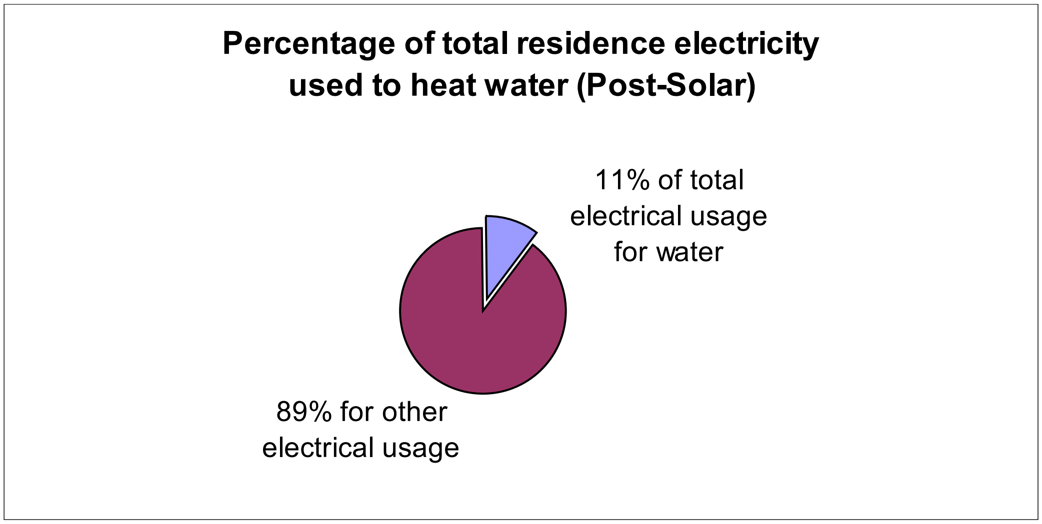


Figure 5.5-2. Percentage of Electricity Used to Heat Water – Post-Solar

Figure 5.5-3. Provides a site-by-site breakdown of the percentage of electrical usage that is devoted to heating water. As this figure indicates, the amount varies by site and is typically a very substantial portion of the utility bill. The solar system installation reduces this percentage dramatically. Note that the 21% of total usage implies that most of the households use the air conditioning on a regular basis. Probably 75% of the homes fall into this category. Note that some of sites with high water heating percentages of the total electrical bill, had no air conditioning (#23), or added air conditioning during the study period (#24, #28). Other sites with high water usage (#8) and/or undocumented changes in air conditioning account for high relative water heating percentages of their electrical bills.

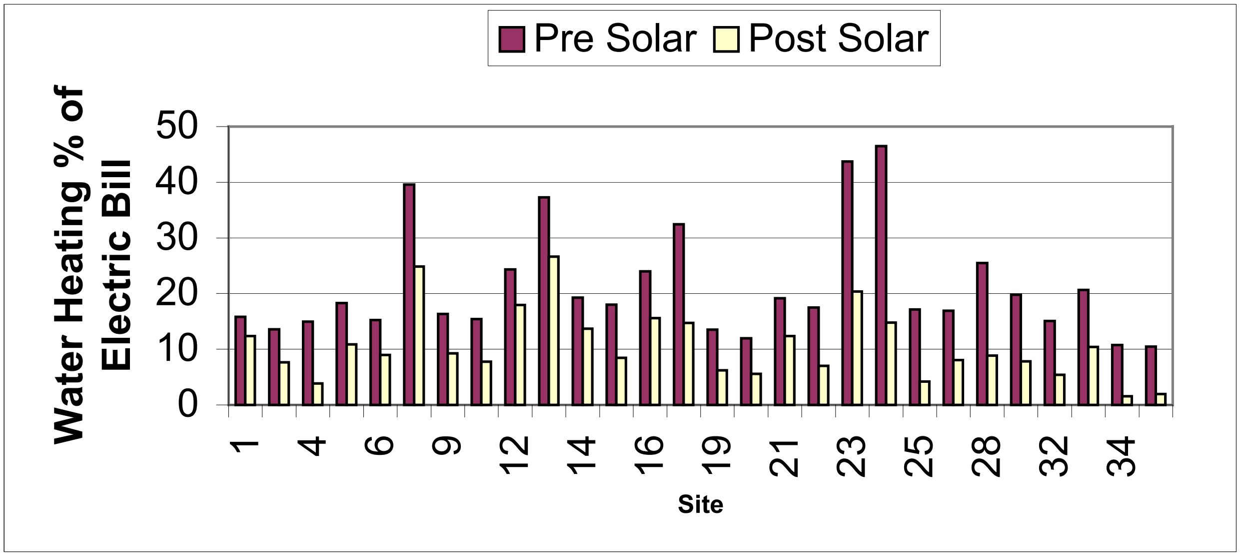


Figure 5.5-3. Percentage of Electricity Used to Heat Water – Pre- and Post-Solar by Site

6.0 INSPECTIONS

One goal of the SWAP program is the verification of installation quantity. One method of evaluating quality of installation is through the random inspection of installed systems. In the four years since the first solar systems were installed, over 25% of all installed SWAP solar systems have been inspected by FSEC staff. These inspections accomplish several objectives:

Ensure that the proper system is installed.
Ensure that major installation problems are found and rectified.
Record equipment installation methods for potential use in long-term reliability studies.
Determine if local WAP agencies are conducting post-installation inspections.

The surveys and corresponding follow-up with the clients serve to verify the accuracy of the results measured in the hard and soft monitoring phase. Without proper installation, system performance degradation and/or failure could occur.

6.1 INSPECTIONS: IMPLEMENTATION

A series of five forms were generated to provide consistency for the inspections. Each of the inspection forms represents the five different system types used in the program:

Integral Collector Storage
Thermosiphon
Differential Control
Timer Control
Photovoltaic Control

The forms address similar types of issues, including:

Approved system installed
Location of collector
Proper positioning of collector
Sealing of roof penetrations
Exterior insulation
Proper installation of valves
Tank location
Description of tank and accessories
Correct plumbing of solar system
Proper controller installed (as applicable)
Proper sensor wiring and placement of sensors (as applicable)
Pump installed (as applicable)
Owners manual/warranty provided

A copy of the inspection forms is provided in Appendix 1. For each inspection performed, a site visit was made and the appropriate form was filled out. Pictures of the installation were also taken to document installation quality and the type of installation issues encountered at each site. Results from the inspection were added to the database that was developed to administer the SWAP program. If large problems were encountered, the local WAP agencies were informed so that they could have the installation contractor remedy the problems. If the problems were minor, FSEC staff made the modification and corrections on the spot.

6.2 INSPECTIONS: RESULTS

The results of the inspections are summarized in this section. A full breakdown of the inspections is indicated in Appendix 13. The information for this section was gathered from two sources; the FSEC on-site system inspection and client survey responses that indicated a problem or perceived problem with their solar system. Problems noted during FSEC inspections and those reported through client surveys were listed in the FSEC SWAP database under problem events. This section of the report deals with the problem events. All of these problem events are presented in this section, rather than the survey section.

As Table 6.2-1 indicates, many of the problems are not significant enough to cause system failure, although they may eventually lead to lower performing systems. However, most of these problems could have been resolved with little additional effort at the time of installation. Of the problems indicated, 53% are solar installation related. All other problems are due to monitoring activities, electrical system, and plumbing. These discrepancies also include not providing clients with system owner's manuals and warranty documentation. Additionally, there appear to be many types of problems. No single major problem was found.

It is quite obvious from the problems and minor discrepancies discovered by FSEC during their inspections that many of the local WAP agencies were not conducting adequate post-installation inspections of the installed systems.

Table 6.2-1. The Eleven Most Common Identified Problems

Problem	Magnitude of Problem	% of Problem Events
No problem exists	N/A	29
Problem not determined*	Varies	5
Exterior piping not UV protected	Minor	5
Piping insulation not well sealed	Minor	5
Hot/cold piping not insulated properly	Minor	4
Reverse thermosiphoning through anti-scald valve	Minor	4
Air in system after ICS installed	Minor (Self correcting)	3
Plumbing leak	Moderate-Major	3
Sensor wires not protected from environment	Moderate	3
No hot water (Actually a symptom)	Major	3
Hot water temperature is too low (A symptom)	Moderate	3
* Information obtained from client surveys.		

The means of identifying problems is also useful to know. The collected data indicate that the inspections were the most effective in identifying problems. The major problem identification means is shown in Table 6.2-2.

Table 6.2-2. The four most common problem identification methods

Problem identification	% of Problems
Routine inspection	70
Homeowner Survey	10
Monitoring (only 4% of systems monitored)	8
Homeowner observation	8

Table 6.2-3. provides a breakdown of the problem types. Installation errors account for the largest number of problems. No problem found was the second largest category. Note that some of the problems listed above (e.g. ICS air entrainment) are not classified as problems in this section because they are not true problems with the product and/or installation (the air leaves the ICS on its own). There is clearly a wide disparity in the quality of work done by installers. Although any installer is likely to have a few problem installations, some installers had an installation problem rate (real problems) of up to 88% (17 installations). A guideline of minimal quality (e.g., 10% problem rate or less) should be used for minimum installer quality.

Table 6.2-3. Most Common Problem Types

Problem Type	% of Problems
Installation	36
No problem *	33
Device failure	8
Other	7
Adjustment	5
Design	4
* FSEC inspection conducted after client problem event notification on survey. No problems discovered.	

As indicated in Table 6.2-3., product failures only constitute 8% of the total problems. After only 2-3 years, this is not expected to be a big problem. Table 6.2-4. indicates the failures observed to date. Note that many of the failures have not been fully documented.

Table 6.2-4. Primary Product Failures (Year 2-3)

Product Failure	% of Product Failures
Corrected (undocumented)*	31
Unresolved (undocumented)**	21
Replaced Air Vent	10
Replaced freeze valve	7
Replaced check valve	7
* Client surveys indicated problem had occurred but was eventually corrected.	
** Information obtained from client surveys.	

Identifying a problem is the first step in getting the system operational. Common symptoms are shown in Table 6.2-5. Note that the largest symptom is that the system appears to be operating. This underscores the fact that many of the problems that have been encountered are minor.

Table 6.2-5. Common Problem Symptoms

Symptom	% of Problem Symptoms
Appears to be working (minor/no problems)*	62
Plumbing leaks	6
No hot water	4
Can't tell if system is working (From surveys)	4
High cold water inlet temperatures (Monitoring)	4
Not enough hot water	3
* For example: Water dripping from roof in winter turned out to be freeze valve functioning as it should, etc.	

Resolution is the key step to maintaining system operation and persistence of savings. Table 6.2-6. indicates the primary means of problem resolution. Many of these have not been fully documented and/or have not been resolved at this point. Note that many of the problems are either not problems (see previous tables) or are not serious enough to require attention.

Table 6.2-6. Problem Resolution

Problem Resolution	% of Problem to be Resolved
No action required	30
Not resolved yet	22
Corrected (undocumented)*	16
No clear resolution	5
Raise thermostat temperature	4
Add check valve to anti-scald valve loop	4
* Client surveys indicated problem had occurred but was eventually corrected.	

6.3 INSPECTIONS: VISUAL SITE INSPECTIONS

The primary purpose of the system inspection process was to make sure that the systems were installed and operating properly and also to characterize the type of installation and system problems encountered. Note that the local agencies' inspection information and data (if inspected) were not included in the final inspection results. FSEC staff were nevertheless, often contacted by local agencies when they conducted a system inspection and needed technical input or assistance in clarifying or resolving noted problems. FSEC routinely inspected systems after initial installation. Since FSEC received installed system report forms (which did not include inspection information, only the status and information on the systems installed) for each system installed by all agencies, FSEC could eventually conduct spot inspections to make sure that the systems were properly installed and that the local agencies were indeed conducting satisfactory inspections.

The majority of inspections were conducted by FSEC during the installation phase of the program. After all systems had been installed, FSEC sent system owner surveys to all clients that had received solar systems. (Please refer to Section 7.0 for a detailed summary of the survey findings.) Several of the clients noted that they had or were having problems with either the solar system, its components, or hot water delivery. At that time, FSEC conducted visits to these sites to investigate the problems. The results of these extra inspections are also included in this study.

FSEC inspected 210 (26% of total installed) solar systems during the SWAP program. This does not include sites that were inspected during the solar site selection process. FSEC staff became quite familiar with low-cost system installations. The following tables provide information on the total number of systems inspected by geographic location as well as by system type.

Installing solar systems requires much attention to detail. In addition, the installation is usually conducted in less than ideal conditions; on roof tops, in extremely hot attics, and in cramped utility rooms and garages. Because of this, shortcuts and lack of attention to details may occur. Although these do not in general, affect the operation of the system in a major way, they can, in the long run, lead to performance and materials problems that could require that the system be serviced.

Installers have to solder pipes, valves, fittings, pumps, and ancillary plumbing materials. Also, they have to install solar collectors on roofs, which includes making roof penetrations and installing of roof flashing. Electrical work is usually centered around installing controllers and necessary sensor wiring, as well as, at times, having to replace electric water heaters. It must be noted that although other licensed trades, such as plumbers, and HVAC contractors, are allowed to install solar systems, they very often do not have the overlapping required skills. For this reason, FSEC provides solar water heating system training programs to increase the level of expertise and knowledge required to install solar systems.

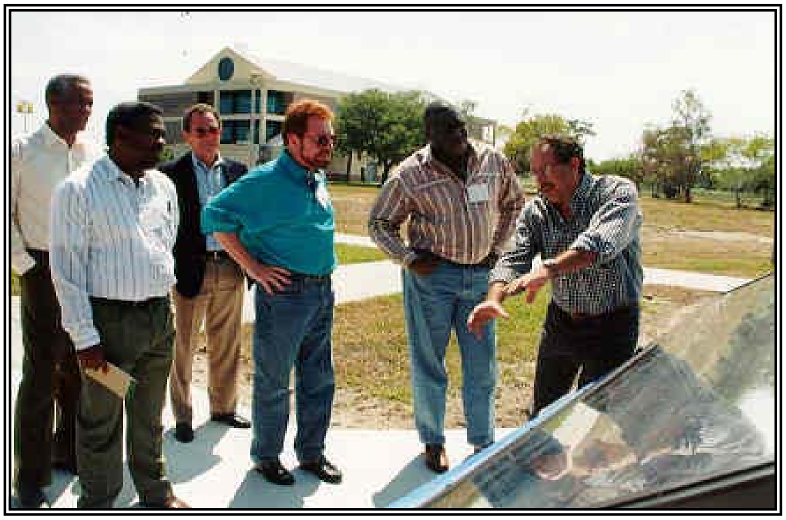


Figure 6.3-1 FSEC staff conducting solar system training.

Solar systems are not purchased in modular forms. Various household appliances come, in most part, as pre-assembled units. This is not the case with solar systems. Most components come separately and have to be installed in the field. This includes the mounting of solar collectors, the plumbing of numerous valves and pumps, the installation of insulation on water piping, the coating of exterior piping to protect it from ultraviolet rays and so forth. Each component must be installed in a particular way to ensure proper system operation and long term reliability.

In conducting the inspections, FSEC was very concerned about identifying not only extreme system problems, such as defective controllers and/or sensors, but also small negligible problems and shortcuts taken that led to less than ideal system installations.

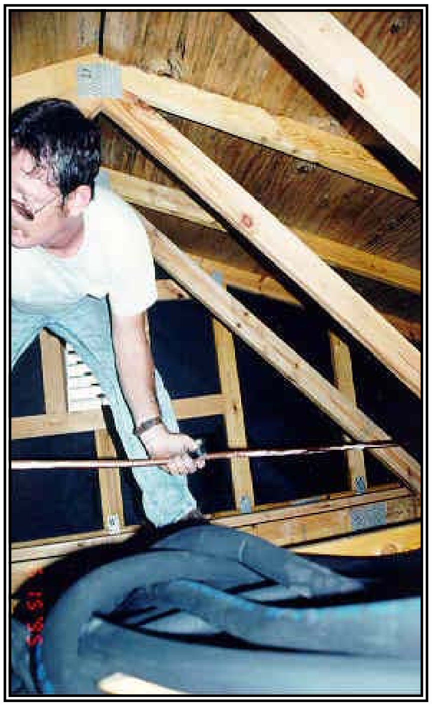


Figure 6.3-2. Installing plumbing and insulation in attic.

Figure 6.3-3. Working in restricted areas.

Table 6.3-1. SWAP System Inspections by Location

Location	Number of inspections	% of total installed systems (in location)
North Florida	38	21
Central Florida	82	37
South Florida	90	23

Table 6.3-2. SWAP Systems Inspected by System Type

System Type	Number of systems	Percent of total inspected systems (by system type)
Active (Pumped) Flat-plate	115	14
Integral Collector Storage (ICS)	93	12
Thermosiphon	2	.03

The majority of discrepancies noted during inspections were of a manner that did not directly affect system performance. Discrepancies were related more to craftsmanship than major system design or material flaws.

Following is a photographic overview of some of the most common inspection discrepancies noted. Each discrepancy will be accompanied by a photograph of a separate installation indicating the proper installation method.

The following pictorial descriptions highlight a variety of discrepancies that were encountered during the inspection of SWAP systems by FSEC staff. This does not include all discrepancies noted, but primarily the major ones and those that were too often repeated. Illustrated is both a problem situation as well as an example of the proper way of conducting the installation task.

COLLECTOR SHADING

Figure 6.3-4a. Collector is shaded during much of the day.

Figure 6.3-4b. Unshaded collector provides solar gain throughout the day.

COLLECTOR AND EXTERIOR PIPE DRAINING

Figure 6.3-5a. Collector return line can not be completely drained due to upswing in piping. At times, this is unavoidable due to the layout of the roof and access locations.

Figure 6.3-5b. Simple roof layout allows easy roof penetration location.

COLLECTOR SECURELY ATTACHED TO MOUNTING HARDWARE

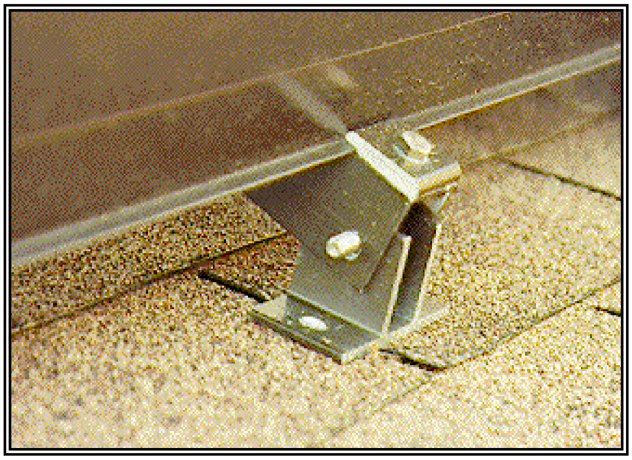


Figure 6.3-6a. Simple oversight while installing the collector without hardware

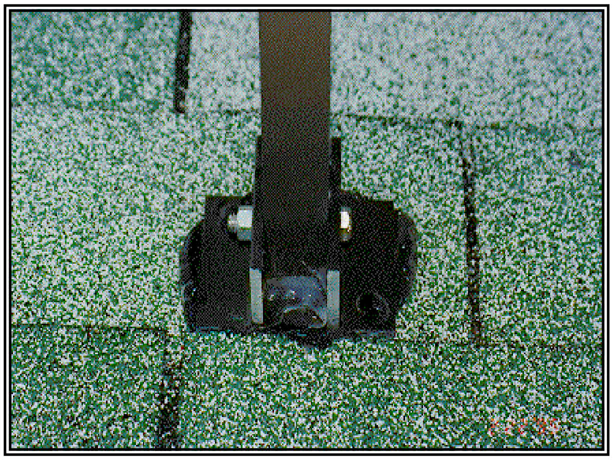


Figure 6.3-6b. Properly bolted mounting hardware.

ROOF PIPE PENETRATIONS ARE PROPERLY AND AESTHETICALLY SEALED

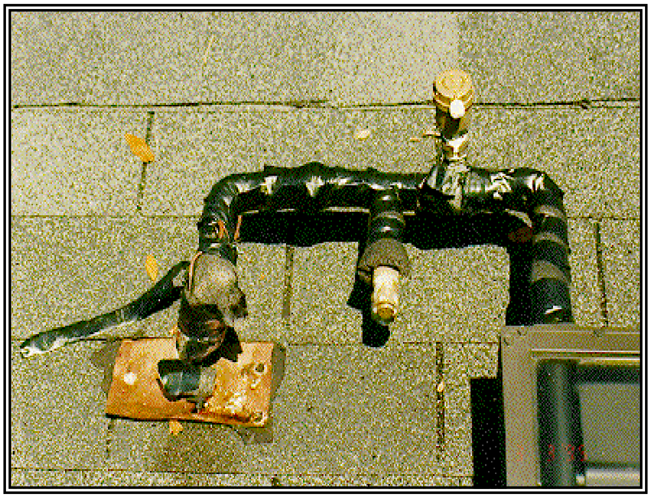


Figure 6.3-7a. Roof flashing is exposed and improperly sealed.

Figure 6.3-7b. Roof flashing is well installed. Insulation is added to cover pipe after copper is soldered.

EXTERIOR PIPING INSULATION PROTECTED FROM ULTRAVIOLET RAYS

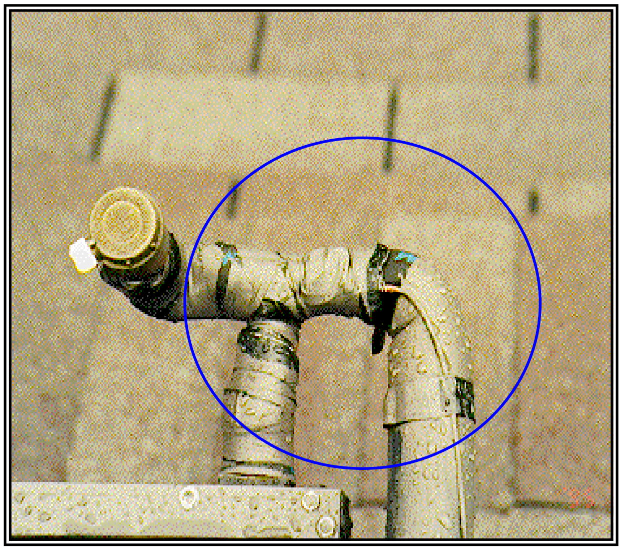


Figure 6.3-8a. Sections of insulation and sensor wiring have not been protected from ultraviolet rays.

Figure 6.3-8b. Care is taken to make sure that all exposed piping and sensor wires are ultraviolet ray protected

Figure 6.3-9a. Cracking and eventual deterioration will occur if insulation is not ultraviolet ray

Figure 6.3-9b. Well protected insulation will last many years.

Figure 6.3-10a. Plastic-based insulation should not be used for exterior piping.

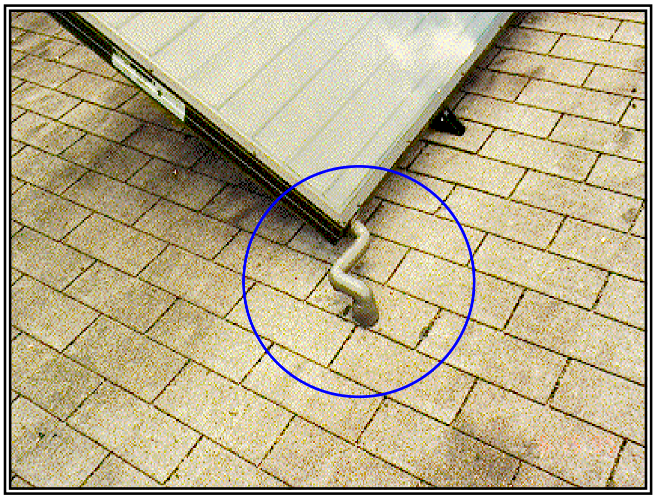


Figure 6.3-10b. A very professional and aesthetically pleasing job.

PIPING JOINTS AND ENDS ARE WELL SEALED

Figure 6.3-11a. Ends of pipe runs should be well butted.

Figure 6.3-11b. Use of 45 degree angle cut and insulation glue provides a positive and aesthetic seal.

AIR VENTS INSTALLED IN VERTICAL POSITION

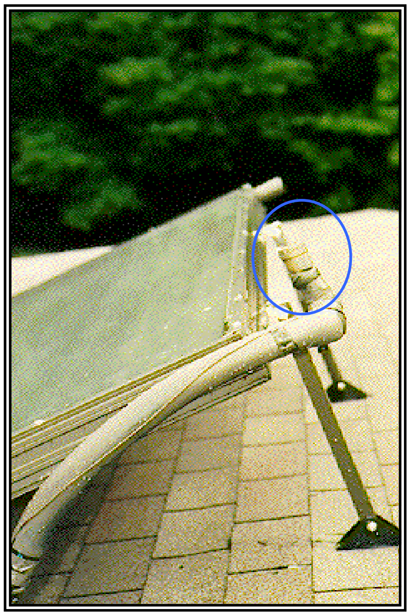


Figure 6.3-12a. Air vent installed in plane of collector instead of vertically true north.

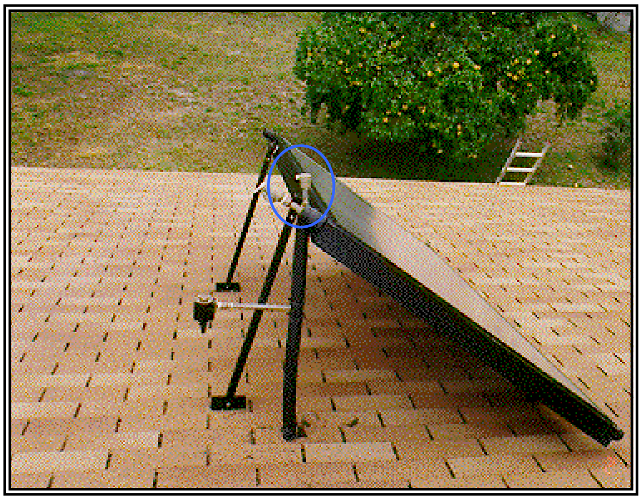


Figure 6.3-12b. Air vent installed in true vertical position.

SENSORS SECURELY ATTACHED AND PROTECTED FROM ENVIRONMENTAL DEGRADATION

Figure 6.3-13a. Collector sensor secure but not insulated or protected from environmental degradation.

Figure 6.3-13b. Collector sensor is secure and protected from environmental conditions.

LOCATION OF COLLECTOR SENSOR

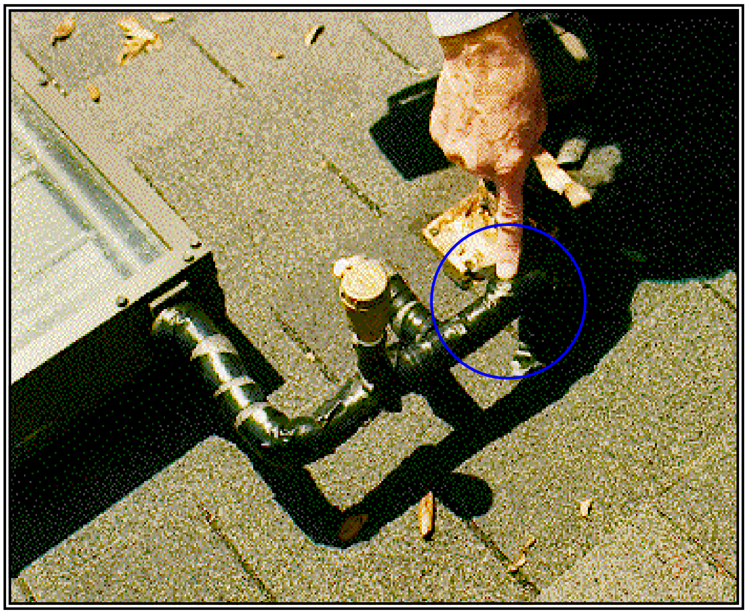


Figure 6.3-14a. Collector sensor installed too far from collector.

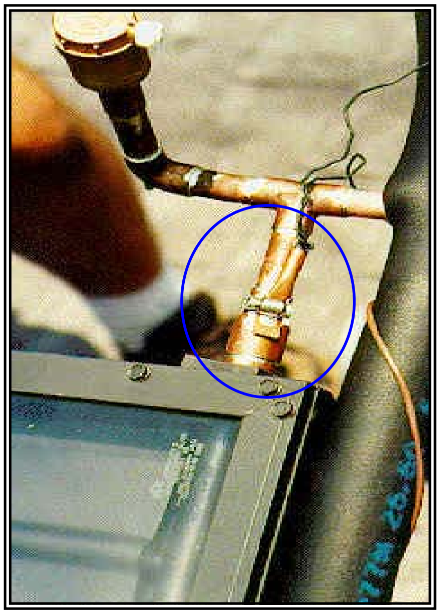


Figure 6.3-14b. Collector sensor securely attached at exit of collector - the hottest point.

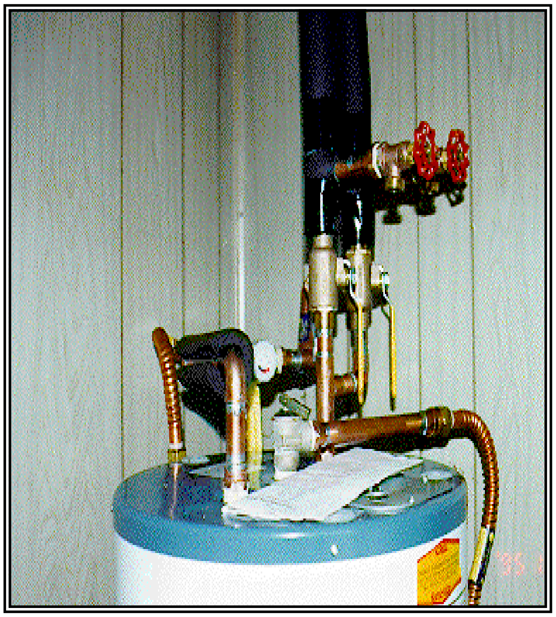


Figure 6.3-15a. External tank piping not completely insulated from heat losses.

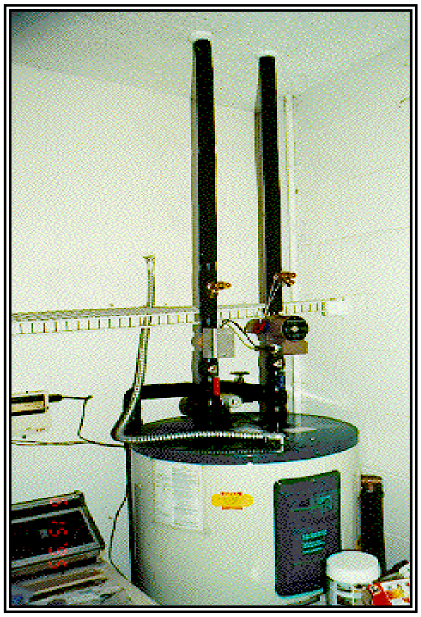


Figure 6.3-15b. Thorough insulation of tank piping.

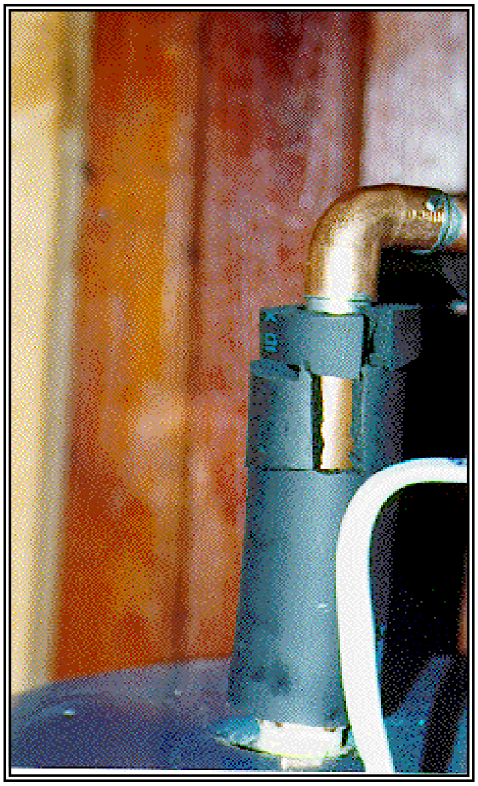


Figure 6.3-16a. Little pride of work reflected in this insulation

Figure 6.3-16b. Excellent insulation installation.

Figure 6.3-17a. Attic insulation must be secured.

Figure 6.3-17b. Attic pipe well insulated and glued together at 45 degree joint.

WATER HEATER NOT PROTECTED FROM ELEMENTS

Figure 6.3-18a. Top and sides of water heater protected, but not front. Pump is exposed to elements.

Figure 6.3-18b. Water heater and components enclosed in storage shed.

Figure 6.3-19a. System controller protected by common Tupperware enclosure.

Figure 6.3-19b. Solar pump and controller are protected.

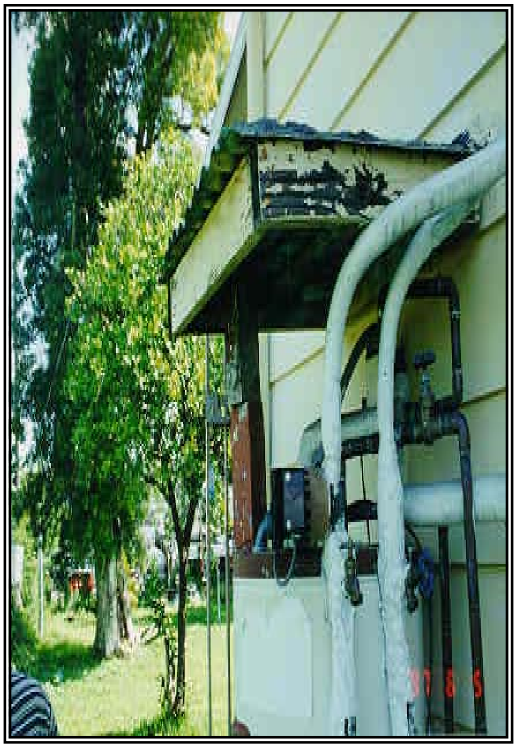


Figure 6.3-20a. Minimal water heater and component protection.

Figure 6.3-20b. Protected water heater and solar components.

Figure 6.3-21a. Ceiling penetration left bare.

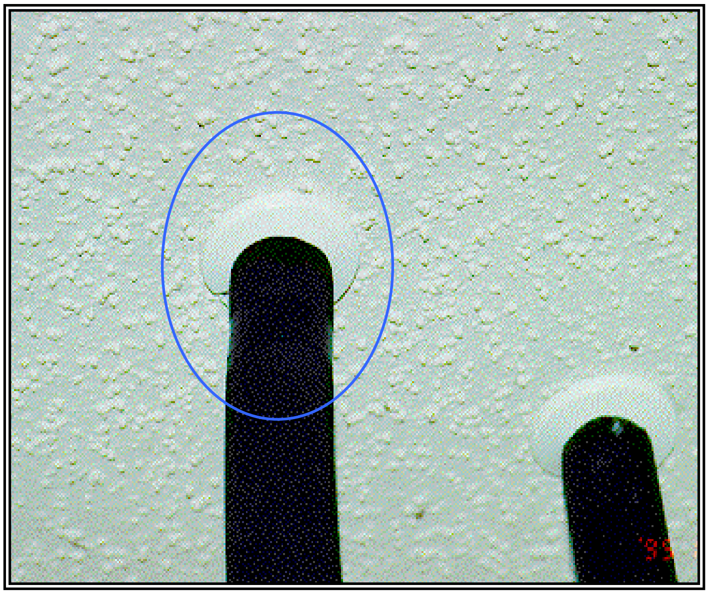


Figure 6.3-21b. Escutcheons used to cover ceiling penetrations.

Figure 6.3-22a.. Extra sensor wiring left dangling on floor.

Figure 6.3-22b. Neat solar plumbing and insulation installation to water heater.

6.4 LIFETIME OF SOLAR SYSTEMS

The anticipated useful lifetime of the SWAP systems is expected to be at least 20 years. The ICS systems could possibly have the longest periods without any service interaction due to their simplicity and lack of major mechanical parts. This of course, will depend on the reliability of the various valves and ancillary plumbing material.

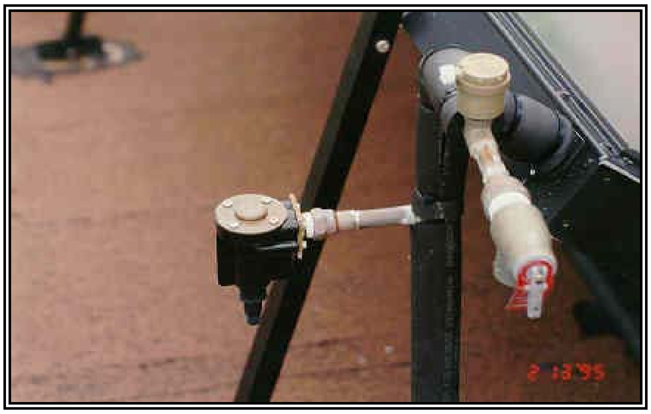


Figure 6.4-1. From left, freeze prevention valve, air vent, and pressure relief valve installed on a flat-plate collector system.

Flat-plate solar collectors also have a twenty-year (minimum) life expectancy. The servicing of various pumps, valves, etc., will undoubtedly occur during this lifetime. FSEC is hoping to continue long term evaluation of the SWAP systems to accurately determine the operational lifetimes and maintenance costs of the various components.

During the implementation phases of this program, FSEC queried major industry representatives in Florida to develop a general idea of the expected lifetime of the various components used in solar water heating systems. Six major Florida manufacturers and installers provided this information. This survey was conducted in 1993. Table 6.4-1 outlines the components and their expected lifetimes. The figures listed are averages. The averages by category refer to general collectors, pumps, controllers, etc.

Table 6.4-1. Average Component Lifetimes

SYSTEM COMPONENT	AVERAGE EXPECTED LIFETIME (YEARS)	HIGH AND LOW RESPONSES	AVERAGE LIFETIME BY CATEGORY
Flat-plate collector	29.0	15 to 40	
Integral Collector Storage Collector	23.0	9 to 30	26.0
Pump, DC	9.8	7 to 15	
Pump, AC	12.0	10 to 15	10.9
Storage tank, solar	9.4	5 to 15	
Storage tank, conventional electric	9.4	5 to 15	9.4
Controller, differential	8.9	4 to 13	
Controller, photovoltaic	14.4	10 to 20	

Controller, timer	9.5	8 to 10	10.1
Freeze prevention valve	4.3	3 to 5	
Air vent	5.5	3 to 8	
Pressure-Temperature relief valve	9.0	7 to 10	
Pressure relief valve	11.6	8 to 20	
Vacuum breaker	7.1	3 to 15	
Isolation valve, gate	5.6	2 to 10	
Isolation valve, ball	13.0	10 to 15	
Drain valve	14.7	7 to 20	
Check valve, vertical	5.9	2 to 10	
Check valve, horizontal	5.1	2 to 10	
Check valve, motorized	8.6	5 to 10	8.2
Piping, copper	20+	20+	20+

Note that these figures are based on verbal interviews with the respondents. There is a wide range reported for similar components. The actual lifetime of specific components, especially the valves, is highly debatable. Also, the brand of components and quality of installation would greatly affect the lifetime of the component. Quality components installed properly have long lifetimes. Local water quality also greatly affects the degradation of components as has been exhibited in the SWAP program. (See Overview of the Installed Systems – Section 2.0)

Funds permitting, FSEC will maintain contact with the SWAP clients and maintain its database to obtain field information on the reliability and lifetime of the SWAP systems and their components. This is a golden opportunity to validate component reliability and lifetime information.

7.0 SURVEYS

The final means of gathering information regarding the performance of the SWAP program is the use of qualitative surveys. Rather than emphasizing performance related issues, these surveys were meant to provide some general information regarding low-income households and also to provide some feedback regarding the solar system. Information from the surveys could be used to address the following:

Perceptions of the solar system.
Problems with the solar system and/or installation.
Compare perceived savings and usage with actual savings and usage.
Identify changes in the household.
Indicate general information about households receiving SWAP systems.

This information could be used to improve a full-scale implementation of SWAP.

7.1 SURVEYS: IMPLEMENTATION

Creation of a survey form and cover letter was the first step of the survey process. The survey form addresses the following categories of information:

Household occupancy.
Water usage patterns.
Perceived savings of the solar system.
Satisfaction with the solar system.
Amount of hot water available.
Other WAP measures taken.
Use of air conditioning.
Understanding of the solar system.
Usage of anti-scald valve and/or water heater on/off switch.
Receipt of owner’s manual.
Additional questions and/or comments.

A copy of the cover letter and survey form is included in Appendix 14. These surveys were mailed (or filled in during an inspection) to all participants in the SWAP program after the systems had been installed for at least one year. The responses from the surveys were entered in to the SWAP database.

7.2 SURVEYS: RESULTS

In general, the surveys indicate satisfaction with the solar systems and the realized energy savings. There are several issues that these surveys have revealed that should be included for future programs. The results documented here sample the more significant points of the survey responses. The details of all the responses are indicated in Appendix 15. Thirty-seven percent of the surveys were returned, yielding a good sample of information from the participants. In general, the results follow the survey form; some items, which have been used for administrative purposes, are not indicated here.

In response to “Are you satisfied with your solar system?”

77%	Responded Yes
14%	Responded No
9%	Responded Somewhat

Of those not satisfied with their systems, the top four reasons were:

29%	No energy bill savings
22%	Not enough hot water
6%	Run out of hot water
6%	Water is not hot enough

This indicates that water quantity accounted for 1/3 of the dissatisfied participants, although it is unclear whether the existing system would have elicited more or fewer complaints.

In response to “Do you see any reduction in your utility bill since the solar system was installed?”

63%	Responded Yes
15%	Responded No
22%	Responded Can not determine

Of those indicating yes, the average monthly reduction was $24.38. This figure is approximately twice the average savings projected from the hard monitoring phase.

In response to “Do you have more hot water than you had before the solar system was installed?”

44%	Responded More
31%	Responded Same
16%	Responded Less
9%	Responded Sometimes

Of those not responding more, the following top 4 reasons were given:

22%	More hot water in summer and less in winter
18%	Not enough hot water when there is no sunlight
18%	The amount of hot weather depends upon the weather
14%	Run out of hot water

These results indicate that the occupants observe the weather-sensitive nature of the system, but are not satisfied when the auxiliary heater cannot keep up with demand.

In response to “Do you use more hot water now that you have the solar system?”

21%	Responded More
65%	Responded Same
11%	Responded Less
2%	Responded Sometimes

Of those responding to all except “Same”, the following 2 reasons were given:

75%	Would use more hot water if water was hotter (3 responses)
25%	Added other appliances that use hot water

The first result is non-intuitive. Perhaps this indicates dissatisfaction with the amount of water available. Note that there were few responses to this question and the responses were mixed.

In response to “Is the water hot enough?”

76%	Responded Yes
14%	Responded No

10%	Responded Sometimes

Of those not responding “Yes”, the following top 3 reasons were given:

50%	There is more hot water in summer and less in winter
17%	There is not enough water when there is no sunlight
17%	No reason given

The responses to this question (and also the general satisfaction) indicate that the majority is satisfied with the water temperature. However, a significant minority feels that the temperature is too cold and too easily impacted by the weather. In many cases, the simple solution to this problem is to increase the temperature of the bottom heating element, although this will reduce solar performance, especially for the active systems.

In response to “Is the water too hot?”

3%	Responded Yes
90%	Responded No
7%	Responded Sometimes

Due to an error in the survey form, the only detailed response of interest was “The hot water took to long to arrive.” From these responses, the overheating of water does not appear to be a big problem.

In response to “Does your solar system have an on/off switch at the water heater for turning the electricity to the water heater on or off?”

36%	Responded Yes
23%	Responded No
41%	Responded Don’t Know

Note that the 41% response to “Don’t know” emphasizes the need for systems to operate with a minimal amount of user intervention.

In response to “If you have this on/off switch, do you use it?”

63%	Responded Yes
37%	Responded No

Of those responding No, the following 2 top reasons were given:

64%	Don’t know how to use the switch
14%	There is not enough hot water when the sun does not shine

This response indicates the need for explanation of the system operation and availability of an owner’s manual. The second response indicates the limitation of this switch.

In response to “Does your solar system have an anti-scald valve installed?”

19%	Responded Yes (43% of these actually have an anti-scald valve)
9%	Responded No (0% of these actually have an anti-scald valve)
73%	Responded Don’t know (23% of these actually have an anti-scald valve)

Of those responding “Yes”, how many know how to adjust the valve:

11%	Yes
89%	No

These results indicate that few users are aware of this device or function.

The surveyed participants were also asked to rank water usage for the top three times of usage. The total count indicates those results:

5-10 Hrs.	160
10-12 Hrs.	80
12-15 Hrs.	71
15-18 Hrs.	137
18-21 Hrs.	191
21-24 Hrs.	110
0- 5 Hrs.	11

In general, the self reported water usage matches the measured profile: The measured peak was from 8-10 PM during the self-reported peak. The minimum was reported in the same time period as the measured minimum. The reported peak appears to dip more than the measured peak, but this may be because only the top three choices were offered.

In response to “Does the solar system inconvenience you in any way?”

6%	Responded Yes
84%	Responded No
10%	Responded Sometimes/Somewhat

For those indicating that the system did or sometimes inconvenienced them, the following 2 top reasons were given:

63%	When no hot water is available
32%	Water does not get hot

This question reaffirms the importance of the amount/temperature of the delivered hot water temperature. Note that no maintenance, operation or aesthetic issues were raised, indicating that these issues were not significant for this group. Overall, few were inconvenienced by their systems.

In response to “Is your system presently working in a satisfactory manner?”

78%	Responded Yes
22%	Responded No

For the “Yes” responses, the reported ways of knowing are:

61%	Plenty of hot water
22%	Appears to be working
6%	Electrical bill has been reduced

For the “No” responses, the reported ways of knowing are (5%=1 response):

14%	No hot water
14%	Run out of hot water
14%	Can’t tell if system is working

10%	Water is not hot enough
10%	Not enough hot water
5%	Water is not hot enough when no sun
5%	Water hotter during daylight hours
5%	Pump is always running
5%	Doesn't know how it works

Both of these questions indicate that there is little correct understanding of how the system responds when it is or is not working. In many cases, these responses indicate a symptom that may or may not exist and a problem that may or may not exist. Unfortunately, diagnosing problems can be difficult without a full understanding of the system operation. Without this knowledge, system failures may not be recognized and rectified.

In response to "Do you understand how the solar system works?"

69%	Responded Yes
31%	Responded No

In response to "Did the solar installer explain to you how the system works?"

74%	Responded Yes
26%	Responded No

In response to "Do you know how to check to see if your system is working?"

33%	Responded Yes
67%	Responded No

The results illustrate that many think they know how the system works, but to the system working question, only 15% gave credible answers regarding checking system operation.

In response to "Do you have the owner's manual that explains how the system operates?"

54%	Responded Yes
46%	Responded No

"If Yes, Have you read the manual?"

54%	Responded Yes
44%	Responded No

This is a very high rate for reading manuals. All of the participants should have received a manual, although some of them may have been lost.

In response to "Do you have any questions about anything you have read in the manual that you do not understand?"

71%	Want an owner's manual
12%	Want to know how to use on/off switch

These responses reaffirm the number without an owner's manual and the lack of understanding about using the on/off switch.

In response to "Have you had any problems with your solar system?"

19%	Responded Yes

81%	Responded No

In response to “Do you have the name and address of the solar installer?”

59%	Responded Yes
41%	Responded No

This information is required by the system certification on the tank and in the owner’s manual and is useful if any problems develop or routine maintenance is required.

In response to “Does your house have an air-conditioning unit?”

30%	Have a window/wall unit
67%	Have a central air unit
3%	Have no air conditioning

Although the interest for this weatherization option is water heating, the air conditioning has a large impact on the analysis of the utility bill data. Clearly, this survey shows that air conditioning is present in most (97%) of the homes that participated in the weatherization program. This is contrary to the belief that low-income residences do not have air conditioning.

In response to “Do you have any other questions or comments regarding the solar system?”

17%	Want an owner’s manual
17%	Don’t know how the systems work
10%	Have inquiries about the system
10%	Don’t know how to use the on/off switch
10%	Have no questions
7%	Expressed their appreciation for the solar system

These responses indicate that having the owner’s manual with adequate explanation about the system and its operation would have eliminated most of the questions. A positive aspect is the voluntary expression of appreciation.

Overall, the results of the surveys indicate several key issues that should be addressed for any future work:

There is a high degree of satisfaction with the solar systems. Perceived energy savings were double the average measured savings.
The most often mentioned shortcoming is low water temperature/lack of hot water supply when the solar is not in operation.
Many participants lacked an owner’s manual that should have been provided.
Many participants are interested in how the system operates, but have little information to this effect.
The indicated ability to evaluate system operation is low. This may be from the fact that the participants do not have an owner’s manual, or the owner’s manual does not contain this information.

8.0 CONCLUSION AND RECOMMENDATIONS

The development of the SWAP program has involved many activities, including system type selection, system sizing, training, hard monitoring, soft monitoring, inspections, and surveys. Much data have been acquired and many lessons have been learned. This wealth of information provides a stepping point for the following recommendations. These recommendations are meant to address the findings from this program and how they can be used to improve upon this implementation of SWAP into the standard WAP program.

MONITORING RESULTS

The hard monitoring phase of the SWAP project yielded much data, denoting an overall SIR of 1.0, indicating the viability of SDHW as a weatherization measure in Florida. The data also showed that the low-income families tend to have peak water usage from 8-10 PM with a continual hourly average use throughout the daylight hours. This indicates that the application of solar to low-income residences is particularly beneficial to the residents and also to the functioning of the solar systems. Although there was considerable scatter to the data, a general guideline is that a minimum pre solar energy consumption of 3,100 kWh (10.6 MMBTU), or a minimum flow rate of 60 GPD will achieve sufficient savings to justify this as a weatherization option. Because reported occupancy data appear to have been at times questionable, the use of some type of short term monitoring of a proposed weatherization site would be recommended. The calculation of the SIR for NEAT could be improved by the inclusion of an estimate of maintenance that is necessary for many appliances, including SDHW systems.

As part of the evaluation of the hard monitoring, F-Chart was used to compare measured and simulated energy usage. The results indicate that the average measured active system energy usage was more closely matched to the F-Chart average predicted energy usage than the ICS average measured energy usage was. A re-examination of the F-Chart program would be useful to explain this difference and the different system type prediction trends indicated. Additionally, F-Chart cannot be used to model more complicated systems that are be encountered (such as PV powered pumps, timers, mixing valves, etc.).

The system sizing criteria indicates an overall agreement with the targeted goal of 50% solar fraction. However, examination by climate zone indicates that 0% of the systems in the Northern zone, 54% of the systems in the Central zone, and 100% of the systems in the Southern zone met this goal. Improvements to the sizing procedure would include sizing the system by load. Additionally, the use of a sizing range would optimize SIR for the systems.

The soft monitoring program was set up to determine if energy savings from SDHW could be evaluated through utility bill analysis, rather than through the more expensive and time consuming process of instrumented monitoring. In general, the results from this analysis were inconclusive on a statewide basis. Even with expanded site selection criteria, fewer than 2/3 of the selected sites had acceptable fits for calculating savings. The state comparison indicated no agreement between the hard monitoring and soft monitoring savings. Although no one problem was identified, several theories were indicated, including undocumented occupant changes intermittent heating usage, and summer seasonality effects. One indicated improvement to the PRISM program is the ability to de-select poor reference temperatures for the automated model selection mode. It is possible that this may have improved some of the fits. Based upon these problems, there is not sufficient evidence to rely upon soft monitoring for measured savings of solar domestic hot water system retrofits.

SYSTEM TYPE SELECTION

One issue of particular concern is if the selection of system types was appropriate and cost effective for this particular application. In general, the active systems did well in Southern Florida, and the Passive systems did well in central Florida. The passive systems in Northern Florida had low performance, with no SIRs above 1.0, due to the cooler winters and higher installation costs. Overheating did not occur on any of the systems. Freeze damage occurred on only one active system (which led to an adjustment of the installation of system types in a small region.

Overall, the ICS systems seem to be the best systems for low-income clients in central and southern areas. ICS systems are so simple in their operation that client interaction is truly not required. There are no moving parts that can malfunction. Ancillary valves, such as air vents and freeze prevention valves, are not necessary on ICS systems installed in Central and South Florida thereby reducing further component use and possible failure. (Of course, ¾" copper piping and ¾" thick pipe insulation should also be used for piping freeze protection.) The other valves installed on this system are the isolation and drain valves, which are unlikely to cause any trouble during the lifetime of the solar system. The only other valve required is the collector loop pressure relief valve, which also is quite trouble free. Therefore, excluding the air vent and freeze valve leaves one with a system that is basically service free for the lifetime of the ICS unit. There is truly no system owner interaction required with these units.

Experience with variations of active system type indicates that certain variations and/or components should be re-examined for use with low-income clients. One of the variations of the active system was the use of a timer instead of a differential controller to reduce installed cost by approximately $100. Inspections of this system indicated that the system's bottom feed/return fitting can be crimped during some installations. This seems to occur primarily when installed on those water heaters that have a convex bottom that blocks the fitting's long input nozzle. Several systems also exhibited what appeared to be airlock problems. Both of these problems severely hindered system performance.

Another problem was that the timers were accidentally or incorrectly re-set, leading to the problem that the systems were not operating properly. In addition, after one year, the timers' back-up batteries need to be replaced. If the batteries are not replaced and eventually expire, the operation set times will be inadvertently changed during power failures. Very often, the installer did not leave timer instructions with the client. Routine inspection of timer systems revealed that the SWAP clients did not know how the timer operated or even that batteries had to be replaced.

Since these systems do require periodic checks to make sure that the timers are still set accurately and require an annual replacement of the timer batteries, unless the clients are willing to devote time and energy to these systems, these may not be the ideal systems for low-income clients.

FSEC inspections also revealed that several differential controllers had somehow been disconnected from the AC power source. This, of course, left the solar system owner with an inoperative system. FSEC also had to replace several controllers as well as sensors that had failed.

These examples serve to emphasize that solar systems used in low-income residences need to be as simple as possible, have a minimum number of components, and require no client interaction.

Another system variation was the use of an on-off switch on the water heater of active systems. As indicated by the monitored data, these switches have the potential to dramatically increase performance, although they were most utilized by the families having small water heating loads and an SIR less than 1.0. They do add some complication and $30-50 to the system cost. They were also often not understood nor used by the majority of homeowners. Although these switches can be useful, they were not found to help high energy use homeowners (the ones with SIR's greater than 1.0) save significant amounts of energy.

Anti-scald valves were required on all active systems as a safety device. Concern leading to the use of these valves centered around the number of small children and elderly clients that could possibly forget to temper the water during hot water draws. The valves are self-adjusting, allowing one to regulate the temperature of the water entering the house. The maximum allowed hot water was 140^0 F at the highest setting. (Settings ranged from 1 to 4, 4 being the hottest.) Most installers set the anti-scald valve at either the 3 or 4 setting. Some clients did not like the valve since it constricted the input of very hot water, which at times they desired.

During inspections on systems that had been installed for at least one year, FSEC staff noticed that some valves became stuck and that quite some force and the use of large pliers were required to turn the valve's adjustment knob. Residents were informed by FSEC that they should exercise the adjustment knob every several months to prevent the valve mechanism from becoming stuck due to hard water calcium build-up, etc. Nevertheless, FSEC also inspected many other systems where the valve was not stuck. Undoubtedly, the condition of the local water has much to do with this.

The need for anti-scald valves is debatable. No clients have reported that they were scalded when using hot water. This includes numerous sites that FSEC inspections revealed no valve had been installed. The valves were installed only on a few of the ICS systems. No scalding problems were reported. The valves do operate quite well when they are new, but only time will tell how many fail due to scale build-up on the inner components of the valve. (FSEC has been advised that the inner mechanisms of the valve are now being manufactured with a Teflon coating in order to prevent possible sticking of the inner components due to scale or other build-up.) Exercising the valves would undoubtedly prevent this from happening, but unfortunately, once again, many clients cannot be expected to provide any type of simple maintenance or interaction with the solar system and its components.

The current building codes (Southern Standard for Florida) are now requiring anti-scald protection for showers; this does not necessarily imply that the solar system requires this device, but concerns of liability may have an influence on this decision.

In regards to when the solar systems should be installed, future program managers may consider conducting solar installation programs during slow periods of the year for solar installers. This is usually during the spring and summer months. The busy season is usually during the cooler months, when solar pool heating systems are being installed. This would provide quicker installations as well as a niche market for the solar industry during their slower periods.

INSPECTIONS

The inspection program was implemented to verify initial installed quality and to verify the quality of SWAP agency inspections. In general the results indicated that the inspections were critical in verifying that the highest quality of workmanship was being used to install the systems. The FSEC inspections showed that few critical problems had been missed and most systems were working fine. However, smaller problems were present at some of the sites.

It is clear that not all of the sites were being adequately inspected by the local agencies and that the quality of installation varied by contractor. This indicates that an on-going program to assess contractor installation quality should be evaluated and that local inspections are critical to getting proper installations. An initial evaluation of component operation indicates that relatively few component failures have occurred.

System approval means little without inspections. System installation inspections are a must for any successful program. All solar collectors and solar systems, including the major equipment used, are certified by FSEC. This ensures that the equipment that is being installed in the field is suitable for that particular system. Unfortunately, FSEC can not currently verify the installation process, as this occurs only when a system is being installed. This is the cause of the majority of discrepancies that have been observed in the field. As stated in the report, since a solar system includes a variety of components, installation steps, and tasks that overlap electrical, plumbing, and roofing disciplines, installers must maintain high levels of workmanship and attention to many details during installations. A successful program requires conscientious inspections of all installed solar systems.

Some type of modularization of system components and/or subsystems would greatly reduce the possibility of errors and improper installations. Modularization is often complicated due to the individual layouts of various water heaters, attics, and roof structures. Nevertheless, work toward that goal should be accelerated.

WATER QUALITY

An unexpected finding from this study centers on water quality. Water heater and solar system manufacturers have known for quite some time that there are areas through Florida and other states that pose specific problems due to local water conditions. This became quite obvious during the course of the SWAP program, since several system problems occurred that were the result of poor water quality. In the future, solar program developers need to be aware of the condition of the local water supply before initiating a solar program in specific areas. This could reduce problems and often exorbitant water and metals analysis costs incurred while attempting to isolate the problems. Very often, a simple pH and TDS meter will suffice to provide suitable information.

PERMITS AND BUILDING DEPARMENT ISSUES

Local building departments need to adopt FSEC's solar equipment certifications and installation methods. Both FSEC and several installers had problems with local building department officials who did not have a firm grasp of solar and did not seem interested in being informed of proper industry wide standards and procedures. The two major problems were in Dade and Pinellas Counties. The Pinellas County problem has been described in the report. Basically, it centered on having to provide structural engineering drawings for each installation. This would have made each installation quite cost-prohibitive. Pinellas County building officials were quite open to meeting with FSEC and interested in resolving this issue. And indeed, the issue was resolved by requiring one type of collector mounting that was applicable to all sites and precluded structural certification requirements for each individual site.

This, unfortunately, was not the case in Dade County. Dade County officials did not accept FSEC and the solar industries' recommended roof penetration sealing methods. Instead, they required a method that did not provide as positive a seal as that recommended. There is a need to educate code officials about solar systems and the available standards and certifications that can make solar approval easier for them and the contractors. This will, of course, also greatly affect the quality of installations.

PARTICIPATING AGENCIES

The majority of agencies participating in the SWAP program were quite enthusiastic about the program potential for their clients. Their enthusiasm for the program and the anticipated savings to their clients carried over to the clients themselves, who were quite eager to obtain these systems. Choosing residences for solar installations was often somewhat frustrating. Although a family may have qualified economically, an inspection of the residence would at times reveal that there was insufficient solar access for the solar systems. Agency staff had to work that much harder to identify enough clients to meet the goals of the program. Nevertheless, the clients that received solar systems and saw the savings that resulted often rewarded the agencies with shows of gratitude.

SURVEYS

The final phase of the program evaluation was the surveying of the recipients of the solar systems. This stage was meant to assess the recipient's perceptions of the systems and perceived savings. In general, the results were positive, but they did indicate several things that could be done to improve the program quality. Among these were that the auxiliary tank temperature and/or volume needs to be large enough for the anticipated load (in many cases raising the lower tank temperature solves this problem), an owner's manual needs to be left with the homeowner (a current requirement), and greater information about system operation needs to be explained to allow for system troubleshooting.

Among other facts gleaned, was that the perceived savings of the solar system were twice the average measured savings and that 97% of the surveyed homes had some type of air conditioning.

CLIENT SELECTION AND INTERACTION

Future low-income solar programs should strive to use clients that have high energy bills (LIHEAP participants, etc.), high verified occupancy levels and use more than 60 gallons of hot water per day (3100 kWh per year). Generally, without using a large amount of hot water, the system will not save enough energy to be cost effective. Unfortunately, determining water consumption can only be done by monitoring actual water usage with a flow meter. This in itself is costly and may include invasive methods. The use of a clamp-on ammeter that totalizes for a short period of time (e.g. one week), could be used along with voltage to project annual energy consumption instead of using a flowmeter.

Low-income clients should be made more responsible toward understanding what the solar system does and what maintenance or periodic checks should be taken. The system should be seen as a personal investment. The client must have some type of interest in the system. Perhaps attending some type of educational seminar on the system, its method of operation, and what the homeowner needs to be aware of, would be beneficial. Unfortunately, FSEC has noticed that many clients do not care to become more aware of the system's (and ancillary components', such as anti-scald valves, and water heater on/off switches) requirements.

Selecting participating agencies and clients from urban areas lowers installation costs related to logistics and provides greater access to certified solar installer and technicians. In addition, and if possible, it is beneficial to select residences that are in the same neighborhoods, or at least close to each other, so that installers can conduct several installations during the course of a day.

EDUCATION AND TRAINING

A client education program must be established for future programs of this type. Without proper instruction, which it seems the solar installer or local agency did not always provide, system owners do not fully understand how the system operates, and more importantly, what such components as the anti-scald valve and water heater on/off switch are for. In some cases, the clients did not even have a system operation manual or the name and telephone number of the installer! FSEC and local staff attempted to educate the clients during system inspections. Explanations were geared for the specific client and often written instructions were left for future reference. Many times, one could tell that the clients were intimidated with this new technology and perhaps created an understanding block simply because they were afraid that they could not understand it. FSEC recommends that in future programs, simple owner's manuals and ancillary system information and instruction handouts be developed separately from the basic solar manufacture's owner's manual.

System inspections reveal that there is a need for additional training of the industry as well as building department officials and their inspectors. Although the quality of equipment that is being installed is of good durable quality, the primary deficiencies are those centered on the installation. As previously stated, solar systems are made up of many components, each of which must be installed separately. Therein lie many of the causes for a variety of the problems that have been encountered. For example, air vents were not always installed in a true vertical position, freeze valves were not installed according to the manufacturer's recommendations, exterior pipe insulation and sensor wiring were improperly installed and not protected from ultraviolet ray damage, etc. Without proper training and education, this will continue.

POST INSTALLATION

Pre-funded routine inspection and periodic maintenance of installed solar systems should be part of future low-income solar system programs. System checks every two to three years are recommended. These would identify any potential problems as well as correct minor discrepancies, such as degraded exterior insulation, leaking valves, etc. The majority of these minor discrepancies could be corrected on the spot. In addition, for those systems that are inoperative, the systems could be fixed and thereby prevent the waste of previous investments.

A long-term study needs to be developed to obtain accurate information on long term operation, maintenance requirements, and maintenance and repair costs of these types of solar systems. FSEC has developed an extensive database of all 801 installed SWAP systems. FSEC staff members have also developed a good rapport with the clients, and would be quite amenable to conducting this long term study, funds provided.

Since all SWAP clients have back-up elements on their electric water heaters, which will provide hot water even if the solar system is not working, they, in general, will not pay to fix a system as long as they have hot water. Also, many "can not" pay to have the system repaired due to their income restrictions.

This very quickly destroys the gains made by the installation of the solar water heating system. Thereby, we need to have a follow-up program to check these systems. A basic operational check of a SWAP system should take no more than 30 minutes. Very often, the required adjustments on problem systems are very minor and can be completed in as short a time, depending on the task.

Overall, the SWAP pilot program was a success. Documents and methods were developed to implement a program that showed the viability of solar water heating as a weatherization option in Florida.

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