FIELD PERFORMANCE OF SOLAR WATER HEATING SYSTEMS

Residential Systems

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I. INTRODUCTION

There are literally thousands of published studies concerning the performance of solar water heaters.[1] As indicated in Table 1, the number of English publications with the words "performance" and "solar water heating" as major topics is 250 times greater than the number of studies publicly available on the performance of electric or gas water heaters! While not all the solar studies could or even should possibly have been reviewed for this report, representative studies covering the early and mid-term periods of solar water heating system development across the United States have been selected for examination. These studies were then reviewed and summarized in order to characterize the actual field performance of solar water heaters in the United States.

TABLE 1. LITERATURE CITATIONS ON THE PERFORMANCE OF SOLAR WATER HEATERS

Item Description	Number of Citations	Number of Citations with Performance as Major Topic and in English
Solar water heaters, solar water heating, and performance	3232	2580
Electric water heaters, electric water heating, and performance	104	2
Gas water heaters, gas water heating, and performance	90	8

Information obtained from U.S. Department of Energy - Energy Science & Technology Database.

Table 2 indicates the solar water heating studies that are discussed in this report, the period of years in which each one was conducted, and the average annual energy savings in kilowatt-hours (kWh) that was determined by each study. The average savings for the early and mid-term group of studies, weighted by the number of systems in each study, is also indicated in Table 2. The discussion (and references) of each study is contained in Section IV of this report and provides, to varying degrees, an assessment of whether actual performance paralleled predicted performance, the impact of the solar water heating system on the electric utility load, and an indication of current system reliability. As seen in Table 2, the studies were conducted by a diversity of interests -- both investor-owned and municipal electric utilities, regional power distributors, government agencies, and regulatory commissions. Therefore, they provide a wealth of useful information not only to the solar industry but also to the sectors which can influence the use of solar water heating systems, including electric utilities.

TABLE 2. SOLAR WATER HEATING MONITORING PROGRAMS

PROGRAM SPONSOR	Year	Energy Savings (kWh/year)
FIRST GENERATION		
Long Island Lighting Company	1978-80	1779
Tennessee Valley Authority	1978-81	2100
U.S. HUD Solar Hot Water Initiative Program		
Northeast Solar Energy Center	1978-80	Not Measured
Atlantic Electric - New Jersey	1981-83	2477
Pennsylvania State University	1979-80	1758
Florida Solar Energy Center	1978-80	2232
Oregon Department of Energy	1979-81	1935
New England Electric System, Phase I	1976-77	Not measured
Weighted Average Savings = 1830 kWh/yr		
SECOND GENERATION		
New England Electric System, Phase II	1984-86	2550
City of Austin Electric Department	1981-83	2813
Florida Public Service Commission	1982-84	2044
Carolina Power and Light	1984-85	2270
Northeast Utilities	1984-86	2640
Weighted Average Savings = 2502 kWh/yr		

The early studies, the "first generation" of solar water heating programs, are useful from a historical perspective. They provide insight as to the range of factors which affect the performance of solar water heaters, and, more significantly, they identify the causes of early system problems and subsequent poor performance. However, despite the perception that early system problems and poor performance were the norm, the studies indicate that the first generation of solar water heaters provided consumers and utilities with substantial benefits. The more recent mid-term studies, the "second generation" of solar water heating programs serve to validate the level of potential energy savings indicated by the first generation. They also demonstrate the maturation of the solar water heating industry.

The authors caution, however, that the studies which are characterized herein as "mid-term" are somewhat dated, with the vintage of most "second generation" solar systems falling between the years 1981 to 1985. Nevertheless, these studies demonstrate that the quality of solar systems, both equipment and installation, has steadily improved over time, indicating that the current generation of solar water heaters should provide even greater benefits to both utilities and their customers than may be indicated in this report. Data regarding this "third generation" will be collected and analyzed as it becomes available and it is hoped that it will be published as a supplement to this report. In the interim, the authors will provide an estimate of the expected performance of these present-day systems now being incorporated in the third generation of solar programs.

II. EXPECTED PERFORMANCE OF TODAY'S SOLAR WATER HEATING SYSTEMS

A. ENERGY EFFICIENCY

Throughout the United States, residential solar water heaters have demonstrated the capability to save an average of 2,500 kilowatt-hours (kWh) of electrical energy on an annual basis. Of course, the actual savings for an individual household depends upon a number of site-specific factors; however, the average savings of 2500 kWh is based on a typical system serving a typical family and is a weighted average of nearly 200 solar systems operating over periods that span six years. Therefore, this average accounts for a wide variation in weather conditions during 1981 to 1986. Finally, this average savings also appears to be the norm regardless of where the system is located in the United States!

This independence of geographic location initially seems to be counterintuitive, especially when one looks at the variation of the available solar radiation, as shown in Figure 1, a map of the annual average daily solar radiation in the United States.[2] However, when one looks at Figure 2, a similar map of the annual average ground water temperature in the U.S.[3], and realizes that a solar system saves just as much energy heating water from 50^o to 100^oF in New York as it does heating water from 75^o to 125^oF in Florida, then the national average savings of 2500 kWh begins to make more sense. As shown in Figure 2, average cold or ground water temperatures in the northern U.S. range from 44^o to 56^oF versus a range of 72^o to 76^oF in Florida. In fact, it appears from Table 2 that solar systems may be able to save more energy in northern climates than they can in southern or Sunbelt locations! This possibility is related to the magnitude of the total hot water load and will be discussed in more detail below.

It also must be pointed out that some of the site-specific factors which affect actual system performance -- such as solar collector area and storage capacity -- can be manipulated in order to increase energy savings. For example, annual savings of 3000 kWh or more are possible with a solar water heater that is larger than the typical residential solar system, especially when the total hot water load exceeds 5000 kWh a year. Furthermore, as will be seen in Section III - Development of Today's Solar Water Heating Systems - and as revealed in Table 2 by the

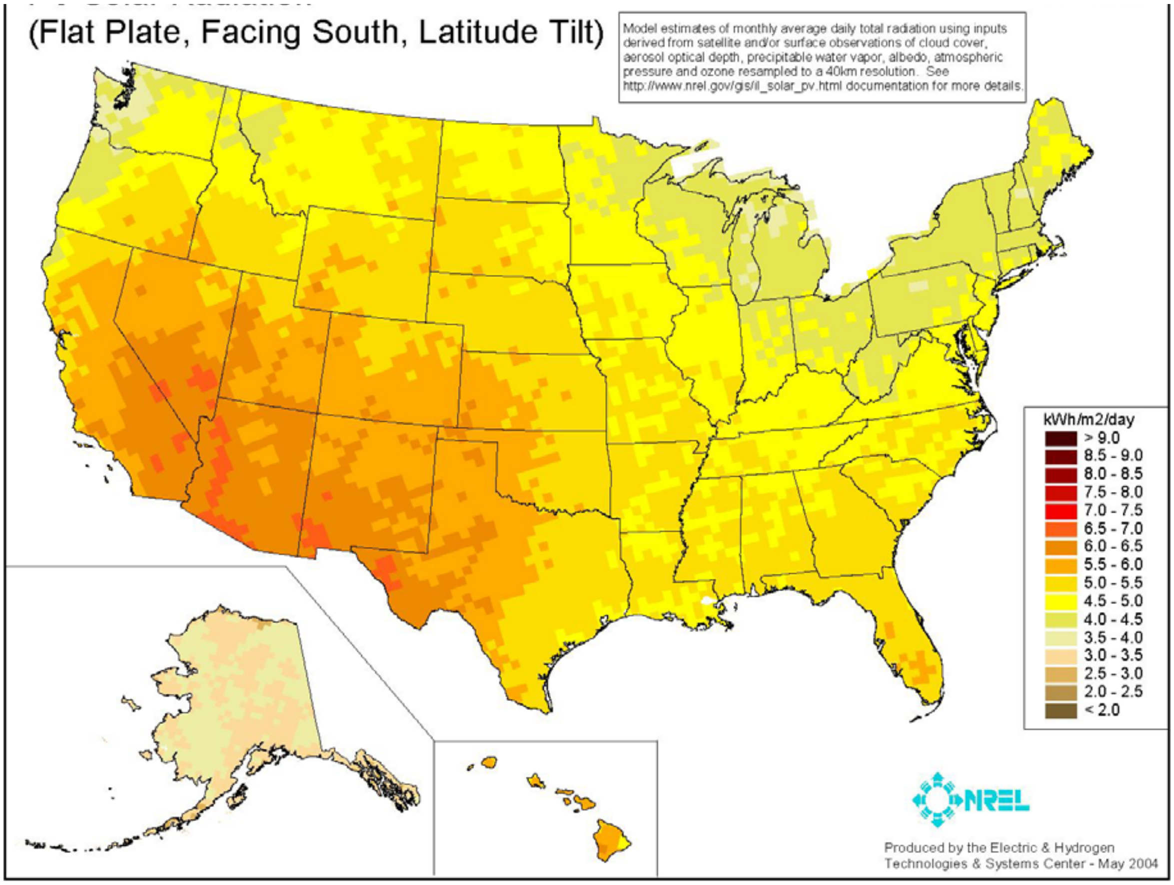

Figure 1. Mean daily annual solar radiation in the United States.

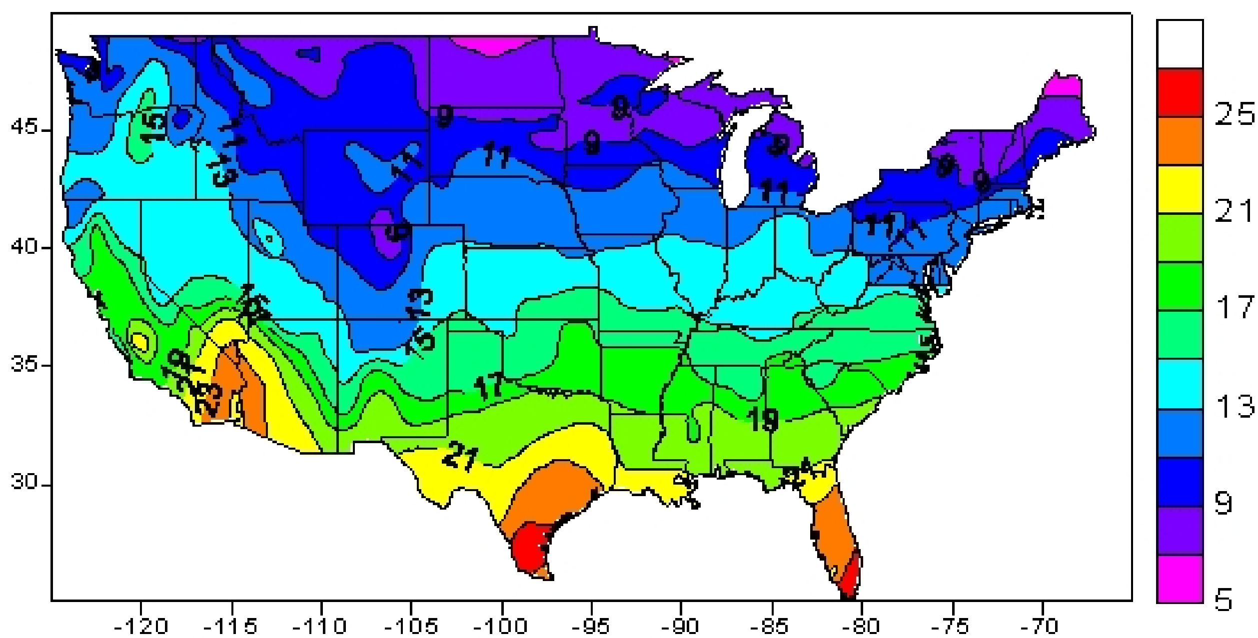

Figure 2. Average ground water temperature in the United States.

increase in energy savings from the first generation to the second generation of systems, one of the most important site-specific factors in the performance of a solar water heater is proper installation by a trained and knowledgeable contractor.

It is also necessary to mention here that many people are familiar with another measure for the performance for solar energy systems that has traditionally been reported in the literature. This measure is the "solar fraction", i.e., the contribution of the solar energy system to the total heating load. In the case of a solar water heating system, the solar fraction f is defined as the
percent of the household hot water demand that is met by solar energy, as indicated by the ratio

$$\frac{\text{Solar energy supplied to load}}{\text{Total hot water load}}$$

Therefore, the higher the solar fraction, the better the relative system performance and the higher the energy savings; however, the more the system generally costs. Consequently, economic considerations established an approximately 70 percent solar fraction as an effective design criteria. However, as will be seen in Section IV, in many of the studies of system performance in the northeastern U.S., the reported solar fraction was in the range of 45 to 55 percent. Only in the Florida studies was the monitored solar fraction reported at approximately 70 percent. And yet the systems monitored in the northeast, despite the lower solar fraction, tended to save as much if not more energy than the systems in Florida. Again this can be attributed to the fact that average cold water temperatures are much lower in the northern states. This colder water requires more energy, electric or solar, in order to be heated to the desired temperature for household use. As pointed out in Section IV, the average electric water heater in the northern U.S. requires 4500 to 5500 kWh per year, while in Florida, the average electric water heater uses approximately 3000 kWh per year.

Therefore, the "total hot water load", the denominator in the definition of solar fraction, is much higher in the northern U.S. and, for the same solar contribution, the solar fraction will be, by definition, lower. Hence, it would appear that using the solar fraction as the gauge of performance for solar water heating systems on a national basis can be misleading. Of course, it is still informative to report solar fraction in a program where cold water temperatures are equal among all the systems. Hence, this relative measure will be reported for each monitoring study that is discussed in Section IV. However, for national electric utility purposes, using the actual energy saved in kWh is a more absolute measure to characterize the performance of solar water heating systems. Average annual savings of 2500 kWh per system is a number all parties -- utilities, regulators, and customers -- can identify with.

B. DEMAND REDUCTION

Throughout the United States, residential solar water heating systems have also demonstrated the capability to reduce utility electrical demand when compared to conventional electric resistance water heaters. This demand reduction has been shown to occur not only on average weekdays during the time period of the utility system peak, but also on the utility's actual winter and summer peak days. Furthermore, the measured reductions have been demonstrated to occur without the need for any type of utility load control or electric resistance element interlock.

As seen in Table 3, solar water heaters have shown the most desirable demand profile relative to electric water heaters in Texas and Florida, with at least a 30-35 percent coincident peak reduction in the winter and a 90 percent coincident peak reduction in the summer. In these

TABLE 3. AVERAGE COINCIDENT PEAK DAY DEMAND REDUCTION OF SOLAR WATER HEATING SYSTEMS

PROGRAM SPONSOR	Year	Number of Systems	Winter Reduction (%)	Summer Reduction (%)
City of Austin Electric Department	1981-83	15	35	97
Florida Public Service Commission	1982-84	20	70	92
Florida Electric Coordinating Group	1983	43	31	NR
Northeast Utilities	1984-86	39	NR	91

NR - Not Reported

Sunbelt locations, solar water heaters are able to reduce the coincident utility peak day demand by a minimum 0.4 kW per customer. Furthermore, these reductions occur without any significant loss of annual load factor compared to electric resistance water heaters. (Load factor is the ratio of the average electrical demand over a designated period of time to the maximum demand occurring in that period.) In a consistent manner, solar water heaters in the northeastern U.S. have similarly demonstrated a capacity to reduce coincident demand on the summer peak day by 90 percent.

Solar water heaters in the U.S. Northeast have also reduced average weekday coincident demand by 30-40 percent in the winter and 82 percent in the summer, as indicated in Table 4. These percentages correspond to a minimum 0.2 kW per customer reduction in the winter and at least a 0.45 kW reduction in the summer. In North Carolina, the average weekday reduction was also in the 30-40 percent range in the winter; however, the summer reduction was only reported at 32 percent because the North Carolina monitoring program included the electrical demand of the solar circulating pump(s) and control.

TABLE 4. AVERAGE WEEKDAY DEMAND REDUCTION OF SOLAR WATER HEATING SYSTEMS

PROGRAM SPONSOR	Year	Number of Systems	Winter Reduction (%)	Summer Reduction (%)
Atlantic Electric - New Jersey	1981-83	20	30	82
Carolina Power and Light	1984-85	24	39	32*
Northeast Utilities	1984-86	39	40	82
Pacific Gas and Electric	1985-86	15	30	62

* Includes pump(s) and control

Finally, in California, the average weekday reduction due to solar water heaters has been shown to be more than 30 percent in the winter and 60 percent in the summer. These measured results are discussed more thoroughly in Section IV of this report; however, they clearly demonstrate the favorable impact of solar water heating systems on reducing the coincident peak demand for a electric utility.

C. RELIABILITY

Unfortunately, there are no reported studies which have assessed the long-term field performance of solar water heaters. Nonetheless, a number of organizations have conducted sequential performance studies of solar water heating systems in their region or service area. In addition, the early or "first generation" studies identified a number of factors which detracted from system performance. This information was then used to improve system design and operation and subsequently achieve a higher level of system reliability.

For example, the New England Electric Solar Program provides the comparative results of two studies conducted in the New England Electric System (NEES) service area in two distinct time periods.[4] The earlier study reports that the average solar fraction for 100 solar water heaters installed in 1975 was just 21 percent. NEES, in cooperation with industry and government agencies, attempted to diagnose the reasons for this lower than expected performance. The majority of the 100 systems were replaced or extensively improved, resulting in an increase in savings to 41 percent the next year. In the course of the initial study, the utility identified several specific problem areas which were subsequently addressed and remedied: untrained solar contractors; insufficient collector surface area and undersized storage tank heat exchangers; inadequate insulation on tanks and piping; off-the shelf components not specifically designed for solar use; and, lack of comprehensive standards for overall system design.[5]

To address these problem areas, the Northeast Solar Energy Center in 1981 began 3-day Solar Water Heating Installation Workshops that were co-sponsored by the New England states. These workshops consisted of "hands-on" demonstrations of solar collector mounting, roof penetrations, system assembly, tank piping, and wiring. A workshop manual was produced on system sizing, installation guidelines, and troubleshooting procedures.[6] The original NEES report on the early system problems was included in the workshop manual as well.

In 1983, NEES conducted a second study with the installation and monitoring of 100 new solar water heating systems. The average annual solar fraction was determined to be 49 percent, with the best 75 systems averaging more than a 65 percent solar contribution. Aside from the other technical results reported by the study (which will discussed in greater detail in Section IV), the researchers concluded that "the solar water heater industry is now mature and that today's solar contractors are, for the most part, thoroughly trained and proficient. The systems in the program have required minimal maintenance and have performed remarkably well."

The reliability of solar water heating systems has also been addressed by other studies. In 1981, Argonne National Laboratory published "Final Reliability and Materials Design Guidelines for Solar Domestic Hot Water Systems" under the sponsorship of the U.S. Department of Energy.[7] These guidelines contained descriptions of the materials and components needed to design reliable solar hot water systems. Solar collector manufacturers and water heating system packagers incorporated many of these recommendations into the solar systems that were marketed in the middle and late 1980's.

Another frequently referenced study on solar system reliability was conducted by the Florida Solar Energy Center (FSEC) from 1978-80. The Consumer Protection Study,[8] again sponsored by the U.S. Department of Energy, demonstrated with great clarity the degree to which proper system design, installation, and operation can have on the performance and reliability of solar water heaters. A survey of Florida solar energy consumers in 1978 revealed a degree of satisfaction with solar water heaters that appeared to be much higher than warranted, given the state of the art and degree to which those same consumers required service or repair on their systems. In order to validate the consumer perceptions expressed in the survey, a series of site visits was conducted to a sample of the surveyed consumers. Those site visits revealed numerous problems which would have a deleterious effect on system performance. The majority of problems identified were related to the installation of the system, ranging from minor, easily correctable problems to major problems which would have required extensive repair or component replacement.

As a result of these findings, FSEC embarked on a campaign of consumer education and installer training. In 1978, FSEC began 3-day Solar Installation Short Courses in conjunction with instructors from the Florida Solar Energy Industries Association.[9] These short courses also consisted of "hands-on" demonstrations of solar collector and storage tank plumbing, pump and control wiring, and roof mounting procedures. In addition, a number of consumer publications on solar

solar water heating were produced, such as "Turning on the Sun - A Consumer Guide to Solar Water and Pool Heating."[10] Informing the consumer about the basics of system operation, and providing simplified troubleshooting guidelines, as well as including comparison shopping recommendations, these publications raised the level of consumer awareness. At the same time, the workshop training of installers and building officials increased the skill of those in the field who were actually installing or inspecting the systems. Finally, the 1981 institution of a statewide Florida solar contractor's license regulated the solar trade and established effective permit and license requirements.[11] In 1982, Florida Power and Light Company (FPL) began a solar water heating incentive program in which they would rebate up to $400 if a customer installed a solar water heater.[12] It is estimated that by 1990 there were over 250,000 properly operating solar hot water systems in Florida.[13] By the end of 1993, 45,900 of these solar systems had been installed under FPL's Water Heater Incentive program.

The New England and Florida experiences were consistent with those of other states who were actively promoting the commercialization of solar water heating. In almost all cases, poor performance in the field was correlated to poor installation methods. The adoption of installer training, contractor licensing, and ongoing consumer education programs were essential for the correction of "first generation" problems and the effective commercialization of solar water heaters. Utilities that are planning solar water heating programs can benefit from this experience and ensure that these necessary foundations are established before a large-scale solar water heating installation initiative is begun.

III. DEVELOPMENT OF TODAY'S SOLAR WATER HEATING SYSTEMS

The solar water heaters on the market today are the product of design and manufacturing innovations resulting from over fifteen years of industry and government quality control efforts. The institution of the following elements has provided the industry and the consumer with a high level of confidence in the long-term performance of solar water heating systems.

- system standards for design and installation,
- testing programs for performance and durability,
- training courses for installation contractors,
- statewide requirements for contractor licensing, and
- guidelines for operation and maintenance.

The development and maintenance of this critical quality control infrastructure remains vital to the continued technical success of the solar water heater industry.

A. SYSTEM STANDARDS

A number of solar water heating initiatives over the years has led to the current system of solar collector and system standards. Early on, the policy of promoting solar energy by state and federal agencies propelled the government into the field of solar energy standards development. Those standards addressed testing solar collectors, accrediting testing laboratories, rating solar collector performance, certifying solar collectors and systems, and recommending installation practices.

Florida and California were the lead states in developing solar system standards, with their programs incorporating the testing standards of other organizations as appropriate.[14,15] For example, the Florida Solar Energy Center (FSEC) was required by a 1976 Florida law to develop standards for all solar energy equipment sold or manufactured in the state.[16] In 1977, FSEC instituted a solar collector testing program using the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 93-1977, "Method of Testing to Determine the Thermal Performance of Solar Collectors."[17] FSEC still operates an outdoor solar collector test laboratory and has tested over 400 collectors to the ASHRAE standard.

In 1980, FSEC, in cooperation with the Florida Solar Energy Industries Association, then developed standards for the design and installation of solar water heating systems.[18] This standards program is also still in effect and is used by other states and territories as well. A solar dealer or manufacturer submits a solar water heating system to FSEC for certification to the standards by specifying the major system components and providing a system diagram and owner's manual. These items are reviewed for compliance with the standards and, if acceptable, the system is listed in an annual publication of approved solar energy systems. Today, there are over 270 solar water heating system models approved for use in Florida.[19]

In 1980, the Solar Energy Industries Association, the national solar trade association, also initiated a standards program with the support of the U.S. Department of Energy. This national program is currently operated by the Solar Rating and Certification Corporation (SRCC), a consortium of public and private sector representatives with an interest in solar energy. SRCC currently publishes two standards, one for solar collectors[20] and one for solar water heating systems.[21] It also operates a system certification process similar to the FSEC system approval program. This process, called the OG-300 protocol, certifies solar water heating systems meeting minimum operating and performance requirements.[22] The OG-300 protocol is designed to be a national certification program.

Collector Performance Ratings

One of the many items addressed by solar energy standards programs is the rated performance of solar collectors and systems. FSEC has developed a collector thermal performance rating that uses the ASHRAE Standard 93 test results in conjunction with weather data for a typical Florida day.[23] Since its scope is national in scale, SRCC has a three collector thermal performance ratings based on the ASHRAE Standard 93 test results and three types of weather conditions.[24] The overriding purpose for developing these rating methodologies was to provide a measure by which system designers as well as consumers could compare solar collector performance.

In the process of certifying a collector to either the FSEC or SRCC standard, a randomly selected solar collector undergoes a series of tests which are designed to determine material durability and thermal performance. The thermal performance rating is then calculated to indicate the average amount of energy provided by the collector on a typical day. This number can then be divided by the collector area to normalize the rating to a number such as Btus per square foot per day.

The experience of the FSEC collector testing program has demonstrated that collector performance has dramatically improved over time. In the first eight years of operation of the collector certification program, from 1977 to 1984, the average thermal performance rating increased 35 percent, from 631 Btu/ft^2/day to 856 Btu/ft^2/day.[25] Today the maximum thermal performance rating is 994 Btu/ft^2/day.[26] According to FSEC test engineers, the increase in performance is accounted for by improved collector designs, construction, and materials.

System Performance Ratings

Collector performance ratings alone, however, will not provide an absolute indication of actual solar water heating system performance. There are a number of factors which, taken together with collector efficiency, affect overall system performance, including the solar system type, heat exchanger effectiveness, storage capacity, and hot water consumption. In order to account for the interaction of all these factors, researchers have developed computer models to simulate the performance of solar water heating systems under different weather conditions. The two most recognized simulation models are the f-Chart solar design method and TRNSYS, both of which were developed at the University of Wisconsin's Solar Energy Laboratory.[27,28] Studies of both methodologies have indicated that there is a good correlation between the simulation's predicted performance and the actual measured performance for a solar water heating system.[29,30]

On of the primary differences between f-Chart and TRNSYS is that the former was designed to be a manual calculation method and that the latter method requires a high-speed computer. TRNSYS -- a Transient System Simulation Program -- is a modular program in which mathematical models of individual system components are connected together to form a complete system for detailed simulation. Generally, the weather data and the simulation timesteps used in TRNSYS are of the order of one hour or less. f-Chart uses monthly average weather data to estimate the performance of solar energy systems. In fact, the monthly correlations used in f-Chart were developed from many detailed TRNSYS simulations.

These two system performance models are of interest because they are used to develop solar water heating system ratings. FSEC uses f-Chart and Florida monthly weather data to calculate a Florida Energy Factor for its approved systems.[31] The definition of energy factor (EF) is the same for all types of water heating systems and is the amount of hot water energy supplied by the water heater divided by the amount of conventional energy used over a prescribed period of time.

$$EF = Q / (E + E_a)$$

where:

Q	=	heat delivered by the water heating system
E	=	electricity (gas) energy used by the storage tank (burner)
E_a	=	ancillary electrical energy to operate a circulating pump and controls; if used

SRCC uses TRNSYS and a standard day's weather to calculate one of six performance ranges -A through F - for a solar water heating system.[32] The system performance ratings are shown on rating labels in the following categories:

A. Less than 15 MJ per day (less than 14.2 kBtu per day)
B. 15 up to but less than 20 MJ per day (14.2 up to but less than 18.9 kBtu per day)
C. 20 up to but less than 25 MJ per day (18.9 up to but less than 23.6 kBtu per day)
D. 25 up to but less than 30 MJ per day (23.6 up to but less than 28.5 kBtu per day)
E. 30 up to but less than 35 MJ per day (28.5 up to but less than 33.1 kBtu per day)
F. 35 MJ or more per day (33.1 kBtu or more per day)

Both the FSEC and SRCC system rating methodologies use a standard hot water load based on a typical family.

B. INSTALLATION GUIDELINES AND TRAINING PROGRAMS

Recommended solar system installation practices evolved over the years as the industry gained experience in the field. Again, the first generation of solar water heating system monitoring programs was essential to the identification of proper design and installation methods. The residential Solar Hot Water Initiative program administered by the U.S. Department of Housing and Urban Development (HUD) in 1977-79 provided 10,000 consumers in eleven states with a $400 grant towards the purchase of a solar water heater.[33] In order to encourage the solar industry to improve and increase its product delivery system, the HUD program established "Minimum Property Standards" for solar heating and hot water systems.[34] These standards contained installation requirements for systems approved for the program and participating contractors were bound to bound to follow these requirements. In addition, HUD in cooperation with the U.S. Department of Energy, published the "Installation Guidelines for Solar DHW Systems in One-and Two-Family Dwellings" in 1979.[35] The standards developed by FSEC and SRCC have incorporated these recommended, and in some cases, required installation practices from the HUD Minimum Property Standards and the HUD Installation Guidelines.

Nevertheless, the early studies which incorporated site inspection programs indicated that the industry did not always uniformly follow these recommended installation practices. In an effort to increase compliance, training programs were established to afford contractors and technicians with classroom and "hands-on" exposure to the recommended system installation methods. These programs were offered nationally in 1981-83 by both the Solar Energy Industries Association and the National Association of Home Builders[36], the Sheet Metal and Air Conditioning Contractors Association[37], and a number of other manufacturer or trade organizations. During 1981-83, the Northeast Solar Energy Center and during 1978-85, the Florida Solar Energy Center offered a series of continuing installation workshops as described in Section II. However, determining actual compliance with equipment standards and installation practices still remained elusive through the early 1980's.

In most cases, the likely person responsible for ensuring compliance was the local building official. Two difficulties were found in this scenario. The first is that building officials typically had little or no experience with solar systems. The second was that few of the early solar contractors followed building permitting requirements, leaving building officials no way of knowing a solar system was being installed in their jurisdiction. In defense of the solar industry in the 1970's and early 1980's, it appeared that contractor licensing requirements were either too stringent or virtually inapplicable to their trade, forcing them to short-circuit the permitting system in order to remain in business. As a result, the licensing process for solar contractors was reformed, and in many states today a separate license is available to those engaging in the business of installing solar water heaters.[38] In addition, training programs were targeted to building officials to increase their knowledge of solar water heating systems and proper installation methods.[39]

Site inspection of installed systems is also a now requirement of a number of utility solar programs.

Florida Power and Light, for example, has trained utility personnel to identify proper installation methods and verify system certification for its solar water heater program.[40] The SRCC OG-300 program also calls for random inspection of certified systems by SRCC inspectors.

C. OPERATION AND MAINTENANCE

Operation Manuals

One of the primary keys to long-term solar water heating system reliability is proper operation and maintenance. The SRCC and FSEC standards for solar water heaters require that the consumer receive an operation and maintenance (O&M) manual with the system at the time of installation. This O&M manual must be specific to the installed system and be comprehensible to the typical consumer. Generic troubleshooting guides have also been developed and advise consumers as to typical operational problems, along with the probable cause and remedy.

Warranties and Service

All solar water heating systems installed today come with warranties from the manufacturers of the various components as well as an installation warranty from the contractor. Typical warranties are five years on the solar collector and storage tank, 90 to 180 days on smaller components, and one year on the installation. During the years of the federal 40 percent tax credit for residential solar systems, warranties of extraordinary duration were often used as a sales tool. Unfortunately for the consumer, those warranties were often worthless once service became necessary since a great many companies went out of business after the tax credit expired at the end of 1985. In response to the large number of consumers with systems from defunct companies, the State of Florida developed an "orphan system" program called the Florida Solar Users' Network (FlaSUN).[41]

The FlaSUN program was initially funded by the Florida Energy Office. A toll-free number was established and promoted to current solar system owners through a variety of methods. Contractors in the solar business who attended a service training workshop and successfully completed an exam were eligible to receive referrals about customers who called the toll-free number and required service on their solar water heater. In most cases, the contractor was paid by the customer for any parts and service labor; however, in some cases, component warranties were still in effect and the contractor was able to provide service accordingly. From 1988 to 1991, the FlaSUN program responded to over 7,000 requests for information or service.

The success of the FlaSUN program was based on the ability to keep existing solar systems operational, satisfy the consumer, and maintain a ready work force of trained solar service technicians. All these factors contributed to the stability of the Florida solar energy industry. The program continues to operate today with the support of the Florida Solar Energy Industries Association. Many states have considered replicating the program and it is strongly recommended as one method of establishing a trained workforce of solar service people and installers before a large-scale solar water heater installation program is begun.

IV. SOLAR WATER HEATING MONITORING PROGRAMS

A. FIRST GENERATION OF SOLAR WATER HEATING PROGRAMS

A number of studies on the performance of solar water heaters were performed in the late 1970's to early 1980's. The majority of the studies were conducted by state and federal government agencies, in addition to those conducted by several "early adopter" utility companies. These studies were initiated to determine the effectiveness of solar water heater programs for which state, federal, and private funds provided subsidies. As stated earlier, these studies cannot necessarily be relied upon to gauge the performance of currently available systems. Rather, they should be viewed as a measure by which systems have improved and for their contribution to the identification of early performance problems. These studies should also serve to reinforce the need to establish and maintain the infrastructure for quality control.

Overview

Table 5 indicates the solar water heating studies that are discussed in this section, the period of years in which each one was conducted, the number of systems that were involved, the average annual energy savings in kWh, and the average annual solar fraction that was determined by each study.

The majority of the first generation monitored systems were installed in the 1977 to 1981 time period. The information gathered in the monitoring programs also enabled some of the researchers to establish levels of hot water use and auxiliary electric requirements. Customer hot water usage patterns were identified in several studies. In some cases, site visits were conducted to verify system performance and determine reasons for less than expected performance.

The average solar fraction reported by the studies typically ranged from 35 to 57 percent, with the exception of Florida, which reported 75 percent. However, the average electrical energy savings, weighted by the number of systems, was approximately 1,830 kilowatt-hours per year, including all locations.

TABLE 5. FIRST GENERATION SOLAR WATER HEATING PROGRAMS

PROGRAM SPONSOR	Year	Number of Systems	Energy Savings (kWh/yr)	Solar Fraction (%)
Long Island Lighting Company	1978-80	632	1779	44
Tennessee Valley Authority				
Memphis 1000	1978-81	7	2698	NR
Solar Nashville	1979-83	18	2100	NR
U.S. HUD Solar Initiative Program				
Northeast Solar Energy Center	1978-80	88	NR	47
Atlantic Electric New Jersey	1981-83	20	2477	57
Pennsylvania State University	1979-80	48	1758	35
Florida Solar Energy Center	1978-80	20	2232	75
Oregon Department of Energy	1979-81	37	1935	40
New England Electric, Phase I	1976-77	100	NR	21
				NR - Not reported

Long Island Lighting Company

Long Island Lighting (LILCO) installed and monitored 632 solar water heating systems, all of the same model, beginning in 1978 and ending in 1982.[42] The system was purchased directly by the utility after a review of available systems and contractors. There was also a strong educational component to the LILCO program in terms of installer training and consumer education. The results of the study revealed an average of 1,779 kilowatt-hours per year displaced by the solar water heater, with an annual solar fraction of 44 percent. The total electrical use to provide hot water for a family of four was determined to be 5,351 kWh. The annual savings to the solar customer was calculated to be $268. The cost of the system in June 1980 was $2499, or $1499 after the 40% federal tax credit was deducted. In 1981, New York State instituted a 15 percent tax credit for solar systems, resulting in a net system cost of $1125. Therefore, the simple payback period with both credits was calculated as 4.3 years. The utility concluded from the program that solar water heating was reliable and could benefit both the utility and its customers.

Tennessee Valley Authority

The Tennessee Valley Authority (TVA) instituted a major solar water heating project in 1978, with a goal of installing 11,000 systems in the Memphis and Nashville regions of its service territory.[43] TVA provided system design, installation, and low interest financing for the systems. The "Memphis 1000" program offered a combination system incorporating an 82 gallon solar tank with a 120 gallon auxiliary tank to allow for 16 hour off-peak load management. The "Solar Nashville" program offered consumers a choice of standard manufactured systems and a selection of qualified installers. A total of 148 sites were selected for monitoring in both programs; however, results are reported for only about 25 systems.

Nashville customers saved an average of 2,000 to 2,200 kilowatt-hours per year, with some customers saving twice the average. The study noted that collector design improvements, such as selective coatings on absorber plates, were not represented in the sample of monitored systems , and hence, the reported savings were at the low end of the spectrum.

Memphis customers reported savings of about 3,000 kWh. This higher degree of savings was attributed in part to a colder water mains temperature than Nashville, which resulted in a larger summer hot water load, when the solar system performance was at its peak.

The study concluded that average hot water use was between 70 and 100 gallons per day, with peak hot water use from 7:00 to 9:00 a.m. and from 8:00 to 10:00 p.m. Nevertheless, summer electrical demand reductions were coincident with the TVA system peak. The results also indicated that solar water heaters were well suited to reducing demand in the afternoon and evening without load management. Load management during the winter was indicated as possibly desirable, especially when peaks occurred in the morning and occasionally in the afternoon. The cost of the systems studied in the program ranged from $2,700 to $3,850.

U.S. HUD Solar Hot Water Initiative

Northeast Solar Energy Center:

Performance results on 88 solar water heaters over a one year period were reported in this study of HUD Solar Hot Water Initiative systems installed in the northeastern region of the United States between 1978 and 1980[44]. In addition, an assessment of operation and maintenance problems was conducted, as well as other factors which influenced performance.

The average solar fraction reported was 47 percent, with daily hot water use established as 16.3 gallons per person. The maintenance summary indicated that 48 percent of the sites had no reported maintenance. With the exception of control failures and collector fogging or frosting, solar system components exhibited the same maintenance frequency as the electric back-up system. Controllers which turned the solar circulating pump on and off were the most frequent component to fail, which obviously caused poor performance. Collector fogging or frosting was the most frequent reported collector problem, but was not responsible for a serious degradation in performance.

According to this study, poor installation accounted for 36 percent of the problems reported about the solar system. Component design and assembly shortfalls by the manufacturer were responsible for 46 percent of the solar maintenance problems and 59 percent of the control failures. They also suggested that another monitoring project of similar scope be conducted using more recently installed systems, due to the rapidly changing status of the solar industry in the early 1980's.

New Jersey:

Atlantic Electric, a utility serving the Atlantic City, New Jersey area, monitored 20 solar water heating systems installed under the HUD Initiative program, along with a control group of 20 electric resistance water heaters[45]. The results indicated that the average electric water heater used 4745 kWh per year and that solar customers saved an average of 2477 kWh per year. Annual solar fractions ranged from 29 to 88 percent, with an average of 57 percent. The author noted that the payback periods were between 7 and 10 years, with the average annual savings of $225.

The solar water heaters also had a favorable impact on the utility's coincident peak load. During the winter season, the average electric water heater contributed 1.182 kW to the utility load, while a solar water heater contributed .831 kW, for a reduction of 0.35 kW per system. During the summer season, however, solar water heaters contributed a more significant 82 percent reduction, with the average electric water heater contributing .731 kW to the utility load, while a solar water heater added only .130 kW.

In the course of the program, Atlantic Electric conducted a survey of the 20 solar users, as well as the 329 other recipients of the utility's solar rebate. The survey was conducted in January of 1984, with a survey return rate of 70 percent. Of those responding, five percent experienced initial system installation problems. 37 percent reported system operation problems sometime later. Of the total reporting problems, 85 percent reported that their systems were repaired satisfactorily. 97 percent of those surveyed thought their solar water heaters were effective.

Pennsylvania:

Pennsylvania State University conducted a solar water heater monitoring program in 1979-80.[46] A total of 48 systems installed under the HUD Initiative program were monitored. The author of this study provided two useful reports -- a summary of the performance results, and an analysis of the factors which may affect performance.[47]

Annual energy savings for a solar water heating system averaged 1758 kWh, with a high of 4237 kWh, and the low a net increase in electric energy use. The average solar fraction for a one year period was 35 percent, with a high of 80 percent and a low of -15 percent. Each household consumed on average 70 gallons of hot water per day. The average system cost, before tax credits and the HUD grant, was $1980, with costs ranging from $1239 to $3504. Approximately one-third of the systems were owner-installed. With electric rates of $.055/kWh, the average return on investment was reported at 9 percent.

Upon completion of the monitoring program, the author initiated a series of site inspections to determine the reasons for the wide range of performance results. The ten best and ten worst sites were selected for further study. The author reported the following results:

- The majority of the high performing systems had the electric back-up element turned off during a significant portion of the year. None of the poor performing systems turned off the electric element.
- The high performing sites had pipe insulation rated good to excellent, whereas the poor

performers had average to poor pipe insulation.

- The author noted that most systems were neat in appearance, used high quality equipment and parts, and workmanship was good to excellent.

Florida:

In 1978, the Florida Solar Energy Center (FSEC), in cooperation with Florida Power and Light (FPL), began monitoring the performance of 20 solar water heaters installed under the HUD Solar Hot Water Initiative Program.[48] The authors concluded in 1981 that the systems which were reasonably sized performed well and produced average energy savings of 2232 kWh per year. However, economic performance was not as great, due to the cost of the system and lack of adequate incentives. The average simple payback period was 11.8 years. The average solar fraction was 75 percent.

Oregon:

The Oregon Department of Energy conducted a monitoring program of 37 solar water heaters installed between the years 1979 and 1981.[49] Systems selected for the program were of a variety of types and manufacturers, with site selection criteria including requirements for electric back-up, proper installation, and an unshaded and appropriate orientation.

The average energy savings was 5.3 kWh per day, or 1935 kWh per year. The median solar fraction was 40 percent. Measured hot water use was approximately 20 gallons per person per day, with a total household hot water load of 13.6 kWh per day.

In the course of the study, a number of system design and installation problems were identified, including poorly insulated piping, controller and sensor problems, improper or unpredictable pump operation, and storage tank heat losses associated with tank location and insulation.

<u>New England Electric System, Phase I</u>

The New England Electric System monitored 100 solar water heaters installed in its service area in 1976-77.[50] These early systems experienced a great deal of difficulty in mechanical operation. There was a general lack of experience on the part of the installers, contractors, and manufacturers/suppliers. Collectors and heat exchanger coils were undersized. Piping, valve, and controller problems resulted from inexperienced workers and unreliable equipment. The primary cause of the mechanical problems that were encountered in the program was determined to be faulty installation. The second most common cause of problems was the improper selection of component sizes and types. The third most common cause was the lack of post-installation inspection and adjustment.

The range of solar fractions for the best performing solar systems in the program was 32 to 47 percent. The average solar fraction for all the systems was 21 percent. Program planners believed a target savings of 50 percent was reasonable, but none of the systems monitored achieved that goal. However, improvements made in the systems during the summer of 1977 showed the promise of meeting that target during the next 12 month period.

B. SECOND GENERATION OF SOLAR WATER HEATING PROGRAMS

Overview

Table 6 presents the solar water heating studies that are discussed in this section, the period of years in which each one was conducted, the number of systems that were involved, the average annual energy savings in kWh, and the average annual solar fraction that was determined by each study.

The majority of the second generation monitored systems were installed in the 1980 to 1985 time period. In contrast to the first generation of monitored systems, the average solar fraction typically ranged from 50 to 60 percent. The average electrical energy savings, weighted by the number of systems, was approximately 2,500 kilowatt-hours per year.

TABLE 6. SECOND GENERATION SOLAR WATER HEATING PROGRAMS

PROGRAM SPONSOR	Year	Number of Systems	Energy Savings (kWh/yr)	Solar Fraction (%)
New England Electric, Phase II	1984-86	100	2550	49
City of Austin Electric Department	1981-83	15	2813	52
Florida Public Service Commission	1982-84	20	2044	68
Carolina Power and Light	1984-85	24	2270	52
Northeast Utilities	1984-86	39	2640	58

<u>New England Electric's Solar 100, Phase II</u>

Solar 100 Phase II was a follow-up of the New England Electric System program discussed previously.[51] 100 customers were chosen from NEES' service area to have solar water heaters installed on their homes. 28 contractors were selected through a bid solicitation to provide these solar water heaters that were designed to contribute 60 percent of the water heating load.

The systems were installed in 1984. The systems saved an average of 2550 kWh per year, with an average solar fraction of 49 percent. Average hot water consumption was measured at 15 gallons per person per day. Based on these figures, the average household saved $180 per year on electric costs. The utility concluded that a family of four uses between 4,500 and 6,000 kWh per year for hot water. Solar water heaters can provide 55 percent of that load, resulting in savings of between $175 and $230 per year.

The utility also noted that design improvements over the last decade resulted in a significant improvement in the performance and durability of solar equipment. Most solar contractors were experienced, well trained, and proficient. The systems performed remarkably well with minimal maintenance. Solar collectors used in the program had more efficient copper absorber plates with selective surface coatings and improved glazing materials. Computer programs had also been developed to accurately size each system based on the family's estimated hot water requirements. Heat exchanger area had increased as had tank insulation. Photovoltaic (PV) powered direct current pumps eliminated the need for alternating current power for the circulating pump. PV-powered circulators also simplified the control circuit, using available sunlight to regulate the speed of the pump.

Systems installed in the program cost from $4,910 to $5,700, and were generally indirect (heat exchanger) systems incorporating two storage tanks with solar collector area ranging from 50 to 150 square feet.

City of Austin Electric Department

The City of Austin Electric Department initiated a program in 1981 to examine the effect of solar water heaters on its utility system.[52] A total of 15 homes with solar water heaters and 15 homes with conventional electric heaters were monitored. Installation of the solar water heaters occurred from October 1976 to February 1982, with an average system age of 3.75 years at the time the monitoring program ended. Savings measured by the solar water heaters averaged 2,813 kWh per year. The electric water heater used an average of 5,419 kWh per year. The annual solar fraction averaged 52 percent. The summer season showed an increase in the solar fraction, with a range of 65 percent to 82 percent. Time-of-day results indicated a benefit to a summer peaking utility, with the greatest demand reduction occurring at the 3-7 p.m. peak.

Florida Public Service Commission

With funding from the Florida Public Service Commission, the Florida Solar Energy Center undertook a study in 1982 to determine the relative efficiency of solar water heaters in comparison to electric resistance, heat pump, and desuperheater water heaters.[53] 20 systems of each type were instrumented for two years to determine time-of-day electrical demand and hot water energy use. Four major Florida population areas were selected for the study: Jacksonville, Orlando/Brevard County, Tampa Bay, and the Broward/Palm Beach area. Five systems of each type were selected in each region, with family sizes relatively similar throughout the samples.

Solar water heating systems operated with the highest average electrical system efficiency and had the lowest average daily electrical demand profile. Electrical resistance water heaters used 8.3 kWh per day compared to 2.7 kWh per day for solar water heaters. Both groups had an average household size of 3.6 people. From these results, the average Florida household consumes approximately 3,030 kWh per year for electric water heating. This consumption was consistent with previous studies conducted by Florida Power and Light Company (FPL)[54] and Florida Power Corporation[55]. The solar water heaters used in this study displaced an average 2,044 kWh or nearly 68 percent of the required electrical energy.

Electrical demand taken at 15-minute intervals showed electric resistance water heaters contribute approximately 1.1 kW of diversified demand to the utility winter peak and at least 0.2 kW to the summer peak. Solar hot water systems exhibited the most desirable demand profile relative to Florida utility coincident peak loads with a 0.7 kW per customer reduction in the winter and a minimum 0.2 kW per customer reduction in the summer. (The Florida Electric Power Coordinating Group (FCG) also measured an average 0.4 kW per customer reduction for 43 solar water heaters at the time of the FPL 1983 winter peak.) Since electric water heaters account for approximately 25 percent of the utility winter peak demand per customer, this study recommended that solar water heating systems would be beneficial to a winter-peaking utility in Florida.

Carolina Power and Light

In cooperation with Carolina Power and Light, the North Carolina Alternative Corporation monitored 24 solar water heaters in the Raleigh-Research Triangle area from December 1984 to November 1985.[56] The systems were monitored to determine both the economic benefit to the consumer and the peak load impact on the utility. The auxiliary electrical element in the back-up tank also operated under direct utility load control. The solar water heaters operated with approximately twice the average annual energy efficiency of an electric water heater in the North Carolina climate. Energy savings were determined to be 2,270 kWh per year. Monthly performance data revealed a strong correlation with solar availability, while individual system performance was significantly improved by lowering the temperature setting of the back-up tank. The average predicted solar fraction of the monitored systems in the study was 58 percent. The actual average solar fraction was 52 percent.

The results also indicated that standby heat loss was greater in two-tank systems due in part to the total surface area exposed to the tank environment temperature. Single tank solar systems had significantly better performance. With the federal 40% tax credit taken into consideration, solar water heaters had a lower present cost than electric water heaters.

Solar water heaters also demonstrated the capability to reduce Carolina Power & Light's winter peak demand by 0.4 kW per system. Annual load factor was metered to be 50% -- approximately the same as electric water heaters. (Load factor is the ratio, expressed as a percent, of the average kilowatt demand over a designated period of time to the maximum demand occurring in that period.) Residential solar water heating's impact on CP&L's summer peak demand was fairly small since residential hot water use generally did not coincide with the afternoon utility peak.

Northeast Utilities

Connecticut Power and Light, a subsidiary of Northeast Utilities (NU), monitored 39 solar water heaters during a study conducted from 1984 to 1986.[57] The systems were installed as early as 1975 and as late as 1984. The sample was selected from among the 8,000 systems believed to be installed in the service area of the utility. All the systems were professionally installed and had electric back-up (with the exception of one gas back-up system included for curiosity sake!) The typical household size was 2.3 adults with 1.1 children. The average solar collector area was 75 square feet with 80 to 120 gallons of storage. The average system cost was $4,140, with a net system cost of $2,484 after tax credits.

The monitored systems saved an average of 2,640 kWh, or $237 per year. The average solar fraction was 58 percent. The study also determined that the value of solar water heating was dependent upon the quantity of hot water usage. Average daily consumption was measured at 66 gallons per household. Hot water usage was 10 to 15 gallons less during the summer months.

Utility data indicated that solar water heaters reduced the winter peak water heating demand by one quarter to one half of the electric water heating demand. This was comparable to the reduction achieved by radio-controlled electric water heaters. Solar water heaters were able to reduce the summer peak water heating demand by 80 to 90 percent.

V. SOLAR WATER HEATING SYSTEMS TODAY

The use of solar water heaters in the residential housing sector is today a proven efficient and reliable means of displacing electrical energy. Through the implementation of state and national standards for system design and installation, the energy savings of solar water heaters has become an accepted fact. In areas where an infrastructure of trained solar contractors and informed system inspectors has been established, both consumers and electric utilities readily perceive the benefits from solar water heating systems.

A. CONSUMER ATTITUDES TOWARD SOLAR

City of Austin Consumer Survey

The City of Austin Electric Department conducted a survey of customers with solar systems that were installed between July 1982 and July 1985.[58] Of the 600 surveys that were mailed, 241 were returned, indicating a 40 percent response rate. The results indicated that 90 percent of those surveyed had satisfaction levels of good to excellent; 84 percent of those surveyed reported no or minor problems. While 49 percent of those surveyed reported no life-style changes, 39 percent turned the electric back-up element off in the summer and 13 percent lowered the thermostat on the tank.

FlaSEIA Consumer Survey

In December 1989, the Florida Solar Energy Industries Association (FlaSEIA) conducted a survey of solar water heating system owners.[59] Of those responding to FlaSEIA, 88 percent were satisfied with their system (43 percent very satisfied, 35 percent generally satisfied, 10 percent somewhat satisfied). In light of the advances in solar system technology and contractor training that has occurred in Florida, it is quite reasonable to assume that these levels of satisfaction reflect the attitudes of the 250,000 solar water heating system owners in Florida.

B. THIRD GENERATION OF SOLAR WATER HEATING PROGRAMS

Sacramento Municipal Utility District

In 1992, the Sacramento Municipal Utility District (SMUD) began a Solar Domestic Hot Water (SDHW) Program to accelerate the replacement of approximately 60,000 electric resistance water heaters in its service area with solar water heating systems.[60] SMUD adopted the SRCC OG-300 certification and rating protocol to qualify solar water heaters for participation in its SDHW program. 900 systems were installed in 1992 with utility rebates of up to $1525. A small-scale volume bidding procedure was then instituted in an attempt to lower the average installed cost of a solar water heating system. However, because this procedure relied on utility energy auditors to make sales, only 200 systems were installed in 1993. Therefore, SMUD has returned to the contractor-driven sales approach with utility financing up to $2950 per system.[61]

Florida Power and Light Company

In 1982, Florida Power and Light Company (FPL) began a solar water heating incentive program in which they would rebate up to $400 if a customer replaced their electric water heater with a solar water heating system. FPL required that all solar systems be approved by the Florida Solar Energy Center (FSEC) according to the FSEC system standards. FPL also required that the solar system be inspected after installation and before the rebate check was issued to the participating contractor. By the end of 1993, 45,900 solar water heaters has been installed under FPL's water heating program.[62] In a warm climate like Florida, these systems displace a minimum of 32.1 MW from FPL's winter peak demand and 9.1 MW from its summer peak demand. Additionally, these systems represent an annual energy reduction of 92 GWh without any significant loss of load factor compared to conventional electric resistance on heaters.

Canada's S-2000 Program

Even in a much colder climate like Ontario, Canada, residential solar water heaters have also been shown to have the potential to displace winter peak capacity and reduce energy consumption. An individual solar system, although larger than the typical United States system, can displace 0.94 kW of utility capacity and 4,190 kWh per year. Again this can be accomplished without a corresponding reduction in load factor.[63]

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