Research Report

Solar Water Heating Performance: Use of Energy Factors

FSEC-RR-30-93

D. L. Block
C. Emrich
T. Merrigan
T. Tiedemann

Florida Solar Energy Center
300 State Road 401
Cape Canaveral, Florida 32920

SOLAR WATER HEATING PERFORMANCE: USE OF ENERGY FACTORS

D.L. Block, C. Emrich, T. Merrigan and T. Tiedemann
Florida Solar Energy Center
300 State Road 401
Cape Canaveral, FL 32920

ABSTRACT

The goal of increasing solar energy installations is widely accepted by all. The Florida Solar Energy Center (FSEC) concluded that the goal of increasing solar hot water system installations in Florida could be greatly enhanced by concentrating its efforts on new construction through simplification of the residential building energy code. Since implementation in 1980, the Florida Energy Efficiency Code for Building Construction has required a calculation procedure that assigns multipliers to residential water heating systems. The multiplier for every water heating system type except solar is based on the system's rated efficiency at standard conditions and is a one- or two-step process. Solar water heating system multipliers were not based on standard conditions and required an eight-step selection process. For these reasons, FSEC initiated a program to simplify the specification of solar water heaters in new home construction to a two-step code process. The process used is to rate solar water heating performance by the use of energy factors -- the same efficiency rating used for electric, gas and heat pump water heaters. This process was adopted for the 1993 Energy Code by the Florida Department of Community Affairs during 1992. This paper presents the methodology used to determine these energy factors for more than 275 solar hot water systems currently approved by the Florida Solar Energy Center for use in the State.

1. INTRODUCTION

In the State of Florida, solar water heating has been encouraged for the past 15 years; however, there is today almost no use of solar water heaters in new home construction. One institutional barrier to the use of solar in new homes has been the difficulty of specifying solar usage in the Florida Energy Efficiency Code for Building Construction [Reference 1].

Under the Energy Efficiency Code, which is administered by the Florida Department of Community Affairs, the energy efficiency of every new home is calculated to determine an Energy Performance Index (EPI). The EPI represents the ratio (multiplied by 100) of the energy efficiency in terms of insulation, orientation, HVAC and appliances of the new home compared to that of an energy-efficient reference home of the same size and general construction. The homebuilder must demonstrate by calculations that each new home has an EPI of 100 or less.

A solar hot water heater is one of the energy-efficient water heating options available which may contribute significantly to reducing the EPI of a home. However, prior to the 1993 Code, the builder was required to complete an eight-step sizing calculation to select an EPI calculation multiplier for a solar water heater. This sizing requirement was implemented when the Energy Code first went into effect in 1980 because of the relative unfamiliarity of homebuilders with the performance of solar water heating systems. However, the selection of an EPI multiplier for a gas, electric resistance or heat pump water heater only involved one, or at most two, simple steps. Using the energy factor rating for an electric resistance, gas or heat pump water heater, the builder was able to simply determine the appropriate EPI calculation multiplier from the Code form.

In October 1990, FSEC and the Florida Energy Office proposed to the Florida Department of Community Affairs that solar water heating systems usage in the Energy Efficiency Code adopt the same efficiency rating method that applies to other water heating systems -- an energy factor.

2. ENERGY FACTOR CALCULATION PROCEDURE

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 to the home divided by the amount of conventional energy used over a prescribed period of time.

$$EF = \frac{Q}{E+E_a} \qquad (1)$$

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

The energy factor for electric resistance and gas systems is always less than one, since they cannot supply more energy than they consume. The energy factor for heat pump water heaters is generally 2, and solar can range from 1.5 to 40.

The f-Chart solar design method developed at the University of Wisconsin Solar Energy Laboratory was selected as the basis to analyze the SWH systems and to calculate the electrical energy used by the storage tank [Reference 2]. F-Chart is a correlation-based method that uses monthly average weather data to estimate the performance of solar energy systems. Its ability to predict the annual performance of solar water heating systems within 10% of actual performance has been documented by numerous researchers [References 3-5]. Note that the time period selected for the solar energy factor calculation is one year. The microcomputer version of f-Chart, F-CHART, was used to find the annual auxiliary electrical consumption of each solar system operating in three Florida climate regions. Apalachicola monthly average solar radiation and temperature data was used for North Florida. Orlando solar radiation and temperatures were used for Central Florida and Miami solar radiation and temperatures were used for South Florida.

The hot water usage in f-Chart was set at 64.3 gallons (243.4 liters) per day, which is the national average hot water consumption used in the U.S. Department of Energy Test Procedures for Water Heaters [Reference 6] -- the standard test for the other types of water heating systems. The delivered hot water temperature was set at 122°F (50°C) to remain consistent with the previous Energy Code sizing calculation procedure, and the temperature of the surrounding tank environment was conservatively set at 75°F (23.8°C). The cold water temperature in each of the three cities was set to 72°F (22.2°C) for each month of the year in order to keep the hot water load equal in all three regions. The average cold water temperature for the state is also 72°F (22.2°C). These parameters produce an annual hot water energy load of 9.79 MMBtu (2868 kWh).

The solar system parameters for f-Chart used the FSEC collector and system approval process for values. Florida state law requires that all solar systems manufactured and/or sold in Florida must be certified by the Florida Solar Energy Center [Reference 7]. In 1979-80, FSEC, in conjunction with the Florida solar industry, developed standards for the design and installation of solar water heating and pool heating systems [Reference 8]. A solar dealer or manufacturer submits a solar water heating system to FSEC for certification to these standards by specifying the major 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. The listing is updated periodically, and approval is good as long as the system is sold without changes. At present, there are 278 certified solar water heating systems.

The FSEC system approval process permits alternate components -- collectors, tanks, pumps and controls -- to be specified for each solar water heating system. The majority of the FSEC-approved solar water heating systems are direct circulation, single-tank systems that use solar collectors with ASHRAE Standard 93 test results [Reference 9]. The ASHRAE 93 test results were used for the collector parameters in f-Chart. However, rated collector performance is permitted to vary by as much as 25 percent among the collector alternates for an FSEC-approved system. Therefore, if several collectors are specified as a system option, the collector with the lowest total performance rating was used as the one in the f-Chart method.

The solar preheat storage tank size for a single-tank system was taken as two-thirds of the actual tank size. This follows the f-Chart recommendation for a single-tank system to use the volume below the heating element [Reference 10]. In a few systems, F-CHART gave an error message because the tank size was less than .925 of the collector area. The storage tank size in these systems was therefore increased to .925 times the collector area in order to get F-CHART results.

The heat loss coefficient UA of the auxiliary tank was calculated using the upper one-third of the tank only -- again following the f-Chart recommendation for single-tank systems. If more than one tank option was offered in the system approval, the one with the largest UA was used.

For the 21 indirect circulation SWH systems, the same collector and system parameters were used, with the addition of f-Chart's heat-exchanger option. The heat exchanger's effectiveness was set at 0.5, and the tank side flow rate was the same as the collector flow rate, which was taken to be 11 lb/hr-ft^2 (53.7 kg/hr·m^2).

If AC circulating pumps are used in the solar system, 2000 hours of pump operation using the wattage of the largest pump alternate is added to the f-Chart annual electrical consumption. This value was determined from side-by-side performance tests on a number of solar water heating systems [Reference 11]. Data from these performance tests showed a range of 1510 to 2190 hours of pump operation for a one-year period with an annual average of 1886 hours. The number 2000 was selected as a conservative value. If the system included an AC control, 8760 hours at five Watts was also added to the f-Chart annual electrical consumption. The energy factor is then calculated by dividing the annual hot water energy load by the total annual electrical consumption.

For each solar system, 36 separate f-Chart calculations are made -- 12 for each of the three Florida regions. In each region, the solar collector orientation is varied in 15° increments, from 45° east or west of south to directly south. Orientations greater than 45° were not considered because these orientations typically allow for collector placement on another roof slope. In addition, the collector is tilted at three angles -- 15°, 30° and 40° from the horizontal. Figure 1 displays the 36 energy factors for one system normalized by the average energy factor for each region. A tilt angle of 40° was used because, as seen in Figure 1, the energy factor calculated at a tilt angle of 45° frequently varied more than 10% from the average energy factor for that region. The 10 percent variation from the minimum value was a tolerance requirement of the Florida Energy Efficiency Code.

Originally all 36 energy factors were averaged together in hopes of determining a single average energy factor for the state of Florida. Figure 2 displays the maximum and minimum energy factors for 52 solar systems compared to the statewide average energy factor for each system. Note the average energy factor is midpoint between the ±10 percent lines. Unfortunately, all of the high value systems still had extreme values which fell outside of 10% from the average.

To correct this undesirably wide distribution, two energy factors were determined to be appropriate for Florida. A North Florida energy factor was calculated as the average of all twelve orientations at Apalachicola. A second energy factor is calculated for Central and South Florida using an average of all 24 orientations in Orlando and Miami. The minimum energy factors for both North Florida and for Central/South Florida are then checked to see if they are within 10% of the average energy factor in each region. A small minority of systems still had minimum energy factors outside this 10% band, and, for these systems, the energy factor was selected as the minimum value plus 10 percent.

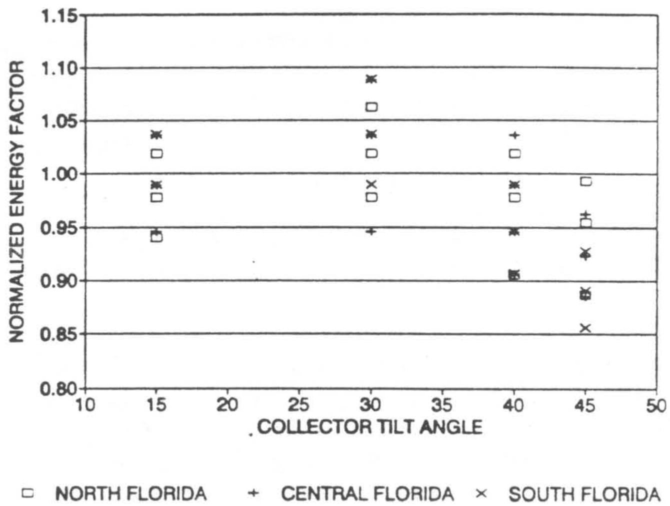

Fig. 1. Regionally normalized energy factors for one solar system at four collector azimuths and four tilt angles.

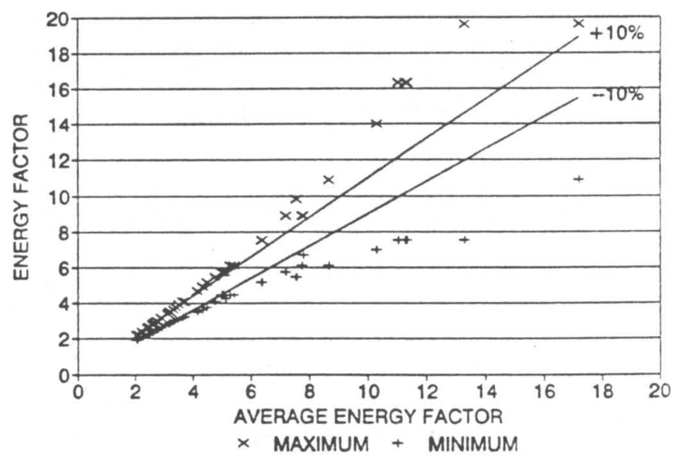

Fig. 2. Maximum and minimum energy factors vs. average energy factor for 52 solar systems.

The published Florida Energy Factor (FEF) for each region is then the minimum of either the average energy factor or the minimum energy factor increased by 10%. This final adjustment ensures that the region's FEF is within 10% of the minimum solar system efficiency due to collector tilt and

TABLE 1. Sample Listing of Florida Energy Factors for Solar Domestic Hot Water Systems

FSEC Number	Company/ System Model Name	Collector/ Glazed Unit(s) Model	Gross Area (sq.ft.)	Tank Volume (gal.)	Florida Energy Factors North	Central/South
	ABUNDANT ENERGY, INC.					
S8010	NOW 80P	SD7CRW 4x8	31	80	3.3	3.5
S8011	NOW 120P	SD6A 4x10	41	120	4.9	5.4
	ALTERNATIVE ENERGY SYSTEMS, INC.					
S7001	A.E.S. 1	TES/ESC 6520	58	80	3.8	4.3
S7002	A.E.S. 2	TES/ESC 6520	72	120	5.9	7.0
S7007	A.E.S. 1-A	TES/ESC 6520	39	80	2.5	2.6

orientation. Note that this method implies that the Florida Energy Factor is not the maximum efficiency expected from the system.

In January 1993, FSEC published a directory of Florida Energy Factors for all solar domestic hot water systems that have been approved for use in the State [Reference 12]. Table 1 displays a sample listing from this eight-page publication. FSEC-approved solar water heating systems are listed alphabetically by company. The first three columns of each listing present the FSEC system identification number, the system model name or number, and the solar collector or glazed unit model used in the system. The next two columns list the minimum gross collector area (in square feet) and the rated volume of the storage tank (in gallons). The last two columns contain the Florida Energy Factors for North Florida and for Central/South Florida.

3. ENERGY FACTORS FOR OTHER SOLAR SYSTEMS

This section details the f-Chart procedure used for integral collector storage (ICS), thermosiphon and self-pumped solar systems.

The seven integral collector storage (ICS) systems with FSEC certification all had ASHRAE Standard 95 (solar preheat) and SRCC Standard 200 Heat Loss test results, which supplied the net energy delivery Q_{NET} and the heat loss coefficient [References 13 and 14]. The auxiliary tank UA was set at 0.75 Btu/hr-F (0.4 W/C) for all the ICS systems, which represents an energy efficient 40-gallon electric water heater typically installed in new homes in Florida. These values, along with the number of glazings, glazing area per unit and number of units, were used in the ICS system option of F-CHART to calculate the electrical energy used.

In the case of the thermosiphon systems, there is no f-Chart thermosiphon model. Thus, the 17 certified thermosiphon systems were divided into four groups, depending on which type of system or collector tests have been done. Long-term performance testing at FSEC on both horizontal and vertical tank thermosiphon systems showed that thermosiphon systems performed approximately the same as direct circulation systems [Reference 15]. Therefore, systems with a collector test and no ASHRAE Standard 95 test were simulated in F-CHART as a direct-circulation system, where the volume of the thermosiphon tank was used for the volume of the DHW storage tank. Thermosiphon systems with an ASHRAE 95 test and no collector test were simulated in f-Chart as an ICS system. If the system had both an ASHRAE 95 test and a collector test, then either method could be used. In the two cases where this occurred, the method selected was the one that allowed all systems within the same vendor group to be analyzed in the same manner.

There were two thermosiphon systems with an FSEC outdoor test only. For these systems, an ASHRAE 95 Q_{NET} equivalent was developed using TRNSYS [Reference 16]. The process used was to first determine the parameters of a TRNSYS simulation model which resulted in agreement with the FSEC outdoor test data. These parameters were then used in a second TRNSYS simulation that corresponded to the ASHRAE 95 system test input [Reference 17]. The heat-loss coefficient was determined through a linear regression of gross surface area for the other thermosiphon systems that had heat loss test results. The two systems were then analyzed as ICS systems in F-CHART.

The final system was a self-pumped system. For this system an ASHRAE 95 test result was available. This system was analyzed using the ICS option with a storage tank volume of one gallon -- the minimum allowable -- since this option

TABLE 2. Florida Energy Efficiency Code for Building Construction
Hot Water Credit Multipliers

Florida Energy Factor	1.0-1.9	2.0-2.9	3.0-3.9	4.0-4.9	5.0 & higher
Hot Water Credit Multiplier	0.84	0.42	0.28	0.21	0.17

attributes storage tank heat losses to the outdoors [Reference 18].

4. USE OF THE FLORIDA ENERGY FACTOR

The Florida Energy Factor is now used to determine the appropriate EPI calculation multiplier for a residential solar water heating system in the 1993 Florida Energy Efficiency Code for Building Construction. This eliminates the involved calculations in the previous sizing procedure and simplifies the selection process for the builder. The FEF can also be used to compare the efficiency of solar water heating systems with other types of water heaters that also use energy factors as a rating measure.

The residential building performance compliance method in the Florida Energy Efficiency Code for Building Construction provides hot water credit multipliers (HWCM) for solar water heating systems based on five ranges of FEFs. The FEF is determined from the FSEC-published directory, and the hot water credit multiplier is determined from the residential code form, as shown in Table 2.

The Energy Code also divides the state into nine climate zones with three zones in each of three regions -- North, Central and South Florida. For Energy Code Climate Zones 1, 2 and 3, the North FEF is used to select the appropriate FEF range. For Climate Zones 4 through 9, the Central/South FEF is used to obtain the multiplier for use in the compliance calculation method.

For the purpose of the Energy Code, the efficiencies of any two systems are considered to be approximately the same if their FEFs fall within the same relative range. This acknowledges that, just as with air-conditioning and heating systems, each installation has site-specific characteristics that can affect the rated efficiency of the system. Therefore, recommended installation procedures must always be followed since they are equally as important in determining a system's overall efficiency.

To receive code credit, the Energy Code now requires that a rated solar collector in a solar water heating system be installed as follows:

1. Tilted to an angle between 15° and 40° of horizontal;
2. Oriented to face a direction within 45° of south.

These installation requirements permit a Florida solar collector to be mounted parallel with a southeast-facing to southwest-facing roof that has a pitch ranging from slightly more than 3 in 12 to a pitch as steep as 10 in 12. For installations that require that the solar collector be installed outside these practical limits, the Energy Code will not provide any water heating credit.

5. DISCUSSION

Solar water heater performance is a topic of never-ending discussion in the solar community. While we know and are confident of the performance of SWH systems, we still must have a means by which to present their performance to both the solar community and the consuming public. It is also critical that both groups have a simple, clear means of comparing SWH systems with other water heating systems. The only performance parameter that meets these goals is an energy factor.

The primary argument against using an energy factor lies in the premise that solar performance is different at each location or city within the U.S. While this statement is valid, it erroneously implies that a rating procedure is to be used as a design tool. The energy factor is to be used for rating solar systems and for comparing solar with other system types, and not as a design tool. Design and sizing are functions to be carried out by the solar manufacturer and company representatives -- not builders or consumers.

The use of energy factors to quantify SWH performance and the adoption of this method for the Florida Energy Code in January 1993 should set a precedent in the United States. Florida will serve as a model for other states and a forerunner of possible acceptance and use of energy factors to rate SWH system performance nationally.

6. ACKNOWLEDGEMENTS

The authors would like to acknowledge the assistance of Ann Stanton of the Florida Department of Community Affairs in the implementation of the Florida Energy Factor into the 1993 Florida Energy Efficiency Code for Building Construction. The authors would also like to thank Ingrid Melody of the Florida Solar Energy Center for her considerable help in publishing the listing of the Florida Energy Factors for solar water heating systems. Finally, the graphics and secretarial staff of both FSEC and FDCA are acknowledged for their professional expertise.

7. REFERENCES

(1) Florida Department of Community Affairs, Energy Code Program, 1993 Energy Efficiency Code for Building Construction. January 1993, Tallahassee, Florida.

(2) Klein, S.A., W.A. Beckman and J.A. Duffie, A Design Procedure for Solar Heating Systems. Solar Energy, Vol. 18, p. 113, 1976.

(3) Duffie, J.A., and J.W. Mitchell, f-Chart: Predictions and Measurements. Journal of Solar Energy Engineering, Vol 105/3, February 1983.

(4) Fanney, A.H., and S.A. Klein, Performance of Solar Domestic Hot Water Systems at the National Bureau of Standards - Measurements and Predictions. Journal of Solar Energy Engineering, Vol 105/311, August 1983.

(5) Block, David, et al., Comparison of Field Data and f-Chart Predicted Performance for Solar Domestic Hot Water Systems. ASME Solar Energy Division Technical Conference, April 1984.

(6) Code of Federal Regulations, Title 10, Part 430, Subpart B, Appendix E -- Energy Conservation Program for Consumer Products (revised as of January 1, 1992), Washington, DC.

(7) Florida Statutes, Section 377.705, Solar Energy Standards Act of 1976 (Revised 1979). Tallahassee, Florida.

(8) Florida Solar Energy Center, Florida Standard Practice for Design and Installation of Solar Domestic Water and Pool Heating Systems. FSEC-GP-7-80, January 1985, Cape Canaveral, Florida.

(9) American Society of Heating, Refrigerating, and Air Conditioning Engineers, Standard 93-1986 (Reaffirmed 1991), Methods of Testing to Determine the Thermal Performance of Solar Collectors. Atlanta, Georgia.

(10) Buckles, W.E., and S.A. Klein, Analysis of Solar Domestic Water Heaters. Solar Energy, Vol. 31, No. 5, 1980.

(11) Tiedemann, T.F., Side-by-Side Comparison of Integral Collector Storage and Conventional Collector Solar Water Heating Systems. Solar Engineering - 1986, American Society of Mechanical Engineers, Solar Energy Division, Anaheim, California.

(12) Florida Solar Energy Center, FSEC Approved Solar Energy Systems: Domestic Hot Water and Pool Heating. FSEC-GP-15-81, January 1993, Cape Canaveral, Florida.

(13) American Society of Heating, Refrigerating, and Air Conditioning Engineers, Standard 95-1987, Methods of Testing to Determine the Thermal Performance of Solar Domestic Water Heating Systems. Atlanta, Georgia.

(14) Test Methods and Minimum Standards for Certifying Solar Water Heating Systems. Standard 200-82, Solar Rating and Certification Corporation, February 1985, Washington, DC.

(15) Cromer, C.J., The Effect of Circulation Control Strategies on the Performance of Open Loop Solar DHW Systems. Solar Engineering - 1985, American Society of Mechanical Engineers, Solar Energy Division, Knoxville, Tennessee.

(16) Klein, S.A., et al., TRNSYS -- A Transient System Simulation Program. Solar Energy Laboratory, University of Wisconsin, Madison, Wisconsin, 1990.

(17) Huggins, J.C., and D.L. Block, Development of Solar Domestic Hot Water Systems Performance Prediction Methodology Based on System Test Results - Final Report. FSEC-CR-100-84, January 1984, Cape Canaveral, Florida.

(18) Zollner, A., S.A. Klein and W.A. Beckman, A Performance Prediction Methodology for Integral Collection - Storage Solar Domestic Hot Water Systems. Journal of Solar Energy Engineering, American Society of Mechanical Engineers, Vol. 107, pp. 265-272, New York, New York, November 1985.