THE INFLUENCE OF RESIDENTIAL SOLAR WATER HEATING ON ELECTRIC UTILITY DEMAND

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ABSTRACT

Similar sets of residences in Austin, Texas with electric water heaters and solar water heaters with electric back-up were monitored during 1982 to determine their instantaneous electric demands, the purpose being to determine the influence of residential solar water heating on electric utility demand. The electric demand of solar water heaters was found to be approximately 0.39 kW less than conventional electric water heaters during the late late afternoon, early evening period in the summer months when the Austin utility experiences its peak demand. The annual load factor would be only very slightly reduced if there were a major penetration of solar water heaters in the all electric housing sector. Thus solar water heating represents beneficial load management for utilities experiencing summer peaks.

INTRODUCTION

Because of the variable nature of solar energy and of energy demand for different applications, the use of solar energy in conjunction with a back-up source, such as that provided by a utility, may have a significant impact on that utility's overall demand, both peak and average. The effect on utility demand, positive or adverse, will depend on the correlation between the availability of solar energy and the utility's electric pattern for other demands. One such application is residential solar water heating. The purpose of this investigation is to examine and assess the effect on the peak, seasonal and annual loads of a summer peaking electric utility, when conventional electric water heaters (EHW) are replaced with solar hot water (SHW) systems that use electric auxiliary.

A number of studies have been performed that relate to either performance of solar energy systems or impact of solar applications on utility demand. Most monitoring studies have emphasized very detailed assessment of the performance of a specific system(s), rather than the impact that many such systems would have on utility demand.

Valuable data on the relative performance (and prediction) for various solar water heating designs, based on NBS comparative controlled tests, is presented in (1). Several papers (2-7) provide data from monitoring studies on solar hot water systems, but generally they stress performance rather than impact on the utility. Lorsch (8,9) has been interested in the effect of solar space heating on utilities. The impact of solar applications on utilities (10-13) has been of specific interest to the Electric Power Research Institute. A review of projects in Texas involving monitored data on the performance of solar systems and possible impact on utilities (14) was conducted by the Public Utility Commission (P.U.C.) of Texas.

In mid 1981 a project was initiated in conjunction with the City of Austin Electric Department that involved the monitoring of fifteen (15) homes having solar water heating with electric auxiliary and a similar set of fifteen (15) homes with conventional electric water heaters. Initial results of this study (15,16) covered only the first few months of monitoring. The current paper summarizes the data obtained over a full calendar year and further details can be found in (17).

SYSTEMS MONITORED AND APPROACH

The approach for acquiring data was to monitor the instantaneous electric demand of a set of residential solar hot water systems (with electric backup) and to compare these results with similar data for a comparable set of conventional residential electric water heaters. This comparative method was selected for its simplicity of data gathering and the lower cost of instrumentation and installation, as compared to a procedure in which hot water flow rate and temperature data would be measured, in addition to electric demand. The comparative method required that solar and conventional samples exhibited similar usage patterns, because hot water flow was not measured.

The large majority of solar units which have been installed in the Austin area are those of a single manufacturer. Consequently, all but one of the solar units monitored in this study were systems from that manufacturer. They were selected from a list of names picked at random from the manufacturer's files. After soliciting further data on each system and its installation by mail and then conducting on-site inspections of potential systems and personal interviews with the homeowners, a set of fifteen (15) systems was selected. Most of the SHW systems monitored in this study were of the open loop design in which water is circulated directly between the storage tank and the solar panels (Figure 1). There was some variation in these

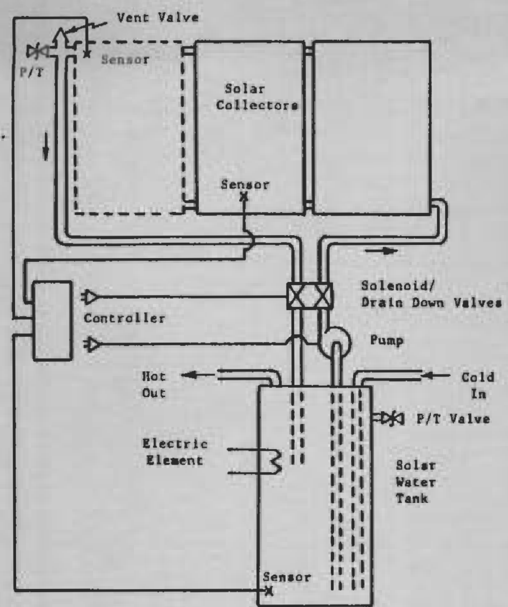

Fig. 1 Schematic of Solar Hot Water System

units, in that two had the newer automatic drain-down freeze protection and thirteen (the older systems) had recirculation freeze protection. The automatic drain-down freeze protection model drains the water from the solar panels and pipes when the temperature of the solar panels drops to 45°F. In the recirculation freeze protection model, water is pumped through the solar panels when the temperature in the panels drops below 38°F. Therefore these older systems exhibit greater energy losses during cold periods.

The average age of the solar systems at the time monitoring ceased on December 28, 1982, was approximately 3 years and 9 months. The oldest solar system monitored was installed in October, 1976, and the newest system was installed in February, 1982.

To help assure similarity in hot water demand of the solar and conventional electric units, the two sets were selected so they had comparable characteristics. Homes with SHW systems were selected first and then a set of homes with conventional electric water heaters was chosen. The essential requirements used in selecting the homes with conventional systems were that each system paired with a home using solar water heating had similar family size and age distribution. In addition, all homes had comparable hot water appliances (dishwashers and washing machines). Table 1 attempts to present a comparison of the "average" characteristics of each of the two sets of systems used in the study.

Characteristic	Number family members	Hot H_2O temp.	Ave. # showers a day	Location of hot H_2O tanks	Insulation on hot H_2O tanks	Length of pipe runs	Amount of pipe insulation
SHW systems	3.50	128	3.0	2.2	1.0	2.4	2.0
Conven. systems	3.33	129	2.8	2.3	1.8	2.2	2.1
Notes				cond'd - 1 util. rm - 2 garage - 3	good-1 avg.-2 poor-3	short-1 med.-2 long-3	insulated-1 in slab-2 exposed-3

Table 1 Comparison of Homes with Solar and Conventional Electric Water Heaters

As Table 1 indicates, the two sample groups are quite similar except for the amount of insulation on the hot water storage tanks. The storage tanks of homes with SHW systems were generally better insulated, with an average R-value of 16. Although many of the homes with conventional electric water heaters had well insulated tanks, a few had average to poorly insulated tanks. The slightly larger number of people living in homes with SHW systems (3.50 versus 3.33), with an accompanying increase in hot water consumption, compensated somewhat for the differences in the amount of insulation on the hot water storage tanks.

The water temperature of the homes with SHW systems was measured during an extended cloudy and cool period so that the temperature measured would indicate the minimum water temperature which is maintained by the backup electric heating element.

The City of Austin Electric Department was an active partner in this study. Personnel of the Austin Electric Meter Shop assisted in screening houses for installation of monitors, supplied and installed the monitoring units, and picked up and exchanged the data recorded by the monitors near the end of each month during the study. The monitors recorded the electricity consumed in 15-minute intervals on one track and time on a second track of magnetic tape. This data was then transcribed onto 9-track 1600-bpi computer tapes. Data was formatted into hourly electric consumption for each home using Fortran computer programs. Statistical analysis of the data was conducted using the Statistical Package for the Social Sciences (SPSS) computer routines.

RESULTS

To provide a comparison between the demands of solar (SHW) and conventional electric (EHW) water heating systems, the data obtained for each of these two sets was averaged over the systems in each set, hereafter called "unit electrical demand".

There are a number of comparisons that can be made between the electric demands of SHW and EHW systems that are important in assessing the impact on electric utility demand, including: the monthly (or seasonal) solar fraction; the demand reduction (for solar) during normal peak periods and the relative load factors. The City of Austin Electric Utility experiences a pronounced peak demand which occurs in the late afternoon-early evening during the summer months.

The unit monthly electrical demands for the SHW and EHW systems are presented in Table 2 for the year 1982. Also presented are the resulting demand reduction and solar fraction. In computing the solar fractions it is assumed that the two sets have equivalent hot water demands because of the similar characteristics of the two sets. Figure 2 shows the same data graphically.

1982	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
SHW avg. kWh	310	310	257	300	329	143	58	60	103	141	288	307	2606
EHW avg. kWh	584	620	487	547	476	413	329	303	336	343	491	490	5419
Avg. red. kWh	274	310	230	247	147	270	271	243	233	202	203	183	2813
Solar frac.	.47	.50	.47	.45	.31	.65	.82	.80	.69	.59	.41	.37	.52

Table 2 Comparison of Unit Monthly Electric Energy Use of Solar and Conventional Electric Water Heaters

It is seen that the solar fraction of approximately 0.8 during the hottest summer period of late June through early September is considerably higher than the 0.4 to 0.5 solar fraction occurring during the colder months of December through February.

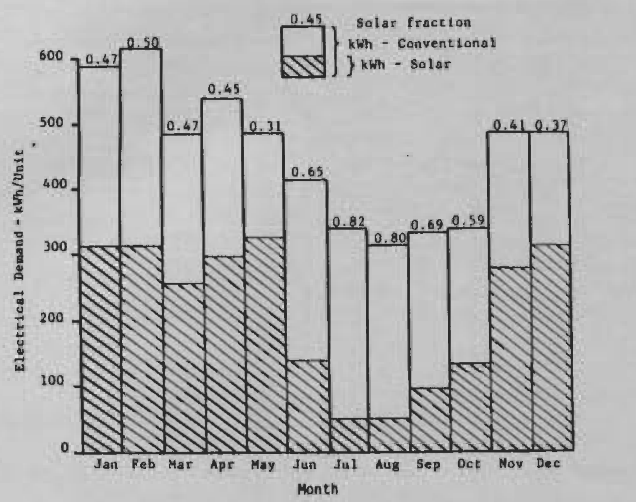

Fig. 2 Average 1982 Monthly Electric Demand of SHW and EHW Heaters and Resulting Solar Fractions

The annual demands of SHW and EHW systems are 2606 and 5419 kWh per home. The average solar fraction for the year is 0.52. The average unit electric energy demand of SHW systems during the summer months is approximately 80 kWh/month, compared to an average of about 320 kWh/month for electric water heaters. In the winter the average electricity used by the SHW systems is about 310 kWh/month compared to 570 kWh/month for the electric water heaters. Solar hot water systems require relatively more electricity during the winter than the summer, and thus appear to be beneficial to a summer peaking electric utility.

A more important effect is the influence of SHW systems during peak demand periods of electric utilities. To better observe the reduction in electric demand during peak demand periods, the electric loads for the ten days having the highest peak demands were averaged to form à summer composite day. (Figure 3).

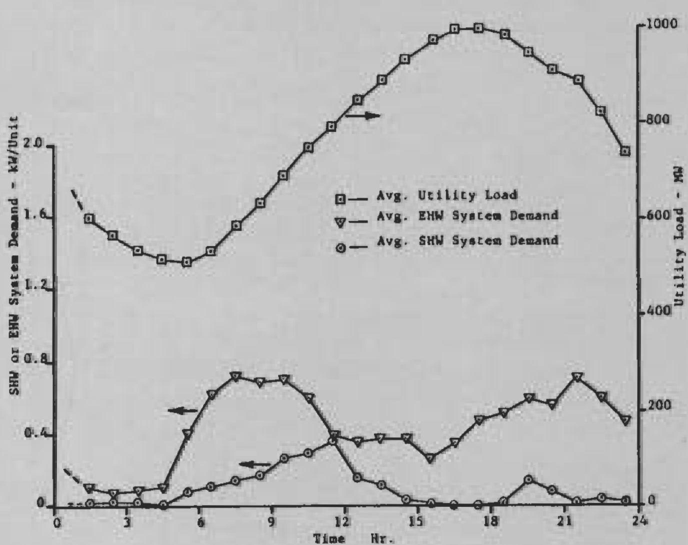

Fig. 3 Average Electric Demand for the Ten Highest Peak Demand Days during Summer of 1982

The highest demand on all ten days occurred between 3PM and 7PM (a consistent summer peaking interval for the Austin Electric utility). The average hourly demands for these 10 days for each of the solar and electric sets of hot water systems are also shown on Figure 3. The solar hot water systems are seen to have greatly reduced demand during the critical 4 to 7PM peak utility demand period.

The electric demand for each of the solar and electric water heating systems was averaged over the 3PM to 7PM period for these ten highest peak days of 1982, to produce the solar and conventional hourly electric demands presented on Table 3. During the

Day	SHW sys. kW	EHW sys. kW	Reduct. kW	Temp. high	Temp. low	% total poss. sun
7/28	0	0.375	0.375	101	76	100
7/29	0	0.328	0.328	100	77	93
8/16	0	0.309	0.309	102	75	98
8/17	0	0.395	0.395	104	79	77
8/18	0.076	0.393	0.317	98	79	49
8/23	0	0.389	0.389	99	75	84
8/25	0.042	0.732	0.690	98	73	91
8/26	0	0.279	0.279	100	74	96
8/27	0	0.389	0.389	102	78	95
9/02	0	0.397	0.397	100	78	95
Avg.	0.012	0.399	0.387	100.4	76.4	88.1
Average 1982 summer weather				96.4	74.0	80.3

Table 3 Solar and Conventional Water Heating Electric Demand (between 3PM and 7PM) and Weather Data for the Ten Highest System Peak Days of 1982

critical peak demand interval the average electric demand for the SHW systems was 0.012 kW per house, while the average electric demand for the conventional electric water heaters was 0.399 kW per house, resulting in a net reduction in electric demand of 0.387 kW per house. There is no apparent reason for the high electric consumption of conventional electric water heaters on August 25. However, the variation in demand may be due to sample size.

The peak demand days occur generally on the hottest days of the year and are a result of the high demand for air conditioning, which peaks during the late afternoon - early evening period. As seen in Table 3 these hottest days are also days which exhibit high percentages of possible sunshine.

This data supports the contention that SHW systems can be counted on to dependably reduce the summer peak demand by about 0.39 kW per house.

There are presently about 22,000 all-electric residential units in Austin, plus a small fraction of multifuel homes having electric water heaters. Estimates of the number of SHW systems presently installed in Austin vary from 1000 to 2000 units. Table 4 indicates the peak megawatt reduction, the gigawatt-hour per year reduction, and the resulting effect on annual load factor of 10% increases in the potential market for SHW systems in the City of Austin. As Table 4 indicates, the reduction in peak demand is offset by

Market penetration of SHW systems	Number of SHW systems	Peak MW reduction	GWh/year saved	Resulting annual load factor
0%	0	0	0	48.37
10%	2165	0.838	6.090	48.34
20%	4330	1.676	12.180	48.31
30%	6495	2.514	18.270	48.29
40%	8660	3.351	24.361	48.26
50%	10825	4.189	30.451	48.23

Table 4 Effects on Austin Utility Load Factor in 1982 Resulting from Increasing Numbers of SHW Systems

a reduction in electricity sold, so that the annual load factor decreases very slightly with increasing numbers of SHW systems. This phenomenon is common for many conservation measures, since peak demand and total electricity sold for the year are both reduced. However, for many other solar applications the effects on utility load factor are more severe than experienced here for solar water heating. The major benefit derived from peak demand reduction when using solar water heating is the possibility of reducing capital investments in electric generation capacity.

The daily load factor provides a good indication of a particular load management option's ability to shift a portion of the electric demand from the peak interval to the periods of the day with less demand (12). Table 5 takes the ten highest peak demand days of 1982 and shows the City of Austin Electric utility's net system electric production, the system peak demand, and the load factor for each day. The last three columns show the reduction in electricity used to heat water, the reduction in electric demand during the daily peak interval and the resulting load factor, if 25% of the residential units in Austin with conventional electric water heaters (approximately 5400 units) were to install solar water heaters.

Day	Total MWh	Peak MW	Act. Daily load factor	Red. per home kWh	Red. per home at peak,kW	Resulting daily load factor
7/28	17,898	974	.7657	8.055	.515	.7660
7/29	18,096	973	.7749	9.075	.464	.7748
8/16	18,055	1000	.7523	5.973	.254	.7520
8/17	18,460	1012	.7600	9.684	.297	.7591
8/18	17,812	993	.7474	6.666	.393	.7475
8/23	18,009	985	.7618	8.487	.568	.7622
8/25	18,040	996	.7547	9.088	.847	.7561
8/26	18,554	1001	.7723	7.390	.308	.7719
8/27	18,562	1008	.7726	8.449	.454	.7726
9/02	18,475	1013	.7599	8.458	.449	.7599
Avg.	18,196	996	.7622	8.133	.455	.7622

Table 5 Effect on Daily Load Factor if 25% of the Conventional Electric Water Heaters in Austin Were Replaced by SHW Systems

As can be seen in Table 5, the daily load factor remains basically unchanged. SHW systems would reduce the peak demand in the summer, but have essentially no effect on the daily load factor.

The Austin Electric Department is also interested in the effect SHW systems may have on winter electric demand, because during the winter period portions of the electric generating equipment go through scheduled down time for servicing. In the winter the utility load profile is more uniform and the peak demands are lower than in the summer (compare Fig. 3 to Fig. 4).

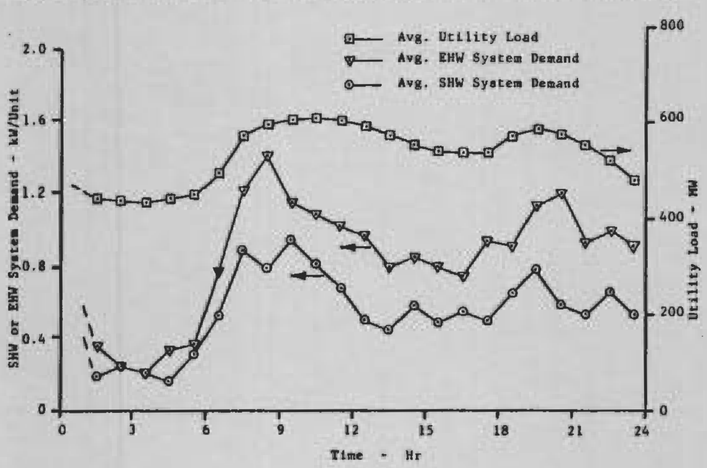

Fig. 4 Average Electric Demand for the Ten Highest Peak Demand Days during the Winter of 1982

The winter daily load profile is binodal, with a slightly higher peak in the morning. Table 6 shows morning utility demand data for the ten winter days in 1982 that exhibited the highest peak demand in the morning. It is seen that the average reduction is about 0.45 kW per house, which is even larger than the late afternoon reduction for summer peak days. However the demand reductions are more erratic in the winter with one day (12/13) showing a slight demand increase and another (2/26) effectively no reduction. Thus the demand reduction for winter days appears to be not so consistent or predictable.

Day	SHW sys. kW	EHW sys. kW	Reduct. kW	Temp.(°F) high	low	% poss sun 6-12AM
12/13	1.077	1.029	-0.047	50	26	30
1/11	0.562	1.345	0.782	30	11	63
1/12	0.626	1.216	0.589	49	27	0
1/13	0.896	1.311	0.415	33	23	0
1/14	1.090	1.265	0.175	56	19	100
2/04	0.726	1.547	0.820	44	32	0
2/05	1.136	1.492	0.356	40	26	0
2/06	0.847	1.075	0.227	34	22	7
2/10	0.730	1.916	1.185	46	27	0
2/26	0.808	0.812	0.004	41	38	0
Avg.	0.850	1.301	0.451	42.3	25.1	20.0
Average 1982 winter weather				62.0	41.2	49.0

Table 6 Solar and Conventional Water Heating Electric Demand (between 8AM and noon) and Weather Data for the Ten Highest Winter System Peak Days of 1982

The majority of the SHW systems monitored had the older circulation freeze protection, which can result in energy losses during cold and cloudy periods. The newer drain-down type of SHW system should exhibit less loss during cold periods and thus result in at least as good demand reduction as measured in this study.

POLICY OPTIONS

Utilities around the country have initiated a variety of programs to encourage the installation of SHW systems (13), including: 1) providing low interest loans through the utility with a small or no down payment; 2) lowering of electric tariffs for homes that install solar water heaters; 3) training and bulk buy-discounts for utility customers in the installation of passive water heaters; 4) public education and SHW system demonstration projects; 5) certification and free inspection of SHW systems; and 6) encouraging the implementation of city ordinances that assure solar access when possible.

At present the Austin Electric Department, partially as a result of this study, provides a rebate of up to $125 as an incentive to purchasers of new, commercially produced SHW systems. To qualify for the cash rebate, the SHW system's distributor must have on file at the Electric Department a copy of test results on the SHW system carried out by an independent laboratory in accordance with ASHRAE Standard 93-77 and NBSIR-1305A. SHW systems must have at least a one-year parts and labor warranty provided by the contractor.

The City of Austin Energy Management Office provides free energy audits of residences and will recommend installation of an SHW system if it is considered cost effective for a particular home.

The Austin Electric Department could help to expand the market penetration of SHW systems by providing potential SHW customers the choice of a cash rebate or a low interest loan. The Austin Energy Management Office currently offers low interest loans for home improvements to help conserve energy, particularly electricity consumed during the summer peak demand interval. However, loans are not available through the Austin Energy Management Office for SHW systems. A criterion required to qualify for a home energy loan is that the total energy savings resulting from the entire loan reduce peak electric consumption by an average of 50%. An SHW system by itself would not reduce peak electric consumption by 50%, but it could be considered as part of a package loan which included money for other cost effective energy conserving measures.

This paper is based on the results of (17) which may be reviewed for more details of the investigation.

SUMMARY

This investigation shows that solar hot water (SHW) systems reduce a utility's peak electric demand in the summer. The average demand reduction of SHW systems compared to conventional electric water heaters during the electric peak demand interval from 3PM to 7PM on the ten highest peak days of 1982 was 0.39 kW.

The average electric energy used by SHW systems for the summer and winter periods was 82 kWh/month and 309 kWh/month respectively. For conventional electric water heaters, the average summer electric energy use was 323 kWh/month, while the winter energy use was 565 kWh/month. Therefore a utility which experiences its highest electric load in the summer would benefit from the greater relative decrease in electric demand during the summer than in the winter.

Since SHW systems can be counted on to reduce peak electric consumption for summer peaking utilities and help to even out the seasonal electric loads, they should be considered as part of an overall loan package to owners of homes with electric water heaters.

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