Solar Versus Heat Pump Water Heaters: An Appliance Perspective

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Introduction and Scope of Study

This poster presents a method and a set of assumptions that can be used to evaluate solar water heating compared to heat pump water heaters and other conservation options. We present approximate ranges of economic benefit for the options involved rather than specific values, since installation cost and field performance vary so much.

Our point of view is that of the consumer in a detached single family residence. In performing economic analysis, we choose a real discount rate of 6% (with constant 1992 dollars).

We use the cost of conserved energy (CCE) (Meier 1983) as the main method for comparing the various options. The primary advantage of this approach is that options can be economically evaluated and ranked on a common basis that is independent of electricity prices. The common basis is important for evaluating the options, each of which saves energy in a different way: Low flow showerheads save water, bottom boards reduce standby loss, and solar and heat pump heaters reduce the amount of input required.

For solar systems, we indicate the range of installed costs for retrofit applications, not new construction. The majority of conventional water heater sales (80%) is for replacement applications. Maintenance costs are not considered.

Methodology

We plot of the CCE versus cumulative water heater energy savings from to several conservation options. The CCE can be viewed as the investment cost of the saved energy, and is independent of the price of the saved energy. Yet the CCE can be readily compared to the price of electricity: If, for example, a solar water heater has a CCE of $.09/kWh, then it is a good investment when the price for electricity is greater than $.09/kWh.

We use 14 years, the reported average lifetime for electric water heaters, to represent the life of all energy conserving options, except for low-flow shower heads, where we used a twenty year lifetime.

Energy Calculations

Total annual site energy consumption in Table 1 is calculated from the equations in the old DOE test procedure (10 CFR 430). The new test procedure does not allow calculation of energy consumption from recovery efficiency and standby loss, as the old test procedure did. We have used the specifications from the new DOE test procedure (64.3 gallons per day, 58°F inlet temperature, 135°F outlet temperature, and 67.5°F ambient temperature) because we assume them to be more representative of current domestic hot water usage.

The energy factor (EF), a measure of average efficiency of the water heater, is the energy added to the water drawn from heater divided by the total energy input to the heater.

The DOE uses the EF measure to establish minimum water heater efficiency requirements according to the mandate of the National Appliance Energy Conservation Act (NAECA) of 1987.

Baseline Water Heater Energy

The baseline is a 52 gallon electric resistance water heater with an EF of .88, the minimum efficiency required by the 1990 NAECA standards. We assumed here that the recovery efficiency is 98%, and obtain standby loss by adjusting its value in order to achieve the .88 value of EF.

Conservation Options

Low flow showerheads were estimated to save 12.9 gallons of hot water per day based on a discussion in the 1991 Northwest Conservation and Electric Power Plan.

The Northwest Power Planning Council estimates savings from bottom boards at 34 kWh/yr. The standby loss was adjusted for the bottom board until the incremental savings from the baseline matched this value.

Solar Water Heaters

Performance and installation costs for systems in different locations in the US were from discussions with people currently active in the solar industry. We have taken this

Table 1. Summary of Calculations

	CCE ($/kWh)	Annual Energy (kWh/yr	Installed Cost ($)	EF	Er	Standby Loss (Btu/hr)	Tank Volume (gals)
Baseline	na	4963	0	0.88	0.98	221	52
Low Flow Shhd	0.008	4082	80	0.86	0.98	221	52
Bottom Board	0.031	4047	90	0.86	0.98	206	52
Case 1 Solar	0.177	2833	2090	na	na	na	80
Case 2 Solar	0.149	2024	2890	na	na	na	80
Case 3 Solar	0.117	1336	3040	na	na	na	80
Case 4 Solar	0.119	202	4340	na	na	na	80
Rated Conditions for HPWHs							
HPWH 1: Add on	0.069	2123	1322	1.65	2.6	354	52
HPWH 2: Add on	0.054	1817	1211	1.92	3	298	52
HPWH 3: New	0.079	1714	1796	2.04	3	243	82
HPWH 4: New	0.062	1671	1460	2.09	3.4	295	52
Worst Case COP for HPWHs:							
HPWH 1: Add on	0.252	3520	1322	0.99	1.2	354	52
HPWH 2: Add on	0.167	3325	1211	1.05	1.2	298	52
HPWH 3: New	0.238	3276	1796	1.07	1.2	243	82
HPWH 4: New	0.182	3239	1460	1.08	1.3	295	52
Best Case COP for HPWHs:							
HPWH 1: Add on	0.063	1930	1322	1.81	3.1	354	52
HPWH 2: Add on	0.049	1608	1211	2.17	3.7	298	52
HPWH 3: New	0.072	1497	1796	2.33	3.7	243	82
HPWH 4: New	0.057	1453	1460	2.40	4.5	295	52

approach due to the lack of a widely accepted method for adjusting solar system test results for climate, tank temperature, and daily water usage.

Solar System #1, with a solar savings fraction (SSF) of 0.3, represents a low performance case based on a 30 gallon capacity breadbox type integral collector/storage (ICS) system in a moderate to poor California climate.

Solar System #2, at SSF=0.5, represents the cost and performance for a 2 panel active system with a 80 gallon storage tank in Portland. This is considered representative of performance in the worst climate zone in the integral US.

Solar System #3, at SSF=0.67, represents the cost and performance for a 1 panel active system with a 80 gallon storage tank in the Central Valley of California. This is considered representative of performance in an intermediate climate.

Solar System #4, at SSF=0.95, represents the cost and performance for a 2 panel active system with a 80 gallon storage tank in Hawaii. The performance is representative of the best solar climate in the US. No freeze protection is required there.

Heat Pump Water Heaters

We obtain EF ratings of HPWHs from the GAMA directory of certified efficiency ratings for water heaters, and adjusted the standby losses (S) until the EF with the baseline draw equals the rated EF. We assume that the recovery efficiency (E_r) at test conditions is equal to the COP shown in the product literature. The values used in this analysis are shown in Table 1.

The total energy consumption per day attributable to a HPWH unit, including interactions with space conditioning equipment, can be characterized by the following expression:

$$E = Q_{DHW} \;/\; COP_{total}$$

$$= Q_{DHW} \;/\; E_r \;\pm\; Q_{spc} \;/\; COP_{spc}$$

$$= Q_{DHW} / E_r \pm Q_{DHW} * (1 - 1 / E_r) / COP_{spc} (1)$$

where Q_{DHW} is the total daily energy into the water (including make-up for standby losses), and E_r and COP_{spc} are the recovery efficiency of the HPWH and the COP of the house space conditioning system, respectively.

Q_{spc} is the daily energy extracted from the house by the heat pump. The expression of Q_{spc} as a function of Q_{DHW} and COP_{DHW} derives from a heat balance for the HPWH. The $\pm$ symbol indicates that space conditioning electrical energy must be added to the heat pump energy during the heating season, and subtracted from the heat pump energy in the cooling season. If a house has no air conditioning, if the space conditioning system is not used (e.g. during a swing season), or the HPWH is located out of doors, then the second term is zero.

We use two extreme cases to establish the bounds on E for each HPWH. The HPWH is located inside the conditioned space for both cases. The most energy intensive case is one in which the home has no air conditioning, electric resistance is the space heating source (i.e., $COP_{spc} = 1$), and the heating season is long. Great Falls, Montana is chosen as representative of a climate with a long heating season. ASHRAE Standard 124P (Method of Testing for Rating Combination Space-Heating and Water-Heating Appliances) gives the length of its heating season as 254 days.

A heat pump conditioned house in an extreme Southern climate, Houston, Texas, is chosen as the least energy intensive case. The predominant space conditioning energy consumption for this climate is cooling. The heating season (88 days, COP_{spc}= 2.0), cooling season (235 days, COP_{spc}= 2.9), and swing season (42 days, Q_{spc}= 0) are estimated from ASHRAE 124P also.

Table 1 presents the COP_{total} values calculated by the above procedure as the recovery efficiencies (Er) for HPWHs.

HPWH #1 and HPWH #2 are both add-on or remote heat pumps that can be attached to an existing tank. HPWH #1 is made by a major water heater manufacturer. HPWH #3 and HPWH #4 are both packaged as a complete system with a tank. The heat exchanger for this HPWH #4 is built into the tank wall.

Retail and shipping costs for HPWHs were obtained from manufacturers or plumbing supply houses. The installation costs were estimated.

Discussion of Results

The results are shown in Figure 1. The first two options are applied sequentially. The other options are mutually exclusive. No paths were drawn to them.

We draw several conclusions from Figure 1. First, the conservation options are much more cost effective than equipment options. With respect to the equipment options, the HPWHs generally have a much better (lower CCE) economic value than solar water heaters. The most interesting results of the present work concern the overlap area for the solar and HPWH ranges of CCE.

The four highest CCE values for HPWHs are for the worst case condition, an electrically heated home without air conditioning, in a harsh northern climate. The overlap of solar and HPWH economic ranges indicates that the two types of systems must be compared carefully. This is especially true for cases in which an indoor HPWH is being evaluated for an electric resistance heated residence or where the cooling available from the HPWH cannot be used to offset space cooling system energy.

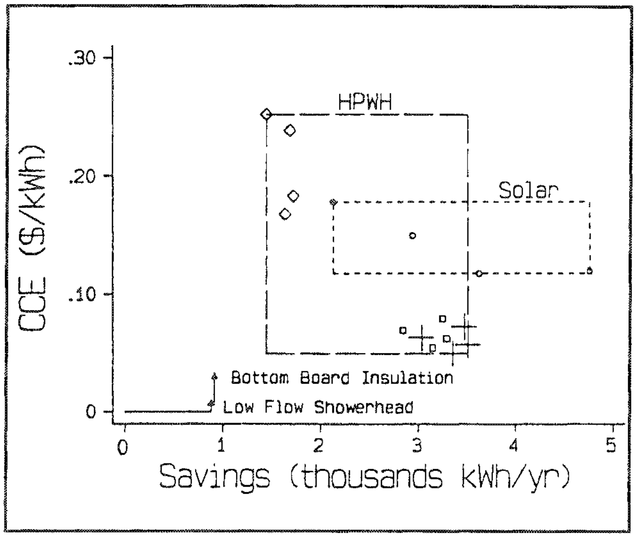

Figure 1. Cost of Conserved Energy for Water Heaters

Some cautions about these results are worth noting. The results here have nothing to do with peak demand: We take the viewpoint of the consumer and not the utility in this analysis.

Also, we analyzed the cost of solar systems without rebates. However, contractor prices obtained for this study appear to be heavily influenced by existing rebates, in addition to climate factors, and energy prices. Thus, a contractor in Hawaii (which has a 35% rebate, excellent solar weather conditions, and electric power rates above $0.10/kWh) can charge a higher amount than a contractor in California (which has no rebate, less favorable weather, and lower electric rates) for the same system and consumer CCE.

References

Meier, A. 1983. "What is the Cost to You of Conserving Energy?" *Harvard Business Review*, 61:36-38.

Gas Appliance Manufacturers Association, *Consumers' Directory of Certified Efficiency Ratings for Residential Heating and Water Heating Equipment*, October 1991, Arlington, VA.

10 Code of Federal Regulations 430, subpart B, Appendix E, *Uniform Test Method for Measuring the Energy Consumption of Water Heaters*, 1990.