The American Council for an Energy-Efficient Economy
Emerging Technologies Report

Advanced Gas Water Heaters

February, 2007

Summary

Definition	Water heating systems that provide amenity levels equivalent to conventional storage water heaters but use much less energy (does not include solar-assisted water heaters or electric heat pump water heaters).				
Base case	*Retrofit:* Residential 40-gallon gas-fired storage water heater with pre-2004 federal minimum efficiency (EF=0.54) *New Construction:* Residential 50-gallon gas-fired storage water heater with 2004 federal minimum efficiency (EF= 0.58)				
New Measure		Percent Savings by App.	2020 Savings (TBtu)	2020 Cost per MMBtu Saved	Success Rating (1-5)
(1) Retrofit High-EF near-condensing gas storage water heater		22%	154	$8.13	4
(2) Retrofit Tankless gas water heater		23%	36	$21.04	2
(3) New Construction condensing gas storage water heater		33%	51	$9.91	4
(4) New Construction tankless gas water heater		19%	29	$27.35	5

Background and Description

Almost all single family and small multi-family housing units in the United States use free-standing storage water heaters to provide “service hot water” (“domestic hot water”) for cooking, bathing, cleaning, and related functions. Smaller numbers use heating system boilers to heat domestic water directly (“tankless coils”) or with insulated water tanks that are heated by an internal coil heated by the boiler. Roughly one third of the heat input to a conventional water heater escapes through the flue. About 15%, including latent heat of water vapor, is lost while the unit is firing, and another 17% is lost in standby, while the burner is off. Another 7% of heat is lost through the jacket, fittings, and other parts. Reducing standby losses substantially would require dampers or the equivalent to prevent air flow through the flue during the off-cycle.

High-efficiency alternatives to conventional storage water heaters, including condensing storage, tankless, solar-assisted, and electric heat pumps, have limited market shares in the U.S. today. Perhaps a hundred thousand tankless units are sold each year, but heat pump water heater sales are only a few thousand annually. The two most viable alternatives for conventional houses (existing and new) are tankless and condensing storage-type water heaters. This report compares the energy savings and market potential of these two distinct approaches in both retrofit and new construction scenarios. Solar-assisted water heaters require additional design considerations and are treated in a separate 2006 ACEEE Emerging Technologies report. Electric heat pump water heaters were treated in the 2004 ACEEE Emerging Technologies Report, as Technology W3.

Caveat: The federal rating method, EF, probably is inadequate for comparing field performance or energy consumption across technologies (e.g., between storage and tankless water heaters). This is discussed in Appendix A.

Current Status of Measure

Near-condensing storage water heaters. Although a few models are available with EF as high as 0.67, there are no “near-condensing” products in the range of 0.68 – 0.70. Their development is a goal of SEGWHAI. This could be an important retrofit technology, because installation requires little change from present methods.

Condensing storage water heaters. A very limited selection of very high-priced models has been available, typically in large capacities primarily marketed for luxury and small commercial applications. We estimate current sales as <10,000/yr. The introduction of the A.O. Smith "Vertex" model, slightly larger than the capacity cut-off for residential units but at a lower price point, may evoke competitive responses and expand the market, partly as a response to higher gas prices. We explore these for new construction, where flue and drain requirements are most easily accommodated, but they will appear in many retrofits, as well.

Tankless (Instantaneous) water heaters. We estimate current sales in the US as ~100,000/yr, or roughly 1% of the total market for water heaters. Tankless units are ubiquitous in Europe. However, there is less experience with the modulating units commonly sold in the US. From a review of manufacturer specifications, we assume that tankless units will require one maintenance visit per year, to de-scale the heat exchanger, and to clean and adjust the mechanism (Kalensky 2007). This is expected to be an absolute requirement, particularly in hard water (calcium carbonate-rich) regions.

Savings Potential and Cost-Effectiveness

Tankless water heater designs are relatively mature; however, units that satisfy North American expectations for whole-house systems (supporting multiple simultaneous uses) require high capacity, modulation, and sophisticated controls that add incremental cost to the technology in the U.S. market. Costs are likely to come down somewhat as domestic sales increase, but probably not dramatically. The high purchase prices, high installation costs (in retrofit markets), requirements for annual maintenance, and high cost of saved energy for both new construction and replacement installations (> $20/MMBtu) all argue that market growth will not be driven by efficiency, but by claims of "endless hot water," an amenity that may not bode well for energy consumption.

Our analysis suggests that storage water heaters are likely to be more cost-effective than tankless water heaters for the US market. However, there is a caveat: Our costs of saved energy, $8.00 - $10.00/MMBtu, are based on incremental costs that must be achieved to meet TRC benefit-cost ratios in California. They are not market prices, or even projected market prices, because the markets do not exist or are very immature. However, the cost of saved energy for tankless units is two - three times as high, ranging from about $21/MMBtu (tankless retrofit, replacing lower efficiency 40 gal. storage water heater) to $27/MMBtu (new construction, alternative to current efficiency 50 gal. Storage water heater).

Market Barriers

As with most emerging technologies, first cost, public awareness and contractor/builder training are key market barriers for all three advanced water heater technologies. The public awareness challenge is much lower for tankless water heaters, which accounts for its high likelihood of success rating in new construction. However, wide adoption of tankless gas water heaters may strain gas utilities during peak hours of hot water use. In retrofit scenarios, contractor/builder training is a significant challenge for tankless units because they require serious attention to venting and sizing of the gas supply line. In addition, many or all tankless units require annual or more frequent maintenance by technicians, with particular attention to the de-liming sensor, water valve, and filters (Kalensky, 2007). Training issues are moderate for condensing units, which use plastic vents but require condensate drain arrangements. Condensing water heater installation closely parallels that for condensing furnaces and boilers, with which contractors have relatively great experience in the northern half of the country.

There are several technical and regulatory "wild cards" for all advanced water heaters today. One technical risk for the replacement market may be availability of 120-volt power near the water heater. It is expected that advanced units will require electricity. If this is line voltage, these installations will require an outlet within 6' of the water heater, which may raise installation cost.

On the regulatory side, there are two principal risks. Codes such as the *Flammable Vapor Ignition Resistance* code *(FVIR;* GAMA 2005a) presents design challenges for components including vent dampers in all three technologies. Restrictions on nitrous oxide (NOx) emissions may also impose additional design considerations that may make advanced water heaters less competitive.

Next Steps

ACEEE recommends that market transformation programs for advanced water heaters are designed to evaluate field experience with tankless water heaters before launching large-scale incentive programs. Key issues include installation quality (conformance to (venting) codes, adequate gas capacity), and actual efficiency, that is measuring hot water delivery to the fixtures relative to gas consumption. For storage water heaters, the SEGWHAI program has prepared technical specifications, market studies, and most of the other groundwork required for a large-scale market transformation program.

Key Assumptions Used in Analysis

Cost estimates for tank-type units are based on the SEGWHAI Final Report (in preparation) projections of levels that have positive benefit/cost ratios for California utilities, but modified to maximum levels consistent with cost of saved energy <$13.00/MMBtu for storage alternatives. ACEEE (2004) suggested lower cost of saved energy. The current estimates are higher for two reasons: (1) In 2004, we could not have corrected the EF based on Davis Energy Group (2006) findings; and we limited ourselves to houses with much higher than average hot water use, where tankless units will be more cost-effective. Electricity use given here is estimated by ACEEE. ACEEE expects the consumer price of gas to remain in the range of $1.20 - $1.60/MMBtu for the next several years .

Average Price of Electricity	$0.083/kWh
Percent New Res. Construction in 2020 (DOE, 2005)	14.8%
Average Price of Natural Gas	$10.16/MMBtu
Projected 2020 End use Electricity Consumption (AEO, 2006)	0.39 quads
Real Discount Rate	4.53%
Projected 2020 End use Gas Consumption (AEO, 2006)	1.25 quads
Heat Rate	10.42 kBtu/kWh

Data Summary

(1)
New Measure: Retrofit High-EF near-condensing gas storage water heater (EF=0.70)
Basecase: Residential 40-gallon gas-fired storage water heater with pre-2004 federal minimum efficiency (EF=0.54)

Application and Status				
Market Sector(s)	**Application(s)**		**End use(s)**	**Fuel type(s)**
Residential	Retrofit Replace on Burnout (long life)		Water Heating Combined Heat/HW	Propane Natural Gas
Market Segment	**National/Regional**		**Region(s)**	**State(s)**
None	National		All	All
Current Status	**Date of Commercialization**			
Research	2008	Based on indications of industry interest		
Market Players/Manufacturers	**Life**			
SEGWHAI	13 years	From SEGWHAI (in prep.); rejects DOE estimate of 9 years (DOE, 2001)		

Basecase Information			*Notes (Source)*
Efficiency	0.54	EF	
Electric Use	0	kWh/yr	
Summer Peak Demand	0	kW	
Winter Peak Demand	0	kW	
Gas/Fuel Use	20.0	MMBtu/yr	
New Measure Information			***Notes (Source)***
Efficiency	0.70		
Electric Use	40	kWh/yr	This represents ~5 W to support sensors, logic, ignition.
Summer Peak Demand	0.005	kW	Figure will have high variability
Winter Peak Demand	0.005	kW	Figure will have high variability
Gas/Fuel Use	15.5	MMBtu/yr	
Savings Information			***Notes (Source)***
Electric Savings	-40	kWh/yr	
Summer Peak Demand Savings	-0.005	kW	
Winter Peak Demand Savings	-0.005	kW	
Gas/Fuel Savings	4.5	MMBtu/yr	SEGWHAI estimated lower savings: 2.8 MMBtu/year
Percent Savings	22	%	
Feasible Applications (%)	90	%	Assumes few on-site installation barriers
Industrial Savings Potential (>25%)	NO		
2020 Savings Potential (Tbtu)	**154**	**Tbtu**	
Cost of Saved Energy ($/MMBtu)	**$8.13**	**$/MMBtu**	
Cost Information			***Notes (Source)***
Incremental Cost	$350	2006 $	SEGWHAI incremental cost must be lest than $200 for cost-effectiveness.
Other Costs / (Savings)	$0	$/yr	

Success Factors			
Market Barriers	**Non-Energy Benefits**	**Current Promotional Activity**	**Next Steps**
- Product Not Manufactured - Lack of Training / Expertise - No Marketing	- Easier installation than tankless	- None	- Prototype Development - Field testing
Priority	**Likelihood of Success**	**Success Rationale**	
5	4	May be trapped below condensing and tankless EF values, and less attractive in the market (depending on costs)	
Data Quality Assessment	**Data Explanation**		
B	Costs are requirements derived by SEGWHAI from Calif. Economic tests for programs, not from product cost, since product is not yet available.		

(2)
New Measure: Retrofit Tankless gas water heater (EF=0.80, decremented to 0.71, see below)
Basecase: Residential 40-gallon gas-fired storage water heater with pre-2004 federal minimum efficiency (EF=0.54)

Application and Status				
Market Sector(s)	**Application(s)**		**End use(s)**	**Fuel type(s)**
Residential	Replace on Burnout (long life)		Water Heating	Propane Natural Gas
Market Segment	**National/Regional**		**Region(s)**	**State(s)**
None	National		All	All
Current Status	**Date of Commercialization**			
Commercialized	2000	For pilot-less, modulating whole-house units (date approximate)		
Market Players/Manufacturers	**Life**			
Takagi, Rinnai, Rheem, others	13 years	From SEGWHAI (in prep.); DOE estimate of 9 years (DOE, 2001) is rejected		

Basecase Information			***Notes (Source)***
Efficiency	0.54	EF	Pre-2004, NAECA min, 40 gallon storage.
Electric Use	0	kWh/yr	Standard tank-type storage WH has no electric connection.
Summer Peak Demand	0.0	kW	
Winter Peak Demand	0.0	kW	
Gas/Fuel Use	20.0	MMBtu/yr	
New Measure Information			***Notes (Source)***
Efficiency	0.71	EF	From California Data (Davis Energy Group, 2006)
Electric Use	40	kWh/yr	Estimated, about 4 watt continuous
Summer Peak Demand	0.005	kW	
Winter Peak Demand	0.005	kW	
Gas/Fuel Use	15.3	MMBtu/yr	
Savings Information			***Notes (Source)***
Electric Savings	-40	kWh/yr	
Summer Peak Demand Savings	-0.005	kW	
Winter Peak Demand Savings	-0.005	kW	
Gas/Fuel Savings	4.7	MMBtu/yr	
Percent Savings	23	%	
Feasible Applications (%)	20	%	Assumes feasible installation in 25% of replacements; replacements are 20% of market
Industrial Savings Potential (>25%)	NO		
2020 Savings Potential (Tbtu)	**36**	**Tbtu**	
Cost of Saved Energy ($/MMBtu)	**$21.04**	**$/MMBtu**	Includes annual maintenance visit
Cost Information			***Notes (Source)***
Projected Incremental Cost	$800	2006 $	Based on SEGWHAI estimates (in prep.)
Other Costs / (Savings)	$150	$/yr	Assume 1 technician visit/yr to backflush, de-scale, etc.

Success Factors			
Market Barriers	**Non-Energy Benefits**	**Current Promotional Activity**	**Next Steps**
- High First Cost - Annual Maintenance Cost - Low Visibility - Lack of Training / Expertise - Capacity Limits	- Endless Hot Water	- Utility Incentives (limited)	- Field Performance Demonstrations
Priority	**Likelihood of Success**	**Success Rationale**	
3	2	Sold for amenity more than efficiency	
Data Quality Assessment	**Data Explanation**		
B	Data based on current sales prices, with little feel for future declines.		

(3)
New Measure: New construction condensing gas storage water heater
Basecase: Residential 50-gallon gas-fired storage water heater with 2004 federal minimum efficiency (EF= 0.58)

Application and Status				
Market Sector(s)	**Application(s)**		**End use(s)**	**Fuel type(s)**
Residential	New Construction		Water Heating Combined Heat/HW	Propane Natural Gas
Market Segment	**National/Regional**		**Region(s)**	**State(s)**
None	National		All	All
Current Status	**Date of Commercialization**			
Commercilaized	~1985			
Market Players/Manufacturers	**Life**			
None	13 years	From SEGWHAI (in prep.); DOE estimate of 9 years (DOE, 2001) is rejected		

Basecase Information			***Notes (Source)***
Efficiency	0.58	EF	
Electric Use	0	kWh/yr	
Summer Peak Demand	0.0	kW	
Winter Peak Demand	0.0	kW	
Gas/Fuel Use	18.9	MMBtu/yr	
New Measure Information			***Notes (Source)***
Efficiency	0.86		
Electric Use	150	kWh/yr	Very rough estimate, includes draft inducer.
Summer Peak Demand	0.017	kW	
Winter Peak Demand	0.017	kW	
Gas/Fuel Use	12.6	MMBtu/yr	
Savings Information			***Notes (Source)***
Electric Savings	-150	kWh/yr	
Summer Peak Demand Savings	-0.017	kW	
Winter Peak Demand Savings	-0.017	kW	
Gas/Fuel Savings	6.3	MMBtu/yr	SEGWHAI estimated higher savings: 5.9 MMBtu/yr
Percent Savings	33	%	
Feasible Applications (%)	20	%	Based on all new construction sales
Industrial Savings Potential (>25%)	NO		
2020 Savings Potential (Tbtu)	**51**	**Tbtu**	
Cost of Saved Energy ($/MMBtu)	**$9.91**	**$/MMBtu**	
Cost Information			***Notes (Source)***
Incremental Cost	$600	2006 $	Costs derived from Calif. Economic tests for programs, not from product cost, since product not yet available.
Other Costs / (Savings)	$0	$/yr	

Success Factors			
Market Barriers	**Non-Energy Benefits**	**Current Promotional Activity**	**Next Steps**
- High first cost - Low visibility - Lack of training / expertise - Contractor is not bill-payer	- Elimination of chimney saves substantial cost - Reduced flue risks	- Advertising (very limited) - Training (very limited)	- Field Performance Demonstrations - Utility / Market Transformation Programs.
Priority	**Likelihood of Success**	**Success Rationale**	
5	4	Easily positioned as premium product	
Data Quality Assessment	**Data Explanation**		
M	Very little cost information is available now.		

(4)
New Measure: New construction tankless gas water heater
Basecase: Residential 50-gallon gas-fired storage water heater with 2004 federal minimum efficiency (EF= 0.58)

Application and Status			
Market Sector(s)	**Application(s)**	**End use(s)**	**Fuel type(s)**
Residential	New Construction	Water Heating	Propane Natural Gas
Market Segment	**National/Regional**	**Region(s)**	**State(s)**
None	National	All	All
Current Status	**Date of Commercialization**		
Commercialized	2000	Guess at date of availability for no-pilot modulating whole-house units	
Market Players/Manufacturers	**Life**		
Takagi, Rinnai, Rheem, others	13 years	From SEGWHAI (in prep.); DOE estimate of 9 years (DOE, 2001) is rejected	

Basecase Information			***Notes (Source)***
Efficiency	0.58	EF	NAECA minimum, 50 gallon, post-2004
Electric Use	0.0	kWh/yr	
Summer Peak Demand	0.0	kW	
Winter Peak Demand	0.0	kW	
Gas/Fuel Use	18.9	MMBtu/yr	
New Measure Information			***Notes (Source)***
Efficiency	0.71	EF	EPACT 2005 credit, decremented by CA experience
Electric Use	40	kWh/yr	Estimated, no inducer fan
Summer Peak Demand	0.005	kW	
Winter Peak Demand	0..005	kW	
Gas/Fuel Use	15.3	MMBtu/yr	
Savings Information			***Notes (Source)***
Electric Savings	-40	kWh/yr	
Summer Peak Demand Savings	-0.005	kW	
Winter Peak Demand Savings	-0.005	kW	
Gas/Fuel Savings	3.6	MMBtu/yr	
Percent Savings	19%	%	
Feasible Applications (%)	20%	%	Assume available for all new construction but no replacements
Industrial Savings Potential (>25%)	NO		
2020 Savings Potential (Tbtu)	**29**	**Tbtu**	Low, because no retrofits permitted in this scenario
Cost of Saved Energy ($/MMBtu)	**$27.35**	**$/MMBtu**	Note: includes annual maintenance charge
Cost Information			***Notes (Source)***
Incremental Cost	$800	2006 $	SEGWHAI
Other Costs / (Savings)	$150	$/yr	Assume 1 technician visit/yr to backflush, de-scale, etc.

Success Factors			
Market Barriers	**Non-Energy Benefits**	**Current Promotional Activity**	**Next Steps**
- High First Cost - Annual Maintenance Cost - Specialized Training Needed - Low Visibility - Capacity Limits	- Endless Hot Water - Lower installation costs in new construction	- Utility Incentives (limited)	- Field Performance Demonstrations
Priority	**Likelihood of Success**	**Success Rationale**	
1	5	Sold for amenity, not savings.	
Data Quality Assessment	**Data Explanation**		
B	Data based on current sales prices, with little feel for future declines.		

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Appendix A: Discussion of Water Heater Efficiency Ratings

All residential water heaters sold in the United States must meet or exceed federal efficiency levels, as measured by a specific test protocol. Water heater efficiency is measured by the "EF" determined by the test. The current standards took effect on January 20, 2004. The minimum efficiency varies with tank size. For gas storage water heaters, the formula is

EF = 0.67 – (0.0019*rated volume).[1]

For common sizes, this gives values of:

Gas Water Heater Minimum EF				
Storage Volume (gal)	tankless	30	40	50
	0.62			
Storage, Minimum EF, 2004		0.61	0.59	0.58
Storage, Minimum EF, pre-2004		0.56	0.54	0.52

Fundamentally, the DOE method subjects each water heater to 6 sequential water draws of just over 10 gallons each, and a very long period in which standby losses are evaluated. In reality, residential use typically shows 20 – 80 hot water draws/day, many quite small. It appears that tankless water heaters do much better in the large-draw test than when challenged with a test draw pattern more like typical installations. Although tankless water heaters are indeed much more efficient in use than tank type, particularly when total hot water use is less than assumed by the test method, the gap is likely to be smaller than indicated by the EF protocol, by about eight or nine EF points (Davis Energy Group, 2006)

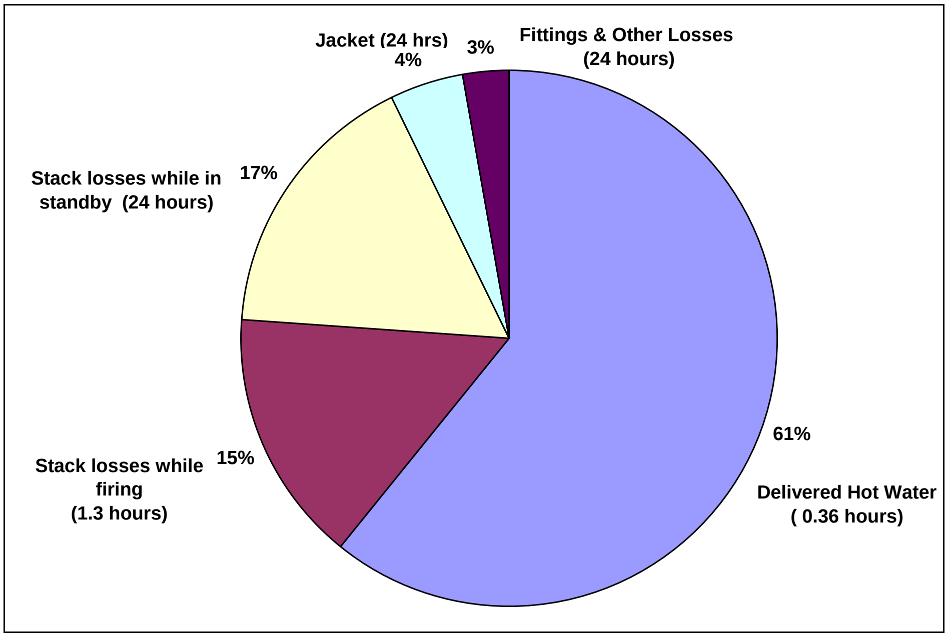
Tank-type or storage water heaters
Conventional storage water heaters may be powered by electricity, natural gas, propane, or oil. Electricity and gas dominate the market, with roughly equivalent market shares of 4.5 million (electric) and 5 million (gas) units (GAMA, 2005b) Electric storage water heaters have high on-site conversion efficiency, and relatively low stand-by losses. However, conversion at the power plant, transmission, and distribution losses reduce the "source" energy efficiency to about 1/3 of the heat value of the fuel at the power plant. Tank-type gas water heaters than can meet the needs of a typical family typically require fuel input no greater than 50,000 Btu/h.
Consider how conventional water heaters distribute energy between useful water heating and waste, as simulated with the TANK model (Lutz, in SEGWHAI final report).

The first major loss is the 17% that passes out through the flue when the unit is off. Almost all of this could be eliminated with flue and stack dampers, but this probably would require pilot-less ignition. In turn, this may require low voltage power. The upper limit of conventional designs is roughly EF 0.70 (Hunt, et al., 2007 (*in prep*))

The second major loss in the TANK model is from high stack temperatures while firing (15%). Raising the combustion efficiency higher, thus transferring a larger fraction of the fuel's energy to the water, means cooler flue gases. The effect is to increase the likelihood that water vapor, a product of combustion, will condense. In equipment not built to deal with liquid water, this can lead to corrosion and failure. Alternatively, a water heater designed to deal with this can capture the fuel's "latent heat" or "heat of combustion" and achieve much greater efficiency. The cost is more expensive material and construction. This requires induced draft or a power burner, stainless or double porcelain clad heat exchanger, and a condensate drain system. One benefit is that the exhaust is cool enough to vent directly to the outside through a PVC (plastic) pipe. The steady state combustion efficiency of a condensing water heater will be at least 90%,

[1] For tankless WH, the formula uses the value 0.62 instead of 0.67; we assume 0 or 1 gal effective volume.

corresponding to an EF ≥~82%. Thus, there are two fundamental technology paths for storage water heaters: Near-condensing, up to about EF 0.70; or condensing, with EF in the range of 0.82 and higher. This follows from the figure above: jacket and fitting losses are not primary heat losses.



Tankless or instantaneous water heaters

As noted in the table above, the minimum EF for tankless water heaters is 0.61, which is very close to steady-state efficiency (there are no standby losses). Units at 0.80 and above are eligible for a $300 tax credit under EPACT 2005. These are not condensing units, but they do have modulating burners that can vary output by a factor of 8 to 10. The high ratings of tankless units are partly deserved, but partly an artifact of the method of test. The federal method requires six even hot water draws of 10.7 gallons each under specified conditions, and then recovery through the rest of a 24 hour cycle. The water draws in this test are large enough to achieve something very close to steady-state operation. However, water use in actual houses seems to be characterized most often as a spectrum from many very small water draws over to a few very large draws. When challenged with such a draw pattern, the performance of tankless water heaters drops off. Davis Energy Group (2006) suggests an adjustment of 8.8 EF points, from 0.8 down to 0.71; we have adopted that proposal in this work.