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The Effect of Efficiency Standards on Water Use and Water Heating Energy Use in the U.S.: A Detailed End-use Treatment[1]

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SYNOPSIS

This paper analyzes US residential water use and water heater energy use. It also investigates water and energy savings associated with existing equipment efficiency standards.

Keywords: Residential codes and standards, Water heating, Water conservation, Forecasting, Program design

ABSTRACT

Water heating is an important end-use, accounting for roughly 16% of total primary energy consumption in the US residential sector. Recently enacted efficiency standards on water heaters and hot water-using equipment (e.g., dishwashers, clothes washers, showerheads, and faucets) will substantially affect the energy use of water heaters in the future. Assessment of current and future utility programs and government policies requires that regulators, resource planners, and forecasters understand the effects of these regulations.

In order to quantify these impacts, this paper presents a detailed end-use breakdown of household hot and cold water use developed for the US Department of Energy. This breakdown is based on both previous studies and new data and analysis. It is implemented in a spreadsheet forecasting framework, which allows significant flexibility in specifying end-use demands and linkages between water heaters and hot water-using appliances.

We disaggregate total hot and cold water use (gallons per day) into their component parts: showers, baths, faucets (flow dominated and volume dominated), toilets, landscaping/other, dishwashers, and clothes washers. We then use the end-use breakdown and data on equipment characteristics to assess the impacts of current efficiency standards on hot water use and water heater energy consumption.

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[1]A shortened version of this report will be published in the proceedings to the 1994 ACEEE Summer Study Conference on Energy Use in Buildings.

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1. INTRODUCTION

The water heating end-use is perhaps the most complicated of all residential end-uses. Usage behavior varies greatly, and depends on ownership of other appliances (e.g., clothes washers and dishwashers), on the characteristics of those appliances and other water-using equipment, on water inlet temperatures, on hot water temperature set points, and on water use temperatures.

Water heating has generally been analyzed in a haphazard manner in the past, in large part because of its complexity. Measurement studies (with a few notable exceptions) have failed to capture the important data necessary for truly understanding how hot and cold water are used in US residences. For example, studies often report the number of gallons per day of hot water use per household, averaged over all households with different appliances. This number is only useful for determining total water heating energy use–it provides no guidance as to what impact different conservation measures might have on that usage. It is also of limited usefulness in assessing the energy use for water heating in a *particular household*. The only way to assess such issues is to disaggregate total hot water use to reflect the various components of hot water loads.

The guiding philosophy behind this paper is that explicit and well-chosen estimates about usage behavior for particular devices (e.g. the number of minutes each person showers per day) can be used to create a "bottom-up" estimate of total usage that is a reasonable portrayal of average water usage. Such detailed bottom-up estimates can be used to assess the effects of policies. In the case of water heating, creating such a disaggregated forecast is the only way to disentangle the effects of the various efficiency standards now affecting this end use. The "order of magnitude" character of the numbers is acceptable for most applications as long as they are derived in an internally consistent and complete manner, and as long as available data, basic physical principles, and common sense are used to guide the choice of parameters.

Characteristics of particular houses may be quite different from the usage assumptions shown here. Nevertheless, we believe that our first-order estimates crudely represent average water usage behavior in US residences. We eagerly await more detailed data on water usage from the many studies now being conducted by US utilities and others.

2. REVIEW OF CORE DATA ON WATER USE AND WATER HEATING ENERGY USE

2.1 Characteristics of water heaters

Table 1 shows the characteristics of residential water heaters of various vintages, derived from US DOE (1993). The relevant characteristics are energy factor (defined as energy delivered in the hot water at the tap, divided by total energy input), recovery efficiency (which is the efficiency of delivering heat to the water in the tank), and the standby losses (which are the constant losses associated with keeping the water in the tank hot and ready for use).

The energy factor, recovery efficiency, and standby losses are related using Equation (1):

$$EF = \frac{\text{Energy content of hot water delivered}}{\text{Total energy used to heat the water}} \qquad (1)$$

Table 1: Characteristics of water heaters

	Units	*Stock 1990*	*Stock 1993 w/1990 stds*	*Sales late 1980s*	*Sales 1990*	*Proposed Stds 1-Jan-98*
Energy Factors						
Electricity	%	82%	83%	84%	88%	189%
Gas	%	49%	50%	49%	54%	57%
Oil	%	46%	46%	47%	51%	67%
Standby losses						
Electricity	Wh.th/hr	97	89	86	57	10
Electricity	Btus.th/hr (site)	332	303	294	194	34
Gas	Btus.th/hr	1576	1453	1510	1125	948
Oil	Btus.th/hr	1576	1453	1510	1125	948
Recovery efficiency						
Electricity	%	98%	98%	98%	98%	193%
Gas	%	76%	76%	76%	76%	76%
Oil	%	76%	76%	76%	76%	76%

(1) Standby losses and recovery efficiency for gas and electric water heaters (WHs) derived from US DOE (1993). Oil water heaters assumed to be the same as gas.
(2) Energy factors (EFs) for stock (1990 and 1993) and late 1980s sales derived from historical shipments taken from Hanford et al. 1994. EFs for 1990 sales equal the 1990 standards.
Proposed 1998 standard on electric WHs requires manufacturers to produce only heat pump water heaters.
Recovery efficiency for heat pump water heaters varies depending on water temperatures.
Recovery efficiency shown here is an overall average.
(3) (Standby losses + the heat content of water used)/recovery efficiency = total WH energy use.
Energy factor = the heat content of water used/total WH energy use.
(4) Calculation of Stock and late 1980s sales standby losses assumes that all measures used by manufacturers to improve the WH EF affected only standby losses.
(5) Wh.th/hr = watt-hour (thermal) per hour; Btus.th/hr = Btus (thermal) per hour.

Where total energy used to heat the water (E_{total}) is defined as in Equation (2):

$$E_{total} = \frac{\text{(Energy content of hot water delivered + Standby losses)}}{\text{Recovery efficiency}} \quad (2)$$

We use these equations to create the characteristics of electric and natural gas water heaters in Table 1, using data from US DOE (1993). Energy factors (EFs) are given either from historic data (Hanford et al. 1994) or for the 1990 standards. These energy factors are used with the above equations to calculate standby losses and recovery efficiencies for cases where those parameters are not immediately available. The calculation of "Stock" and "Late 1980s sales" standby losses assumes that all measures used by manufacturers to improve the water heater EFs affected only standby losses.

2.2 Water temperature assumptions

Table 2 describes the end-use temperatures assumed in our calculations. The hot water temperature is the weighted average from a survey of water heater temperatures cited in Bancroft et al. (1991). The cold water temperature represents a rough average across the US and over the year, adopted from data in Labs (1979). These two temperatures and the assumed end-use temperatures imply a certain percentage breakdown of hot and cold water use. These percentage breakdowns are used to calculate hot and cold water use from total water use below.

2.3 Showers, sinks, and faucets

Table 3 summarizes usage times and flow rates for showers, baths, and faucets. We disaggregate these uses into flow and filling uses because the standards have different effects on them. Flow rate standards affect only the flow portion of the water use. Filling water uses are not affected by these flow rate standards. Flow assumptions for these end-uses were created after reviewing the available literature (Bancroft et al. 1991, Kempton 1984, Perlman 1987, Rohles Jr. and Konz 1981, Taylor et al. 1991, Thrasher et al. 1990). We rely most heavily on Brown and Caldwell (1984), which has the most careful and comprehensive treatment of total water use data (though its treatment of hot and cold water disaggregation is cursory at best).

Flow rates for existing showerheads (and faucets) are 3.4 gallons per minute, which is approximately the flow rate found by Brown and Caldwell (1984) and Warwick (1993). The EPACT standards reduce flow rates to 2.5 gallons per minute. Shower usage is assumed to be 5 minutes per person per day (2.67 persons per household), which is again based on Brown and Caldwell (1984), and is on the high end of estimates from Rohles et al. (1981) Faucet filling is always assumed to be equal to base case flow for bathrooms, kitchens, and laundry faucets, respectively (filling is not affected by standards).

For homes without dishwashers, we account for the increase in faucet usage associated with handwashing of dishes. We assume that the amount of hot water used for the dishwasher is also used for handwashing, with the added cold water used to bring the temperature of this additional water to 105 degrees F for both flow and filling components of hand dishwashing. This additional water use is split 50:50 between filling and flow for Pre-1994 households. For Post-1993 households, the flow part of the additional use is reduced to reflect the 1994 EPACT flow standards. Table 4 shows the results of the calculations, weighted by the fraction of homes with and without dishwashers.

Table 2: Water temperature assumptions and implied hot/cold water use breakdowns

	Vintage	*Usage temperature degrees F*	*% hot*	*% cold*
Sink filling		105	57%	43%
Faucet flow		80	25%	75%
Bath filling		100	51%	49%
Showers		105	57%	43%
Clotheswasher	Existing	83	29%	71%
	Post-1993 w/standards	78	22%	78%
Dishwasher		139	100%	0%
Toilets		60	0%	100%
Yard watering/other		60	0%	100%
Hot water temperature =			139	degrees F
Cold water temperature =			60	degrees F
Warm water temperature =			99	

(1) New clothes washers assumed to eliminate warm rinse option. Temperature for clothes washers is a weighted average based on P&G data, as cited in DOE 1990 p. 3-11.
(2) Temperature for dishwashers set at highest allowable level.
(3) Faucet flow assumed to be 50% cold and 50% warm (warm = 50% cold, 50% hot).
(4) Hot water temperature is a weighted average from a survey cited in Bancroft et al. (1991).
(5) Cold water temperature represents a rough annual US average adopted from data in Labs (1979).
(6) Warm water temperature assumed to be a simple average of cold and hot water temperatures.
(7) Shower temperature taken from surveys cited in Brown and Caldwell 1984.

Table 3: Usage times and flow rates for showers, baths, sinks, and faucets.

		Flow uses						Baths/sink filling		
		Usage/person min/day	*Usage/HH min/day*	*Flow rate GPM*	***Total flow gals/day***	*Hot flow gals/day*	*Cold flow gals/day*	***Total gals/day***	*Hot filling gals/day*	*Cold filling gals/day*
Showers/baths	Pre-1994	5	13	3.4	**45**	26	19	**19**	9.5	9.2
	Post-1993	5	13	2.5	**33**	19	14	**19**	9.5	9.2
Bathroom faucets	Pre-1994		1.2	3.4	**4.1**	1.0	3.1	**4.1**	2.3	1.7
	Post-1993		1.2	2.5	**3.0**	0.8	2.3	**4.1**	2.3	1.7
Kitchen faucets w/DW	Pre-1994		1.5	3.4	**5.1**	1.3	3.8	**5.1**	2.9	2.2
	Post-1993		1.5	2.5	**3.8**	0.9	2.8	**5.1**	2.9	2.2
Laundry faucets	Pre-1994		0.3	3.4	**1.0**	0.3	0.8	**1.0**	0.6	0.4
	Post-1993		0.3	2.5	**0.8**	0.2	0.6	**1.0**	0.6	0.4
All Faucets w/DW	Pre-1994		3.0	3.4	**10.2**	2.6	7.7	**10.2**	5.8	4.4
	Post-1993		3.0	2.5	**7.5**	1.9	5.6	**10.2**	5.8	4.4
Kitchen faucets w/o DW	Pre-1994		3.4	3.4	**11.6**	5.0	6.6	**11.6**	6.6	5.0
	Post-1993		3.4	2.5	**8.5**	3.7	4.9	**11.6**	6.6	5.0
All Faucets w/o DW	Pre-1994		4.9	3.4	**17**	6.3	10.4	**17**	9.6	7.2
	Post-1993		4.9	2.5	**12.3**	4.6	7.7	**17**	9.6	7.2

(1) All hot and cold water breakdowns taken from Table 2.
(2) Base shower flow rates (3.4 gpm) from Brown and Caldwell 1984. EPACT standard mandates flow rates of 2.5 gpm starting 1 January 1994.
Shower usage of 5 minutes/capita/day adapted from Brown and Caldwell 1984 (1990 US average is 2.67 persons/household).
(3) Total water use for baths using assumptions for per capita use (0.14 baths per capita per day and 50 gals/bath) from Brown and Caldwell 1984, multiplied by 2.67 persons per household.
(4) Base case faucet flow rates assumed to be the same as shower flow rates (3.4 gpm). EPACT standard mandates flow rates of 2.5 gpm starting 1 January 1994.
Faucet flow usage assumed to be 3 minutes per day per household, with 40% going to bathroom faucets, 50% to kitchen, and 10% to laundry.
(4) Faucet filling is always assumed to be equal to base case flow for bathrooms, kitchens, and laundry faucets, respectively. Filling is not affected by standards.
(5) For homes w/o DW in the "Pre-1994" case, additional hot water use for washing dishes is assumed to equal 7.47 gals/day, which is equal to the usage of pre-1994 DWs. The associated cold water usage is calculated assuming a delivered water temperature of 105 deg F for the additional water for hand dishwashing.
Additional water use associated with hand dishwashing is split 50:50 between filling and flow. In the "Post-1993" case, flow is reduced by the ratio 2.5gpm/3.4gpm.

2.4 Toilets

Table 4 also shows usage per household for toilets. This usage is based on an assumption of 4 flushes per person per day (Brown and Caldwell 1984) and 2.67 persons per household. In the base case, toilets use 4.3 gallons per flush. This value represents the weighted average for 1983 from Brown and Caldwell (1984), adjusted assuming that all new toilets installed between 1983 and 1993 use 3.5 gallons per flush. The EPACT standards reduce this for new toilets after January 1, 1994 to 1.6 gallons per flush.

2.5 Dishwashers and clotheswashers

Dishwasher and clothes washer water use per cycle are taken from US DOE (1990). Total cycles are taken from a Proctor and Gamble survey as cited in US DOE (1990). Dishwasher standards save only hot water (because dishwashers only use hot water) while clothes washer standards save both hot and cold water.

Table 4 shows the results of these calculations for pre-and post-1994 standard washers and dishwashers on a saturation-weighted basis (all other end-uses [e.g., toilets] are assumed to have a saturation of 100%). Saturations for dishwashers, clothes washers, and water heaters are taken from the electronic version of US DOE (1992) Weighted average water use per household associated with clothes washers and dishwashers is higher for Post-1993 households than for Pre-1994 homes because of the greater saturations of these appliances in new houses.

2.6 Other uses

To estimate the size of the “Yard/other” water use, we subtracted the water usage per household for pre-1994 households for all identified end-uses in Table 4 from the US Geological Service’s estimate of total residential water use per household (Solley et al. 1993) . This approach assumes that the total water usage per household does not change between 1990 and 1993. We also assume that this residual usage is the same across all house vintages, appliance vintages, and fixture/fitting vintages, and is constant over the forecast period.

3. FORECASTING METHODOLOGY AND RESULTS

We create a simple frozen efficiency forecast for both water use and energy use for water heating. We assume that the saturation and efficiency of equipment existing in the base year remain the same until that equipment is replaced. The saturation and efficiency of new equipment installed throughout the forecast remain at the same level as saturations and efficiencies for new devices in the base year. Equipment retires at an exponential rate equal to the inverse of the equipment lifetime.

3.1 Forecasted number of households

Table 5 shows the forecast of number of households, taken from US DOE (1994). We disaggregated this forecast into 4 different combinations of house vintages, appliance vintages, and fixture/fitting vintages. We use exponential retirement rates from Koomey et al. (1993) as stated in the Table to estimate for any year the remaining stock of houses associated with each combination of equipment vintages.

Table 4: Saturation-weighted hot and cold water usage per household by end use, house vintage, and appliance vintage

	Home vintage	*Appliance vintage*	*Fixtures and fittings vintage*	*Sink filling gals/day*	*Faucet flow gals/day*	*Bath filling gals/day*	*Showers gals/day*	*Clotheswasher gals/day*	*Dishwasher gals/day*	*Toilets gals/day*	*Yard/other gals/day*	*Total gals/day*
Baseline												
Hot water	Pre-1994	All	All	7.9	4.6	9.5	26.0	8.2	3.4	0.0	0.0	59.5
	Post-1993	All	All	6.7	3.4	9.5	26.0	9.8	5.8	0.0	0.0	61.1
Cold water	Pre-1994	All	All	5.9	9.2	9.2	19.4	20.3	0.0	59.3	86.4	209.7
	Post-1993	All	All	5.0	8.3	9.2	19.4	24.2	0.0	59.3	86.4	211.8
Standards case												
Hot water	Pre-1994	Post-1993	Post-1993	7.9	3.4	9.5	19.1	5.6	2.7	0.0	0.0	48.1
	Pre-1994	Post-1993	Pre-1994	7.9	4.6	9.5	26.0	5.6	2.7	0.0	0.0	56.2
	Pre-1994	Pre-1994	Pre-1994	7.9	4.6	9.5	26.0	8.2	3.4	0.0	0.0	59.5
	Post-1993	Post-1993	Post-1993	6.7	2.5	9.5	19.1	6.6	4.6	0.0	0.0	49.0
Cold water	Pre-1994	Post-1993	Post-1993	5.9	6.7	9.2	14.3	19.4	0.0	29.9	86.4	171.9
	Pre-1994	Post-1993	Pre-1994	5.9	9.2	9.2	19.4	19.4	0.0	59.3	86.4	208.8
	Pre-1994	Pre-1994	Pre-1994	5.9	9.2	9.2	19.4	20.3	0.0	59.3	86.4	209.7
	Post-1993	Post-1993	Post-1993	5.0	6.1	9.2	14.3	23.2	0.0	29.9	86.4	174.1

(1) Saturation of CW is 76% and 91% for Pre-1994 and Post-1993 homes, respectively. Saturation of DW is 45% and 77% for Pre-1994 and Post-1993 homes, respectively. Source: RECS 1990; Post-1993 saturations derived by calculating saturations for homes built 1985-90 (US DOE 1992).
All dishwasher owners are assumed to own clotheswashers. Existing homes without DW or CW do not acquire them during the analysis period.
Appliance saturations for Post-1993 homes also remain constant over the analysis period. Saturations of sink filling, faucets, showers, baths, toilets, and other is 100%.
(2) Reference case is frozen efficiency: existing equipment remains at 1990 average efficiency until replaced by new devices. New devices always have same efficiency as new devices in 1990.
(3) Faucet and shower usage from Table 3.
(4) Hot water use per appliance for pre-1994 CW is 10.72 gals/day; for post-1993 CW is 7.29 gals/day. Hot water use per appliance for pre-1994 DW is 7.47 gals/day; for post-1993 DW is 5.96 gals/day. Source: US DOE (1990). Usage estimates (CW cycles per year = 380. DW cycles per year = 229) taken from a Proctor and Gamble survey cited in US DOE (1990).
(5) Toilets flushed 4 times per person per day (2.67 persons/household) from Brown and Caldwell 1984. Capacity of average existing toilet is 4.3 gals/flush, while new toilets meeting EPACT standards use 1.6 gals/flush. Toilet water use includes leakage (20% of the toilets leak 24 gals/capita per day; taken from Brown and Caldwell 1984).
(6) Water use for yard and other uses (e.g. car washing, window washing) is calculated as the difference between total US domestic water use per household (from Solley et al 1993) and the sum of water use per household for kitchens, bathrooms, dishwashers, and clotheswashers from our bottom-up calculations. We assume in this calculation that overall water use per household does not change between 1990 and 1993.

Table 5: Number of US households by home vintage, appliance vintage, and fixtures/fittings vintage

	Home vintage	*Appliance vintage*	*Fixtures and fittings vintage*	*Millions of households* 1993	2000	2005	2010
Number of households	Pre-1994	Post-1993	Post-1993	0.0	23.9	35.5	43.9
	Pre-1994	Post-1993	Pre-1994	0.0	12.2	15.1	15.5
	Pre-1994	Pre-1994	Pre-1994	95.9	54.8	36.7	24.6
	Post-1993	Post-1993	Post-1993	0.0	10.9	18.5	26.4
	All	All	All	95.9	101.7	105.9	110.5
% of households	Pre-1994	Post-1993	Post-1993	0%	23%	34%	40%
	Pre-1994	Post-1993	Pre-1994	0%	12%	14%	14%
	Pre-1994	Pre-1994	Pre-1994	100%	54%	35%	22%
	Post-1993	Post-1993	Post-1993	0%	11%	18%	24%
	All	All	All	100%	100%	100%	100%

(1) Baseline household forecast from US DOE (1994).
(2) 1993 households derived assuming a linear absolute annual increase in households between 1992 and 2000.
(3) Lifetimes for clothes washers, dishwashers, and water heaters assumed to be 13 years, based on Hanford et al. (1994).
(WH and DW life = 13 years, CW life = 14 years. We assume 13 years for all to reduce complexity).
Lifetimes for fittings and fixtures assumed to be 20 years.
(4) Appliances retire faster than fittings and fixtures, so we assume for simplicity that there are no homes with new faucets/SHs and old appliances.
(5) Home retirement rates taken from Koomey et al. (1993) are 0.77%, averaged over all house types.

3.2 Baseline and standards case forecasts: water use

To calculate total water use, we multiply the water usage per household in each vintage bin in a given year by the number of households in each bin. Table 6 shows the resulting hot and cold water usage by end-use for the US as a whole for 1993 and 2010. The largest end-use by far is "Yard/other" which represents about one-third of total water use in the base case. Next is toilets, followed by showers and clothes washers. Showers, bath filling, and clothes washers are the largest *hot water* end-uses. Total water savings is largest for toilets, followed by showers and clothes washers.

3.3 Baseline and standards case forecasts: energy use

We use the saturations of different water heater fuel types (new and existing), the hot water usage in Table 6, the standby losses and recovery efficiencies from Table 1, and the equations above to calculate total energy use in the baseline and standards cases. Saturations for water heaters are taken from the electronic version of US DOE (1992) (saturations for new equipment are derived using the saturation of water heaters for homes built 1985-1990). Table 7 shows the results of these calculations. For electric water heating, showers are the largest end-use, followed by standby losses, bath filling, and clothes washers. For gas and oil water heating, standby losses are the largest end-use followed by showers, bath filling, and clothes washers.

3.4 Energy savings

Table 8 shows the savings from the standards by end-use. The 1990 water heater standards only affect standby losses, while the 1994 fixture/fitting, clothes washer, and dishwasher standards affect only flow rates for these end-uses.

For electric water heaters, the flow-related standards save more than twice as much electricity as the 1990 water heater standards. For gas and oil-fired water heaters, the 1990 water heater standards save about 60% more energy than the flow related standards. Of the flow related standards, showerhead standards save the most, followed by clothes washers and dishwashers. Total savings in site energy terms are about 0.5 quads per year in 2010, while savings in primary energy terms would be about 0.8 quads per year in 2010 (assuming electricity is valued at 11,157 Btus/kWh).

4. FUTURE WORK

4.1 Sensitivity analysis/further disaggregation

This framework would easily allow testing of the sensitivity of the forecast results to changes in different parameters. Water usage varies by house type, number of persons per household, age of occupants, water prices, water rate structures, source of water (public systems or wells), geography, and income levels. In particular, the effect of standards on households with different appliance ownership and water usage patterns could easily be tested within this framework. An examination of extreme cases (exceptionally low or high water use) would also be illuminating. We believe that creating such a sensitivity analysis should await the arrival of more accurate data on water usage patterns and how these patterns vary across the country.

Table 6: U.S. hot and cold water usage and savings by end use

	Year	*Sink filling*	*Faucet flow*	*Bath filling*	*Showers*	*Clotheswasher*	*Dishwasher*	*Toilets*	*Yard/other*	*Total*
		Billion gallons per day								
Baseline										
Hot water	1993	0.75	0.44	0.91	2.49	0.78	0.33	0.00	0.00	5.7
	2010	0.84	0.48	1.05	2.87	0.95	0.44	0.00	0.00	6.6
Cold water	1993	0.57	0.88	0.88	1.86	1.94	0.00	5.68	8.29	20.1
	2010	0.63	0.99	1.02	2.15	2.34	0.00	6.55	9.55	23.2
Total water	1993	1.32	1.32	1.79	4.35	2.73	0.33	5.68	8.29	25.8
	2010	1.47	1.47	2.06	5.01	3.29	0.44	6.55	9.55	29.8
Standards										
Hot water	1993	0.75	0.44	0.91	2.49	0.78	0.33	0.00	0.00	5.7
	2010	0.84	0.40	1.05	2.38	0.71	0.37	0.00	0.00	5.7
Cold water	1993	0.57	0.88	0.88	1.86	1.94	0.00	5.68	8.29	20.1
	2010	0.63	0.83	1.02	1.78	2.27	0.00	4.48	9.55	20.5
Total water	1993	1.32	1.32	1.79	4.35	2.73	0.33	5.68	8.29	25.8
	2010	1.47	1.22	2.06	4.17	2.97	0.37	4.48	9.55	26.3
Savings										
Hot water	1993	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
	2010	0.00	0.08	0.00	0.48	0.24	0.07	0.00	0.00	0.9
Cold water	1993	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
	2010	0.00	0.16	0.00	0.36	0.08	0.00	2.07	0.00	2.7
Total water	1993	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
	2010	0.00	0.24	0.00	0.85	0.32	0.07	2.07	0.00	3.5

(1) Total usage calculated using weighted average daily per household usage from Table 4 and housing populations from Table 5.
(2) Increase in cold water usage for clotheswasher in standards case caused by elimination of warm rinse cycles and increasing saturation of clotheswashers in new buildings.
(3) Toilet water use includes leakage.

Table 7: Forecasted US energy use for water heaters by end-use in the baseline and standards cases

	Year	*Fuel type*	*Use-related water heating energy consumption* *Sink filling TBtu/yr*	*Faucet flow TBtu/yr*	*Bath filling TBtu/yr*	*Showers TBtu/yr*	*Clotheswasher TBtu/yr*	*Dishwasher TBtu/yr*	*Standby losses TBtu/yr*	*Total TBtu/yr*
Frozen efficiency baseline	1993	Electric resistance	69	40	83	227	72	30	107	628
		Natural gas	135	79	163	445	140	58	993	2012
		Oil	13	7	16	42	13	6	95	192
	2010	Electric resistance	87	49	110	301	101	49	129	825
		Natural gas	139	79	172	470	153	69	1015	2096
		Oil	12	7	15	40	13	6	87	179
Baseline + 1990 WH stds	1993	Electric resistance	69	40	83	227	72	30	98	618
		Natural gas	135	79	163	445	140	58	916	1935
		Oil	13	7	16	42	13	6	87	185
	2010	Electric resistance	87	49	110	301	101	49	92	788
		Natural gas	139	79	172	470	153	69	802	1883
		Oil	12	7	15	40	13	6	69	161
Baseline + 1990 WH stds + 1994 fixture/fitting/CW/DW standards	1993	Electric resistance	69	40	83	227	72	30	98	618
		Natural gas	135	79	163	445	140	58	916	1935
		Oil	13	7	16	42	13	6	87	185
	2010	Electric resistance	87	40	110	246	75	40	92	690
		Natural gas	139	67	172	395	115	58	802	1747
		Oil	12	6	15	34	10	5	69	151

(1) Energy use for clotheswashers and dishwashers does not include motor energy, only the energy needed to heat water.
(2) Electricity measured in site energy at 3412 Btu/kWh.
(3) Saturations of water heating fuel assumed to remain constant throughout the analysis period for existing homes (no conversions).
New homes throughout the analysis period are assumed to have the same saturation as new homes in 1990.
(4) WH = water heating; CW = clothes washer; DW = dishwasher.
(5) Saturations of electric water heaters: Pre 1994=38%, Post 1993=61%; Gas WHs: Pre 1994=57%, Post 1993=37%; Oil WHs: Pre 1994=5%, Post 1993=1%.
Source of saturations: RECS 1990; Post-1993 saturations derived by calculating saturations for homes built 1985-90 (US DOE 1992).

Table 8: Forecasted US energy savings by end-use for water heaters in the standards cases in 2010

	Units	*Fuel type*	*Use-related water heating energy use* *Sink filling TBtu/yr*	*Faucet flow TBtu/yr*	*Bath filling TBtu/yr*	*Showers TBtu/yr*	*Clotheswasher TBtu/yr*	*Dishwasher TBtu/yr*	*Standby losses TBtu/yr*	*Total TBtu/yr*
1990 WH stds	*TBtu/yr*	Electric resistance	0	0	0	0	0	0	37	37
		Natural gas	0	0	0	0	0	0	214	214
		Oil	0	0	0	0	0	0	18	18
	% of total	Electric resistance	0%	0%	0%	0%	0%	0%	100%	100%
		Natural gas	0%	0%	0%	0%	0%	0%	100%	100%
		Oil	0%	0%	0%	0%	0%	0%	100%	100%
1994 fixture/fitting/CW/DW standards	*TBtu/yr*	Electric resistance	0	8	0	55	27	8	0	98
		Natural gas	0	12	0	75	37	11	0	136
		Oil	0	1	0	6	3	1	0	11
	% of total	Electric resistance	0%	9%	0%	56%	27%	8%	0%	100%
		Natural gas	0%	9%	0%	55%	28%	8%	0%	100%
		Oil	0%	9%	0%	55%	28%	8%	0%	100%
1990 WH stds + 1994 fixture/ fitting/CW/DW standards	*TBtu/yr*	Electric resistance	0	8	0	55	27	8	37	135
		Natural gas	0	12	0	75	37	11	214	349
		Oil	0	1	0	6	3	1	18	29
	% of total	Electric resistance	0%	6%	0%	41%	20%	6%	27%	100%
		Natural gas	0%	4%	0%	21%	11%	3%	61%	100%
		Oil	0%	4%	0%	21%	11%	3%	62%	100%

(1) Energy use for clotheswashers and dishwashers does not include motor energy, only the energy needed to heat water.
(2) Electricity measured in site energy at 3412 Btu/kWh.
(3) Saturations of water heating fuel assumed to remain constant throughout the analysis period for existing homes (no conversions).
New homes throughout the analysis period are assumed to have the same saturations as new homes in 1993.
(4) WH = water heating; CW = clothes washer; DW = dishwasher.

4.2 Energy losses in delivering water to the tap

We have not accounted for energy losses associated with transporting hot water from the water heater to the tap. It is not certain how large these losses are, but they may be significant. Multi-family buildings with recirculating water systems are totally different than single family dwellings in this regard, and probably should be analyzed separately in the future. More measurements of such effects are needed.

4.3 Measurement of water use

It is crucially important that future programs to measure water use take a comprehensive bottom-up perspective like the one in this paper. Measurements of hot water consumption alone are not sufficient. Cold water use, water heater set point, cold water inlet temperature, and usage temperature must also be measured. In addition, the results must be correlated with detailed information on the characteristics of each household (including saturations and efficiencies of water-using devices) because estimates of water use in the aggregate have little meaning. Finally, accurate measurements of actual usage behavior (i.e., number of flushes per day, minutes of faucet on-time) are also crucial to estimating total water use and the potential for water savings.

4.4 Comparison to other forecasts

There are several other widely used forecasts of water heater energy use to which the estimates developed here could be compared (Geller and Nadel 1992, Koomey et al. 1993, US DOE 1994). We have not undertaken this comparison for the sake of brevity, but any further work using this framework should do so. The documentation for these forecasts typically does not include the detailed information needed to make such a comparison, but this information can often be inferred from conversations with the modelers.

4.5 "Upstream" and "Downstream" issues

We have ignored energy, economic, and technological issues related to pumping and treatment of water. These issues are complex and have not typically been included in policy studies that focus on direct energy savings from more efficient end-using equipment. They may in some cases be important, especially when conducting cost-benefit analyses in regions where the choice for the local water district may be efficiency policies or adding peak capacity to its water treatment facilities. These issues can also be important for those users not connected to the public water system, because well pumping and septic tanks are substantially affected by changes in total water usage.

4.6 Enforcement of standards

If low-flow devices do not deliver equivalent service, then customer satisfaction may lead to circumvention of regulations or changes in usage patterns (i.e., longer showers). We have assumed in this analysis that the low flow devices work exactly as advertised 100% of the time, and that they do not affect usage behavior. To improve the accuracy of the forecasts, we need data on whether this assumption is even roughly correct.

5. CONCLUSIONS

This paper describes a detailed end-use breakdown of hot and cold water use, and uses this breakdown to estimate the effects of recent appliance and fixture/fitting standards on water use and energy use. Such a detailed and comprehensive breakdown is essential for truly understanding the water heating end-use. Previous efforts at measurement have generally been inadequate or incomplete, and we hope that this attempt to systematize the various data will serve as a model for future measurements and analysis.

Forecasted water savings from the EPACT standards are largest for toilets, followed by showers, clothes washers, and dishwashers. Hot water savings are greatest for showers and clothes washers, followed by faucets and dishwashers. Forecasted standby loss energy savings from the 1990 electric water heater standards are only about one third as large as electricity savings associated with the EPACT 1994 flow standards. For natural gas water heaters the situation is reversed, with standby loss energy savings from the 1990 gas water heater standards being about 60% larger in magnitude than gas savings associated with the EPACT 1994 flow standards. Overall primary energy savings associated with current standards affecting water heaters and hot water use are projected to be about 0.8 quadrillion Btus/year by 2010.

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