CALCULATING AVERAGE HOT WATER MIXES OF RESIDENTIAL PLUMBING FITTINGS

Using the ANSI 301-2019 Hot Water Draw Model and National Residential Data to Estimate Hot Water Use in Showerheads and Lavatory Faucets

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DISCLAIMER

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ABSTRACT

Available studies of hot water use percentages may not necessarily be generalized to a national level given regional differences, varying methodological approaches, and limited sample sizes. While some publicly available usage data, reports, and surveys estimate actual household usage, a lack of water use data specific to end uses make more precise savings calculations difficult. Additionally, most hot water draw models tend to focus on overall household use and may not readily estimate lavatory fixture use. However, reviewing more recent studies and standards enables the U.S. Environmental Protection Agency's WaterSense program to update its estimates for hot water use and consumers' corresponding energy and monetary savings to better reflect real-world conditions. This report specifically focuses on improving hot water use and savings estimates of lavatory faucets and showerheads. To estimate the hot water use of lavatory faucets and showerheads, we employed the 2015 Residential Energy Consumption Surveys (RECS) microdata alongside the ANSI 301-2019 Hot Water Draw Model. These estimates account for regional differences in hot water use, including regional cold water inlet temperatures. As a result, the refinements presented in this report are more robust, more recent, and better describe the geographic variation than previous inputs used by the WaterSense program. In addition, the approach described in this paper can be updated over time or tailored to regionally specific needs given available inputs. We conclude that hot water percentages for showers and faucets calculated using publicly available national data are close to the percentages found by regional studies and are consistent with household-level models of water use.

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1 INTRODUCTION

All water contains a specific energy signature due to the energy needed to extract, transport, treat, and deliver water and wastewater. Hot water-using fittings and appliances have an additional and substantial impact at the point of use in the form of hot water, with U.S. households spending an average of $300 annually on energy to heat water alone (U.S. EIA 2015a). Consumers typically use hot water from a range of water-using appliances and fittings, including those found in the kitchen, lavatory, and laundry room. Reductions in the amount of hot water used by water-using fittings and appliances can be expressed as energy (kWh or therms), as financial impacts quantified from consumer water and electric bills, and as greenhouse gas emission impacts quantified from U.S. Environmental Protection Agency (EPA) carbon dioxide multipliers. EPA's voluntary WaterSense program estimates savings associated with labeled water-efficient fittings, products that have been third-party certified to meet both the efficiency and performance requirements of the WaterSense specifications. A full and accurate accounting of the program's impact on water and energy use, and associated cost and carbon savings, requires:

- accurate measure of water use impact influenced by
  - installed products/appliance,
  - hot water piping configurations,
  - household occupancy,
  - occupant behavior, and
  - occupant age,
- water heater energy use influenced by
  - fuel source,
  - inlet water temperature,
  - efficiency of the water heater/hot water system, and
  - water heater set point,
- cost of energy,
- carbon impact of energy generation/usage, and
- mix of hot and cold water influenced by
  - water heater set point,
  - inlet water temperature, and
  - desired warm water output temperature.

The WaterSense program employs several analytical models to estimate the change in water use attributable to these products (Schein *et al.* 2019). Other publicly available datasets also address other factors listed above. This paper focuses on creating a nationally representative picture of the likely mix of hot and cold water in residential plumbing fittings at the point of use.

Capturing hot water savings more accurately would better characterize the benefits (1) from using water-saving fittings and appliances generally and (2) from using WaterSense-labeled products specifically. Current residential WaterSense-labeled product categories that use hot water are showerheads and lavatory faucets, which are thus the focus of this report. Energy savings increase as hot water use is reduced. Hot water use in residential buildings varies according to a number of factors: regional climate (which impacts inlet water temperature), water heater set point temperature, hot water flow piping configurations from the water heater equipment, installed fittings and appliances, household occupancy numbers, occupant behavior, and household occupant ages (Evarts and Swan 2013). Additionally, building codes and industry standards use certain values to specify sizing and piping configurations for hot water end uses to meet the needs of different building types and project demand (ASPE 2015). However, three variables have significant impact on hot water use: cold water inlet temperatures, household size, and percentage of household occupants between 13 and 23 years of age (Evarts and Swan 2013; Parker *et al.* 2015).

While some publicly available usage data, reports, and surveys estimate actual household usage,[1,2] a lack of water use data specific to end uses, especially those that consistently track water usage across years with a national representative sample, make more precise savings calculations difficult. Currently, to track its savings impact, EPA's WaterSense program employs end-use data from a study of limited geographic scope and sample size (DeOreo and Mayer 2000) and applies the average percentage of hot water use by showerheads and faucets to its overall water savings estimates from these products (Schein *et al.* 2019). This end-use data along with data inputs from the American Housing Survey (AHS) and estimates regarding water heater efficiency and temperature rise also contribute to WaterSense final estimates for energy savings. More recent studies share similarly limited geographic study areas and sample sizes. Outlining a method that uses consistent and reliable data source inputs and readily available data from the Residential Energy Consumption Survey (RECS) microdata allows for an approach that is more representative of the true national impact of saving energy by reducing showerhead and faucet flowrates. Additionally, such an approach will allow estimates to remain current as both water use trends and the make up of the housing stock continue to change over time. This report presents the underlying methodology and estimates average national hot water use percentages of lavatory faucets and showerheads.

Before describing the refinement of hot water use estimates for lavatory faucets and showerheads, this report presents a review of recent literature on residential indoor hot water use, including studies that disaggregated hot water use into individual indoor end uses. This report also compares values in existing studies with the showerhead and faucet hot water usage calculated using the authors' approach. The RECS 2015 microdata, which comprise a sample of 5,686 households with associated sample weights and household characteristics to make the analyses nationally representative, was used in conjunction with the ANSI 301-2019 Hot Water Draw Model to estimate hot water use of lavatory faucets and showerheads. The refinements presented in this report improve the previous inputs used by EPA's WaterSense program. These modifications do not impact the overall water savings attributed to the program, but do improve estimates for cost, energy, and carbon savings.

[1] For example, DeOreo and Mayer (2000) estimated the hot water portion of the warm mix of faucet use for 10 studied homes in Seattle at 72.7 percent hot water for faucet use, 73.1 percent for shower use, and an overall hot water usage of 39.6 percent of total indoor water use. Last accessed April 30, 2020.

[2] More recent studies in wider geographical areas show similar hot water percentages of total indoor hot water use but do not separate out the products covered by the WaterSense label, making it difficult to attribute carbon savings to reduced faucet and showerhead usage volumes (Escriva-Bou *et al*. 2015; Evarts and Swan 2013). Last accessed April 30, 2020.

2 SUMMARY OF EXISTING STUDIES

All publicly available hot water usage data are useful; however, consideration needs to be taken when comparing study results since there may be fundamental differences between study approaches and execution. For example, the studies cited in this section have differences including: sample size, geographic location, end uses included, water heater types and fuels, and data acquisition methodologies used to determine hot water percentages of a given appliance or fixture. Where possible, we have noted these variations, but without source data or more detailed study descriptions we are unable to account for all study differences. We include the studies for the purpose of broad comparison and do not suggest that detailed comparisons are appropriate.

Until the late 1990s, studies of North American residential indoor hot water use presented volumetric figures only at the household level instead of being disaggregated into indoor end uses. In addition, these field measurement studies have generally been centered on one geographic location with small to medium sample sizes. Taken together, Perlman and Mills (1985), Gilbert Associates Inc. (1985), and Merrigan (1988) reported average household hot water use to range between 56.9 and 66.2 gallons per day based on measured use occurring over at least one year in anywhere from 24 to 110 single-family residences. Perlman and Mills (1985) and Merrigan (1988) showed seasonal patterns in which hot water use is highest in winter months. Becker and Stogsdill (1990), in analyzing data from the aforementioned as well as six additional studies, reported a daily average use of 62.4 gallons of hot water per household. Also within the same range is the average use of 62.1 gallons of hot water per day from Abrams and Shedd (1996), who also found strong seasonal variations from their study of 13 single-family homes in Georgia.

Residential indoor hot water use began to be disaggregated into end uses in the late 1990s via different methodologies: using thermocouples on hot water lines and performing flow-trace analysis based on assumptions for "flow signatures". Lowenstein and Hiller (1998) placed data loggers on four hot water lines at each of 14 test homes and found average daily hot water use of 57.3 gallons, categorizing hot water volumes for dishwashers, showers, clothes washers, baths, and "other" end uses. Next, DeOreo and Mayer (2000) employed simultaneous flow traces from hot and cold water lines for 10 homes in Seattle to establish average hot water use of 65.3 gal/day, with the same end uses as monitored by Lowenstein and Hiller (1998) in addition to also disaggregating hot water use from faucets and leaks. Henze *et al.* (2002) compared a flow trace signature analysis technique to a temperature-based event inference method for one single-family residence in Nebraska, evaluating disadvantages and advantages of each and yielding average hot water use for each relevant fixture and appliance in the home.

More recent figures on household-level hot water use—from both field measurement and modeling—may indicate the effects of slightly smaller household sizes and water-efficient fittings installed over time. Lutz (2005) used a residential appliance saturation survey that provided figures on total gas use by water heaters in California to arrive at total household hot water use of 52.6 gallons per day (gal/d). U.S. Department of Energy (DOE) (2010) determined a national average of 49.3 gal/d by running the Water Heater Analysis Model from Lutz *et al.* (1996) with a simulation of 10,000 Monte Carlo samples based on RECS 2005 housing characteristics of 4,381 sample housing units. To project post-2015 usage, DOE took into account federal energy conservation standards for clothes washers that became effective in 2007 and for dishwashers that became effective in 2010 (the Code of Federal Regulations at 10 CFR 430.32(g)[3]), which reduced the national average to 43.0 gal/d. Hendron *et al.* (2010) developed a spreadsheet tool that generates random event profiles based upon reasonable probability distributions for hot water event parameters, with input assumptions drawn primarily from two Aquacraft residential use studies (EBMUD & Seattle 2008 and REUWS 1999); their estimate of 60.0 gal/d assumes a typical house with four sinks, two showers, two bathtubs, one clothes washer and one dishwasher. They acknowledge this estimate depends upon geographic location and number of household occupants. Indeed, Evarts and Swan (2013) found via an annual-total water and energy-use billing data survey of 1,019 Nova Scotia households that a weighted mean of 55.2 gal/d sits in the middle of the range from 36.7 gal/d for a one-person household and 92.7 gal/d for a household with six occupants—and that hot water use does not scale linearly with the number of occupants. Events that use hot water but are shared among all household members, such as cleaning dishes and washing clothes, contribute to the non-linear volumes of hot water use by number of household occupants. Additionally, water use by age groups vary significantly by types of use and volumes.

Within the last five years, Parker *et al.* (2015) used measured hot water use in 69 households in California, Florida, Minnesota, and New York to determine an average of 51.1 gal/d per household with a mean of 3.02 occupants. Escriva-Bou *et al.* (2015) arrived at nearly the same figure (51.0 gal/d) via a Monte Carlo model using a sample pool of more than 700 single-family homes from 10 utilities across California drawn from DeOreo *et al.* (2011) and a probability distribution of hot water draws from Mayer *et al.* (2003). Finally, in the REUWS 2 study, DeOreo *et al.* (2016) employed flow-trace analysis in 94 homes in nine different sites in Arizona, Colorado, Florida, Georgia, Ontario, Texas, and Washington state to reveal average hot water household use to be 45.5 gal/d, with per capita use of 20.9 gal/d. They also observed regional patterns in line with climatic variations, ranging from an average of 35.9 gal/d in Scottsdale, AZ and San Antonio, TX households to 54.2 gal/d in Kitchener, Ontario.

Figure 1 presents average household hot water use by year of publication for the aforementioned sources; we exclude any reviewed studies with a sample size fewer than 10 (Henze *et al.* 2002). As previously discussed, it should be noted that these studies employed different methods and were conducted in different geographical locations under various conditions. For example, most studies have a limited sample size in a particular geographical location, and the scope of the studies varied in terms of household size and type of homes. Also, the studies employed different techniques for quantifying hot water use including direct field measurements, derived hot water use based on billing data, and derived hot water use based on household characteristics. Even field metering studies could be significantly different due to uncertainties associated with using different measurement techniques, definitions of hot water, time periods in which measurements were conducted, and end uses considered. Despite limited ability to compare these studies, the overall trend of average household hot water usage appears to be clearly decreasing, implying that in general hot water usage has declined over time. Multiple factors can help explain this potential hot water use reduction within these years, such as increased efficiency standards for dishwashers and clothes washers leading to significantly decreased hot water use for these appliances, increased use of high-efficiency showerheads and faucets/aerators (such as those labeled by the WaterSense

[3] https://www.ecfr.gov/cgi-bin/text-idx?SID=86e70cbc87e5af18caca2e5c205bd107&mc=true&node=se10.3.430_132&rgn=div8. Last accessed May 7, 2020.

program), demographic shifts (such as decreasing number of occupants per household or increasing fraction of households in warmer climates), behavior changes (such as taking shorter showers, decreasing the temperature for clothes washing, or decreasing hot water waste), and decrease in leaks or drips (because of better plumbing installation practices and/or increased conservation awareness).

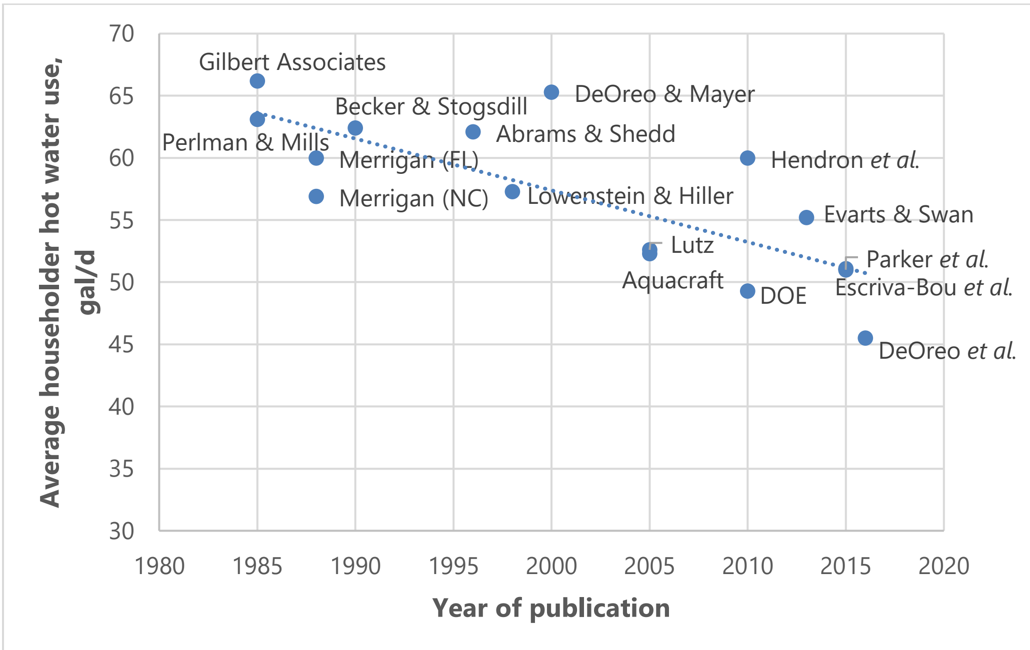

Figure 1 Average Household Hot Water Use vs. Publication Year for 15 North American Studies

Next, using various technologies to collect data at high time resolution, several reports present the share of total residential hot water use by end use as seen in Table 1.

Table 1: Share of Total Residential Hot Water Use by End Use

	Lowenstein & Hiller (1998)	**DeOreo & Mayer (2000)**	**Henze *et al.* (2002)**	**Escriva-Bou *et al.* (2015)***	**DeOreo *et al.* (2016)**
Location	Not specified	WA	NE	CA	AZ, CO, FL GA, ON, TX, WA
Sample size	14	10	1	>700	94
	Percent of total residential hot water use, by end use (%)				
Clothes washers	12.6	15.5	26.4	8.2	9.7
Dishwashers	10.8	3.6	1.4	2.2	4.8
Showers	41.6	25.1	30.9	41.0	39.1
Baths	8.0	16.7	0.5	5.9	5.7
Faucets	-	34.3	37.8	39.0	33.8
Leaks	-	4.8	-	3.5	4.6
Other	27.0	0	3.1		2.0

*Modeled, not measured; used sample of more than 700 single-family homes at 10 utilities across California from DeOreo *et al.* (2011) and a probability distribution of hot water draws from Mayer *et al.* (2003).

Other studies have determined the percent of overall water use that is hot water at each fixture. Flow-trace analysis was employed in 10 single-family homes in Seattle (DeOreo and Mayer 2000); in 20 typical single-family homes in the San Francisco Bay Area and Seattle before and after being retrofitted with high-efficiency toilets, clothes washers, showerheads, and faucets (Aquacraft 2005); and in 94 homes across nine locations in North America (DeOreo *et al.* 2016). Table 2 presents these values.

Table 2: Share of Overall Water Use That Is Hot Water at Each Fixture

	DeOreo & Mayer (2000)	**Aquacraft (2005)**		**DeOreo *et al.* (2016)**
Location	WA	CA, WA		AZ, CO, FL, GA, ON, TX, WA
Sample size	10	20		94
	Percent of overall water use that is hot water at each fixture (%)			
		Pre-retrofit	*Post-retrofit*	
Showers	73.1	64	72	66.2
Baths	78.2	-	-	59.1
Faucets	72.7	83	72	57.0
Clothes washers	27.8	20	14	20.0
Dishwashers	100	86	88	100
Leaks	26.8	8	13	11.8
Other	35.1	-	-	22.5

3 ANSI 301-2019 HOT WATER DRAW MODEL

EPA reports the impacts of its WaterSense program on an annual basis. The models that estimate the program's impacts need to use readily available and nationally representative data. However, field metered data tend to be collected via regionally applicable, one-time efforts, while national data sets can omit critical model inputs such as occupant age differentiation. The American National Standards Institute (ANSI) 301 standard (ANSI 301-2019) hot water draw model permits comparable hot water use estimates for the end uses of interest: lavatory faucets and showerheads, while including related hot water waste. The ANSI 301-2019 model relies on number of bedroom counts and does not depend on the reporting of household age groups or number of occupants. This allows for estimates of hot water use at the population scale without detailed demographic data such as household age groups and number of occupants for each household, and accounts for the fact that these demographic data are not fixed over time. The appropriateness of using the number of bedrooms to approximate the household age groups and size is evaluated in Section 5.2. This approach of using readily available national representative data will allow the EPA WaterSense program estimates to remain current as both water use trends and the make up of the housing stock continue to change over time.

ANSI 301-2019 is a voluntary consensus standard developed under the Residential Energy Services Network (RESNET). The ANSI 301 standard was established with the goal of providing a "consistent, uniform methodology for evaluating and labeling the energy performance of residences." Standards are established through participation of its national members, associated societies, and public review. While the standards are continuously open for revisions, the standards development committee is required to issue an update at least every five years.

The first 301 standard, *ANSI/RESNET/ICC 301-2014, Standard for the Calculation and Labeling of the Energy Performance of Low-rise Residential Buildings using an Energy Rating Index*, was published in 2014. With subsequent addenda, the equation established a method to assess daily hot water gallon use through dishwasher and clothes washer use, a number of climatic conditions, and dwelling characteristics thought to have implications on household size, among other factors.[4] The ANSI 301-2019 hot water draw equation as amended is shown below.

$$\boldsymbol{HW_{gpd}} = (\boldsymbol{refDW_{gpd}} + \boldsymbol{refCW_{gpd}} + \boldsymbol{F_{mix}} \times (\boldsymbol{refF_{gpd}} + \boldsymbol{refW_{gpd}})) \qquad \textbf{Equation 3-1}$$

Where:

HW_{gpd} = gallons per day of hot water use,

$refDW_{gpd}$ = reference dishwasher gallons per day,
= $(0.7801 \times Nbr) + 1.976$,

$refCW_{gpd}$ = reference clothes washer gallons per day
= $(0.6762 \times Nbr) + 2.3847$,

F_{mix} = $1 - \frac{(T_{setTemp} - T_{mix})}{(T_{setTemp} - T_{inletTemp})}$; see Section 4 for description of these temperatures,

$refF_{gpd}$ = reference climate-normalized daily fixture water use in Energy Rating Reference Home (in gallons per day)
= $14.6 + 10.0 \times Nbr$,

$refW_{gpd}$ = reference climate-normalized daily hot water waste due to distribution system losses in Energy Rating Reference Home (in gallons per day)
= $9.8 \times Nbr^{0.43}$,

Nbr = number of bedrooms in the rated home, not to be less than 1.

4 ACCOUNTING FOR REGIONAL TEMPERATURE DIFFERENCES USING RESIDENTIAL ENERGY CONSUMPTION SURVEY MICRODATA

Estimating the hot water use in faucets and showerheads requires calculating the percentage of hot water in the warm water mix. This calculation includes three temperatures: the water heater set point temperature, the inlet water temperature, and the temperature mix (or user-desired temperature) for shower and faucet use. See Equation 4.4-1. Previously, the EPA WaterSense program calculated carbon emissions reductions using a temperature delta of 75 ºF between the

[4] Hendron and Engebrecht (2009) were the first to come up with an estimation procedure based on the number of bedrooms. The estimates were based on using 2005 RECS (U.S. EIA 2005) data along with some empirical data sources. Their study methodology accounts for seasonal variation in inlet water temperatures using a sinusoidal estimate of annual inlet water temperature based on empirical data. The ANSI 301-2014 values for $refF_{gpd}$ and $refW_{gpd}$ were derived by Parker *et al.* (2015) using RECS 2009 (U.S. EIA 2009) data and more recent field data. Last accessed April 30, 2020.

cold water inlet and the water heater set point to conclude that 73 percent of all water use for showerheads and lavatory faucets is hot.

4.1 Water Heater Set Point Temperature

The water heater set point temperature ($T_{setTemp}$) also varies by household. No national household datasets reporting set point temperatures exist.[5] For the hot water percentage calculations, we use 125 ºF based on ANSI 301-2019 (ANSI 2019).

4.2 Inlet Water Temperature

Previous studies have shown that inlet water temperature can be effectively estimated from either air or groundwater temperature as a primary input. Water inlet temperature influences the energy impact of hot water-using plumbing fittings both by influencing the required temperature rise to the water heater set point, and by influencing the temperature of cold side premise plumbing. Colder temperature in the cold water lines can result in a higher percent mix to achieve the user-desired warm water temperature. We used the equation in ANSI 301-2019 to calculate cold water inlet temperature.[6] The ANSI 301-2019 equation for cold water inlet temperature can be simplified to calculate the annual average cold water inlet temperature by using the annual average outdoor temperature ($T_{airTemp}$) plus 6 °F offset. This equation takes into account interactions with the house hot water piping in determining cold water inlet temperatures. EIA's RECS 2015 now reports average annual groundwater temperatures (T_{gwt}) in 2015 for each household (U.S. EIA 2015b). Using the relationship between the annual average groundwater temperature and the annual average outdoor air temperature based on Yoshitake *et al*. (2002), the resulting equation is:

$$\boldsymbol{T_{inletTemp} = T_{airTemp} + 6\ °F = \frac{(T_{gwt} - 12.1)}{(0.83)} + 6\ °F} \qquad \textbf{Equation 4.2-1}$$

Groundwater temperatures may vary by geographic region by over 30 °F, as do cold water inlet temperatures (see Table 4). Table 3 shows the proposed temperature delta values to be employed by EPA's WaterSense program.

Table 3: Current Values Used by EPA's WaterSense with Estimates Using RECS 2015 data

	Temperature delta (Water heater – cold water inlet)
	°F
Current value	75.0
Using RECS 2015	125.0 – 60.5* = 64.5

*See section 4.4 for calculation of cold water inlet temperature

4.3 Temperature Mix for Shower and Faucet Use

Warm water temperatures *(T_{mix})* for showers are assumed to be 105 °F based on ANSI 301-2019. The target temperature is considered to be the same for showerheads and for faucets. An

[5] A regional study of 127 homes with electric resistance water heaters in Central Florida (Parker 2002) showed that audited set point temperature averaged 127 °F, and field measurement studies in California by Lutz (2012) showed the average set point temperature to be 123 °F. Last accessed April 30, 2020.
[6] This equation was first referenced by Hendron *et al.* (2004) and is based on the paper from Burch and Christensen (2007). Last accessed April 30, 2020.

adjustment is made for faucet hot water use given that people do not use hot water from showerheads in the same manner as hot water from faucets. For example, many people brush teeth and wash hands use cold water only, while hot water may be mixed into cold water when people shave or face wash. No sources indicating lavatory faucet hot water use could be found. To avoid any potential over-estimate, we took the average ratio of hot water use by faucets and showerheads from field studies[7,8,9] (weighted by number of sample households) to assume that faucet use includes hot water for 89.4 percent of overall use. It should be noted that these studies looked at all indoor faucets including those in lavatories, kitchens, and laundry rooms, and installed elsewhere throughout the home, not just lavatory faucets.

4.4 Hot Water Percentage for Shower and Faucet Use

Fixture hot water percentages are calculated using three temperatures: water heater set point, water inlet, and temperature mix (fixture/user target temperature). This fixture hot water percentage is for general use and assumes no volumetric measurement.[10] See Equation 4.4-1 based on ANSI 301-2019.[11] The temperature for the water heater set point is assumed to be 125 °F, explained in Section 4.1. Adjusted RECS 2015 data are used for cold water inlet temperature, which varies by household. The temperature for showerheads and faucets is represented by T_{mix}, 105 °F.

$$F_{mix} = 1 - \frac{(T_{setTemp} - T_{mix})}{(T_{setTemp} - T_{inletTemp})} \quad \textbf{Equation 4.4-1}$$

Table 4 shows calculated hot water percentages for showerheads and faucets by Census Division, with study values included for comparison. A weighted average calculation for both fixture types and inlet water temperature is also presented.

[7] DeOreo *et al.*, 2000 showed a ratio of 0.995 of faucet to shower hot water use. Last accessed April 30, 2020.
[8] The Aquacraft study of 2005 shows a ratio of 1 of faucet to shower hot water use. Last accessed April 30, 2020.
[9] DeOreo *et al.*, 2016 showed a ratio of 0.861 of faucet to shower hot water use. Last accessed April 30, 2020.
[10] This assumption assumes that hot water may be turned on by the consumer but no hot water may be delivered.
[11] ANSI 301. 2018. ANSI/RESNET/ICC 301-2019 Standard for the Calculation and Labeling of the Energy Performance of Dwelling and Sleeping Units using an Energy Rating Index. http://www.resnet.us/blog/resnet-consensus-standards/ Last accessed April 30, 2020.

Table 4: Distribution of Hot Water Use Percentages by Census Division Calculated from RECS 2015 Data and Study Comparisons *(proposed values bolded)*

Census Division	Population	Groundwater temperature from RECS 2015 (°F)	Inlet water temperature (°F)	Hot water percentage for showerheads	Hot water percentage for lavatory faucets
1	5,628,844	46.8	47.8	74.0	66.2
2	15,377,694	49.8	51.4	72.7	65.0
3	18,094,391	49.2	50.7	73.0	65.3
4	8,277,344	50.6	52.4	72.3	64.7
5	23,474,851	64.7	69.4	62.6	56.0
6	7,197,189	61.9	66.0	65.6	58.7
7	13,769,934	67.9	73.2	61.0	54.6
8 (North)	4,246,877	46.4	47.3	74.2	66.3
8 (South)	4,266,870	63.6	68.1	64.1	57.3
9	17,874,256	60.1	63.8	66.7	59.6
Weighted average		**57.4**	**60.5**	**67.8**	**60.7**
Aquacraft (2005)[12]				72.0	72.0
DeOreo *et al.* (2016)[13]				66.2	57.0

The percentages given in Table 4 feed into the estimation for hot water by end use as a share of total residential hot water use in Equation 3-1.

5 RESIDENTIAL HOT WATER USE END-USE ESTIMATES

In order to confirm the hot water percentage estimates discussed above, we compared these results against independent field studies on residential hot water end uses. To estimate the percentage of total hot water used by individual plumbing fittings while accounting for variations in housing characteristics, as well as geographic location, we started with an equation from the ANSI 301 Standard that accounts for fixture hot water use and water waste (see Equation 3-1). The ANSI 301 hot water draw equation uses numbers of bedrooms as an approximation for household size.[14] The following sections discuss details of our use of the ANSI 301 hot water draw equation with the RECS 2015 dataset: using bedrooms as a proxy for household demographics, including hot water waste, accounting for the presence of water-using appliances, and clarifying assumptions made about faucet and shower use. Although various household age groups use water at different volumes (Evarts and Swan 2013; Parker *et al.* 2015), neither the ANSI 301 equation, the 2017 *American Housing Survey* (AHS 2017,[15] nor RECS 2015 enable the suitable disaggregation of hot

[12] Values are from post-retrofit stage of the study, and faucets encompassed all faucets, not only lavatory faucets.
[13] Faucets in this study encompassed all faucets, not only lavatory faucets.
[14] Other hot water draw models use additional parameters in their calculations: occupant age, outdoor air temperature, water heater tank size, and water heater efficiency. ANSI 301-2019 does not account for these parameters.
[15] U.S. Census Bureau, Housing and Household Economic Statistics Division. 2017 *American Housing Survey*. Washington, DC. 2019. http://www.census.gov/hhes/www/housing/ahs/ahs.html Last accessed April 30, 2020.

water use by age group; therefore, this report does not address the influence of age groups on hot water use.

5.1 Hot Water Use Estimates Using Residential Energy Consumption Survey Microdata

Multiple studies suggest that residential hot water use volume is related to the number of household occupants (Parker *et al.* 2015 and Lutz 2005). The ANSI 301-2019 hot water draw equation (Equation 3-1) uses numbers of bedrooms as an approximation for household size. Data from the U.S. Census shows the changing household size for the country (Figure 2), as well as occupant ages. Average household size has generally declined throughout the study period. Using RECS 2015 data allows regional adjustments to total household water use and hot water use by appliance or fitting with improved accuracy. Parker *et al.* (2015) showed that while the number and age characteristics of home occupants is a better predictor of hot water use in individual homes, the best surrogate for occupancy (if these data are not available) is the number of bedrooms in the home. Employing the ANSI 301-2019 method using only the number of bedrooms as an indicator of household occupancy allows for estimation of hot water use when the number and age characteristics of home occupants are not known (as is the case for home energy ratings and building code calculations for unoccupied or new homes).

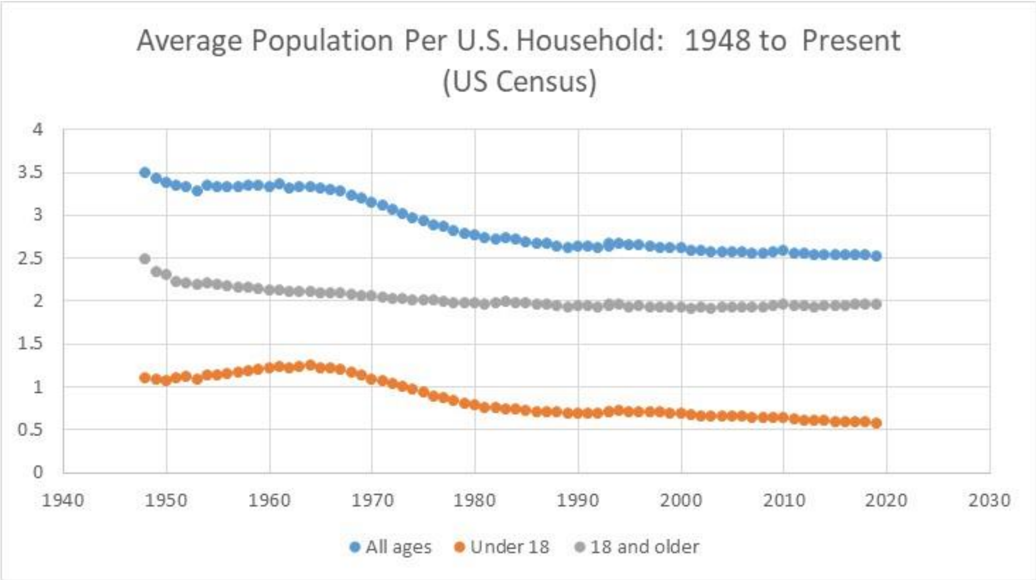

Figure 2: Changes in Household Population Size and Age[16]

[16] U.S. Census Bureau. 2019. Historical Households Tables. November. https://www.census.gov/data/tables/time-series/demo/families/households.html Last accessed April 30, 2020.

5.2 Numbers of Bedrooms as an Indicator of Household Size

Because ANSI 301-2019 uses number of bedrooms as a way of gauging household size (in terms of the number of occupants), we examined the relationship between household size and number of bedrooms using several nationally-representative data sets. Both the RECS 2015 and the AHS 2017 data were analyzed to evaluate the correlation among the numbers of bedrooms and household size for single-family homes. In RECS 2015 data, the assigned weight of each housing record represents the number of households with similar demographic data. Figure 3 shows that with a robust sample size, the number of household members has a linear and positive correlation with the number of bedrooms. A similar correlation can be obtained using the AHS 2017 data (see Figure 4), in which the number of bedrooms variable is divided into five groups. The AHS 2017 data record numbers of bedrooms up to three. For more than three bedrooms, the records are collected into one group: number of bedrooms equal to and larger than four. For both analyses, we obtain a clear positive correlation between the number of bedrooms and household size, with little variability. However, for households with zero or one bedroom, the positive correlation cannot be confirmed.

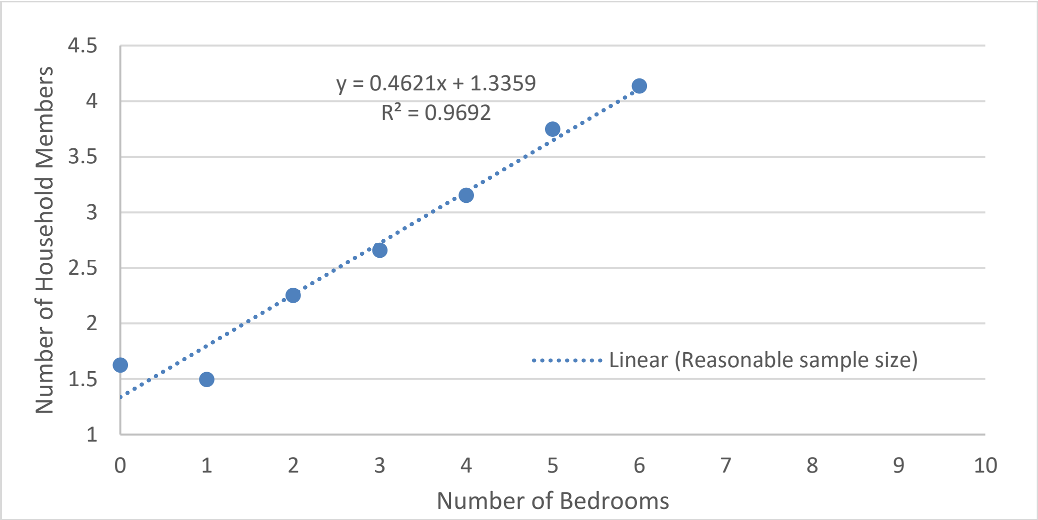

Figure 3: Weighted Average Household Size as a Function of Number of Bedrooms (RECS 2015)

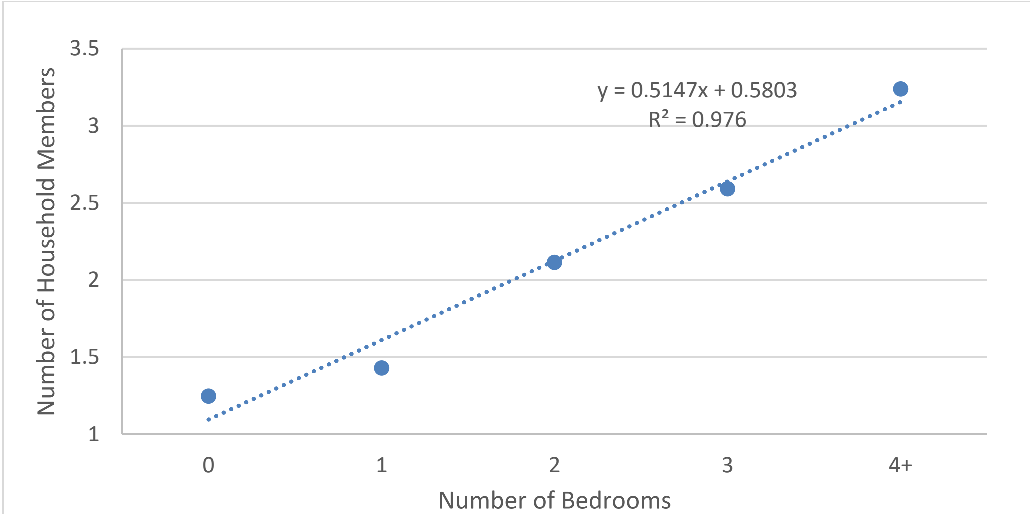

Figure 4: Weighted Average Household Size as a Function of Number of Bedrooms (AHS 2017)

Figure 5 illustrates the probability of having different number of household members for those households that have 0, 1, 2, 3, 4, 5, and 6 bedrooms based on RECS 2015. Having more bedrooms implies larger household sizes. However, this does not always hold true, especially for households with more than 6 bedrooms, given the small number of sample households in this category. When the same analysis is performed with the AHS 2017 data, the probability trends are clearer. See Figure 6. Having more bedrooms in the household clearly indicates larger household sizes (a higher number of household members).

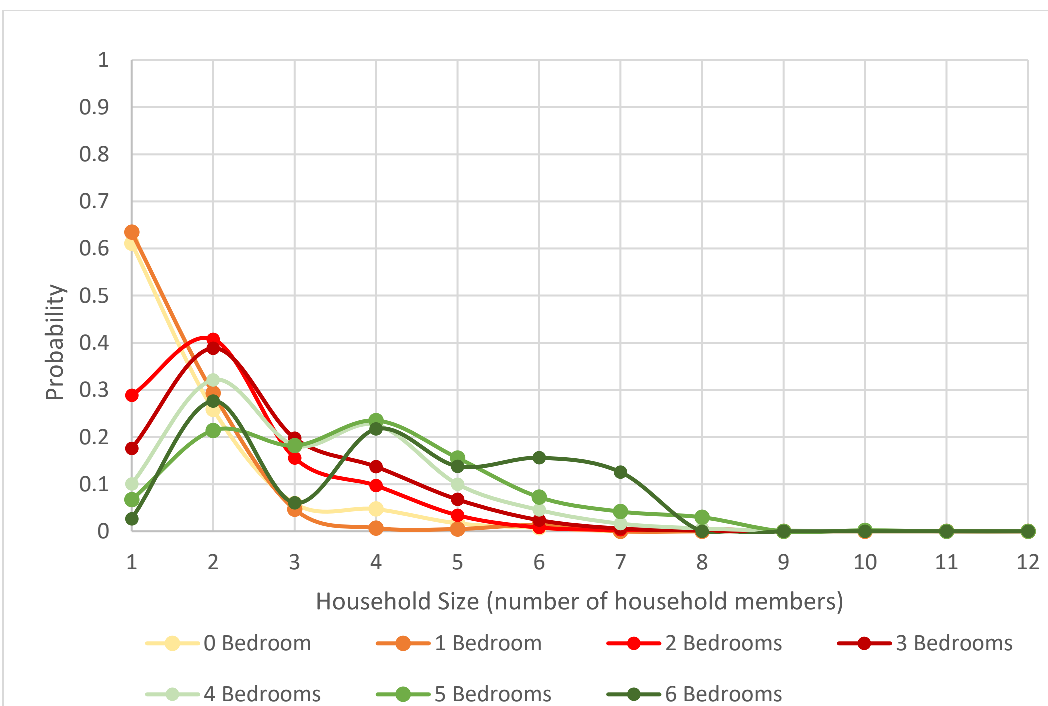

Figure 5: Probability Function of Household Size by Number of Bedrooms (RECS 2015)

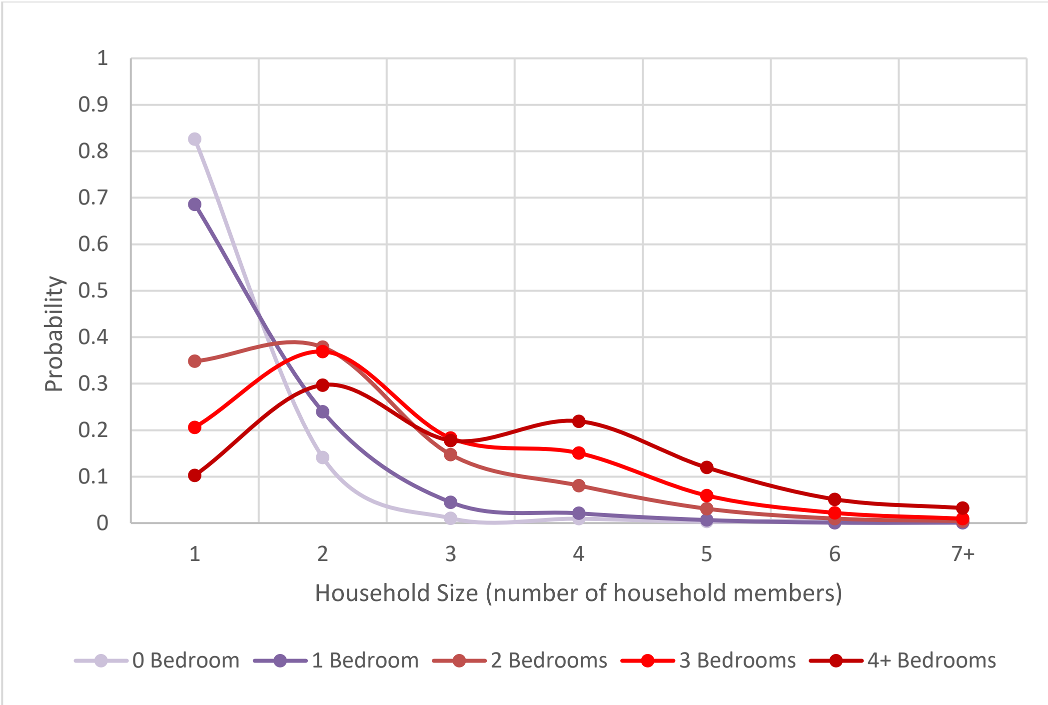

Figure 6: Probability Function of Household Size by Number of Bedrooms (AHS 2017)

Based on the information presented above, it is reasonable to conclude that the number of bedrooms can be a proxy for household size.

5.3 Hot Water Waste Calculation

Hot water produced by a water heater, called by an opened hot water tap, may not always be used in a functional or beneficial way by the consumer. Several factors determine hot water waste: hot water can cool unused in the hot water distribution piping of the house, the end use can be turned off before hot water arrives, and hot water can run until reaching the user's desired temperature. The amount of water wasted can be a considerable share of water heated, according to ANSI 301-2019.[17] Water waste is estimated in the hot water draw calculations presented in ANSI 301-2019 and included in this report.

5.4 Appliance, Faucet, and Showerhead Water Use

For RECS 2015 households with no clothes washers, we assumed no hot water was used for hand washing clothes. While some dishwashers on the market perform are designed with no pre-treatment of the dishes, older dishwasher models that require pre-washing dishes are still in use.[18] No adjustment was made in our calculations for pre-washing dishes.

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[17] Water waste can amount to as much as 25 percent of hot water use. ANSI/RESNET/ICC 301-2019 Standard for the Calculation and Labeling of the Energy Performance of Dwelling and Sleeping Units using an Energy Rating Index. http://www.resnet.us/wp-content/uploads/archive/resblog/2019/01/ANSIRESNETICC301-2019_vf1.23.19.pdf Last accessed April 30, 2020.

[18] According to ENERGY STAR, a new ENERGY STAR certified dishwasher uses about a quarter of the energy used when washing dishes by hand and saves more than 7,000 gallons of water each year. https://www.energystar.gov/products/appliances/dishwashers?qt-consumers_product_tab=2#qt-consumers_product_tab Last accessed April 30, 2020.

Other variables to determine water use by faucets and showerheads include estimates for gallons per minute per use and minutes per day per person. See Table 5. Our calculation uses the federal standard for flow rate, recognizing that this value will vary in residential use.

Table 5: Inputs for Lavatory Faucet and Showerhead Water Use Calculations

Input	Kitchen faucets	Lavatory faucets	Showerheads
Minutes per person per day	5[*]	3[*]	5[*]
Gallons per minute	2.2[**]	2.2[**]	2.5[**]

[*]Duane D. Baumann, John J. Boland, and W. Michael Hanemann, Urban Water Demand Management and Planning (New York: McGraw Hill, 1998), 254. https://www.epa.gov/sites/production/files/2017-03/documents/appendix-b-benchmarks-used-in-conservation-planning.pdf

[**]Energy Policy Act 1992, Federal Standard from EPACT 1992 https://www.govinfo.gov/content/pkg/CHRG-106hhrg58509/html/CHRG-106hhrg58509.htm

The ANSI 301-2019 model estimates total fixture hot water use without distinguishing between showerheads, baths, kitchen faucets, or lavatory faucets. To arrive at a hot water percentage used by showerheads, we multiplied total fixture hot water by the ratio of shower use in minutes over all fixture use in minutes. A similar approach was used to distinguish faucet use between kitchens and lavatories. On average, bath use is assumed to be 13 percent of total fixture use based on Escriva-Bou *et al.* (2015) and DeOreo *et al.* (2016).

Table 6: Estimates of Percentage of Showerhead and Faucet Hot Water Use

<table>
<tr><th colspan="2"></th><th>Lowenstein & Hiller (1998)</th><th>DeOreo & Mayer (2000)</th><th>Henze et al. (2002)</th><th>Escriva-Bou et al. (2015)</th><th>DeOreo et al. (2016)</th><th>Using ANSI 301-2019 and RECS 2015 data</th></tr>
<tr><td colspan="2">Location</td><td>Unspecified</td><td>WA</td><td>NE</td><td>CA</td><td>AZ, CO, FL GA, ON, TX, and WA</td><td>National</td></tr>
<tr><td colspan="2">Sample size</td><td>14</td><td>10</td><td>1</td><td>>700</td><td>94</td><td>5,686</td></tr>
<tr><td colspan="8">Percent of total residential hot water use, by end use (%)</td></tr>
<tr><td colspan="2">Showers</td><td>41.6</td><td>25.1</td><td>30.9</td><td>41</td><td>39.1</td><td>34.8</td></tr>
<tr><td rowspan="2">Faucets</td><td>Kitchen</td><td rowspan="2">--</td><td rowspan="2">34.3</td><td>25.8</td><td rowspan="2">39</td><td rowspan="2">33.8</td><td>27.5</td></tr>
<tr><td>Lavatory</td><td>11.9</td><td>16.5</td></tr>
</table>

Table 6 compares the estimated hot water use percentage by fixture to those from selected studies found in the literature review. The DeOreo *et al.* (2016) report and other studies (excluding Henze *et al.* 2002) calculated water flow for all household faucets in lavatories and kitchens; therefore, a direct comparison with the RECS calculation cannot be made. However, the hot water percentage for showers calculated using the ANSI 301-2019 hot water draw equation and RECS 2015 data is close to the percentage found by DeOreo *et al.* (2016) using regional data in 2016.

6 CONCLUSION

Given regional differences, limited sample sizes, and different methodologies, as well as the changing nature of water use patterns, previously available studies of hot water use percentages may not be easily generalized to the national scale. This paper describes approaches to estimating residential hot water use in the existing literature before recommending an improved approach for how the WaterSense program can estimate hot water usage of lavatory faucets and showerheads. We employed RECS 2015 microdata to account for regional differences in hot water use, in conjunction with the updated ANSI 301-2019 Hot Water Draw model, to determine nationally representative values for hot water percentages of residential showerhead and lavatory faucet use (see Table 7). We also tested the validity of the assumption behind the ANSI 301-2019 Hot Water Draw equation that the number of bedrooms is a reasonable proxy for household size by investigating the correlation between the number of bedrooms and the number of household members in RECS 2015 and AHS 2017—with favorable results. Future work could employ nationally representative datasets to update ANSI 301-2019 to better account for variances in hot water volumes used by different age groups.

Table 7: Hot Water Percentage by End Use from ANSI 301-2019 and RECS 2015 Data

End use	Percent of total residential hot water use (%)	Percent of end use hot water
Showers	34.8	67.8
Lavatory faucets	16.5	60.7

Ultimately, we consider that the updated inlet temperature delta and hot water percentages obtained with our proposed approach will increase the accuracy of estimated annual energy and monetary savings for EPA's WaterSense program, as well as the carbon emissions reduction estimates attributable to water-efficient showerhead and faucet use.

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