

# WQRF Softened Water Benefits Study - Energy Savings

*Excerpted and edited for clarity*

**T**his study tested devices fed with softened and unsoftened water under controlled laboratory conditions designed to accelerate the water side scaling in the device and quantify the performance efficiency. The project specifically focused on efficiency improvements in household water heaters from use of softened water, and the subsequent effect on performance of fixtures, such as low flow showerheads and faucets and appliances, such as laundry washers and dishwashers. For this study, the Water Quality Research Foundation (WQRF) contracted with the Battelle Memorial Institute in Columbus, OH. Battelle tested 30 water heaters supplied by WQA over a 90-day period using a Battelle-developed and WQA-approved test protocol. Battelle simultaneously studied the effect of water hardness on performance of faucets, low-flow showerheads, dishwashers, and laundry washers. Using the empirical data generated from the water heater testing and the effect on performance of fixtures and appliances, Battelle developed a differential carbon footprint assessment for homes using unsoftened water verse softened water.

## WATER HEATER EXPERIMENTAL SET-UP

Battelle set up and tested ten storage-type gas water heaters, ten storage-type electric water heaters, and ten instantaneous gas water heaters with the following specifications using an accelerated scaling methodology developed at Battelle.

- Gas Water Heaters (10), 40 gal, 38,000 Btu/h burners
- Electric Water Heaters (10), 40 gal, 4500 W heating elements
- Tankless (Instantaneous) Gas Water Heaters (10), 199,000 Btu/h burners

Five of each type of device were tested without any preconditioning of the water supply, and the other five were tested using a water softener to remove hardness constituents from the water supply. Five units were chosen for each of the groupings in order to be able to calculate 95 percent confidence intervals for the results.

At the start of the test and at approximately one week intervals, the thermal efficiency of each water heater was measured to determine the change in efficiency as water side scale built up in each water heater. Each water heater was instrumented to measure the inlet and outlet water temperature at 15-second intervals, the amount of hot water generated, and the amount of energy (gas or electric) used to produce the hot water. These data were used to calculate the average thermal efficiency of the water heater.

The accelerated test protocol was based on the following assumptions.

- The amount of scale buildup in the water heaters is proportional to the amount of hot water put through the device.
- The water heaters use a periodic water draw of approximately 1.25 gpm for 4 minutes, which is a total draw of 5 gallons of hot water through the device.
- To allow the water heaters to reheat sufficiently before the next draw, the time between water draws was 15 minutes for the gas storage-type water heaters, 30 minutes for the electric storage-type water heaters, and 12 minutes for the instantaneous gas water heaters.
- A control system was setup to automatically withdraw water from each tank at the set intervals for 24 hours a day. This yielded a total of 240, 480, and 600 gallons per day of hot water generated by the electric storage water heater, gas storage water heater, and gas instantaneous water heater, respectively.
- An average family in the US uses about 50 gallons of hot water per day.
- The acceleration factor for the water usage is 4.8, 9.6, and 12 for the electric storage water heater, gas storage water heater, and gas instantaneous water heater, respectively.
- The amount of scale buildup in the water heaters is directly proportional to the water hardness. With a water source with a hardness of approximately 26 grains per gallon, the scale buildup in the water heater to be approximately 2.6 times the amount than if Battelle were using a water source with 10 grains per gallon hardness. In this case, the acceleration factor for the water hardness is 2.6 (= 26/10).

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In addition, a rough rule of thumb is that for every 20°F increase in setpoint temperature of the unit, the amount of water scale buildup is doubled. Electric storage-type water heaters are shipped from the factory with their thermostats preset at 120°F. Battelle operated the test units at a setpoint temperature of 140°F for instantaneous water heaters, 160°F for gas storage water heaters, and 150°F for electric storage water heaters. Compared to the same unit operating at 120°F, the instantaneous water heaters, gas storage water heaters, and electric storage water heaters are expected to generate 2, 4, and 2.8 times as much scale, respectively, due to the higher operating temperature.

Using the above correlations, the overall acceleration factor for the cases described above is 35, 100, and 62 per day of testing for electric storage, gas storage, and gas instantaneous. Table 1 summarizes the individual factors and the composite. Each water heater was tested for 90 days at the above conditions.

**Table1.** Summary of Acceleration Factor Calculations

Water Heater Type	Acceleration Factors			Composite, Estimated Days Real Life to Actual Days Tested
	Water Volume	Hardness	Temperature Increase	
Electric Storage	4.8	2.6	2.8	35
Gas Storage	9.6	2.6	4	100
Gas Instantaneous	12	2.6	2	62

The well water Battelle used for this testing contained an elevated concentration of iron which imparted red staining to the scale, the appliances, and the fixtures as is evident throughout the test results presented in this section. The unsoftened well water contained 26.2 grains per gallon of water hardness and 0.99 parts per million (ppm) or milligrams per liter (mg/liter) of iron. The softened well water contained less than 0.55 grain per gallon of water hardness and 0.27 ppm of iron. Samples of the scale were dissolved in solution and a quantitative analysis performed of the solutions to determine the percentage of calcium carbonate, magnesium, iron, and other species in the scale deposits. (Full results presented in Appendix Q of the full report.)

The analyses show the concentrations of calcium, magnesium to be 2079 ppm, 96 ppm, 164 ppm, 28 ppm, and 21 ppm,

respectively. This shows that calcium carbonate is the most significant constituent of the scale. However, iron present in the water gave the hard water deposits a red/brown tone. Iron causes unsightly red and/or brown staining in not only the scale but also on fixtures, faucets, porcelain, and clothing that contact the water.

Iron is a rather common water problem in addition to and often accompanying hard water scaling. Iron is the fourth most abundant element on earth. It enters water naturally as it is dissolved from the earth’s crust or as iron or steel pipes corrode. As iron reacts with oxygen, it is converted from a water soluble and ionic ferrous iron into a precipitated red water ferric iron, which causes staining. Like water hardness, iron does not cause health related problems in water supplies.

Iron and water hardness rather create aesthetic and economic problems. The US Environmental Protection Agency advises a secondary maximum contaminant level (SMCL) for iron of 0.3 ppm to avoid aesthetically displeasing iron staining. Cation exchange water softeners replace hardness causing ions of calcium and magnesium as well as dissolved ions of other metallic elements, including iron and manganese, for those of sodium or potassium.

Water softening is generally considered effective for treating levels of iron up to 5 ppm, although many field installations have performed very satisfactorily removing up to 15 ppm of dissolved Fe+2 iron with cation exchange water softeners. Many homeowners purchase water softeners to remove iron from their water supply in addition to calcium and magnesium. The appliances using unsoftened water were prone to heavy iron staining on all internal surfaces, whereas those appliances on softened water did not show this effect.

## WATER HEATER RESULTS

At the start of the test and at approximately one week intervals, the thermal efficiency of each water heater was measured to determine the change in efficiency as water side scale builds up in each water heater. Each water heater was instrumented to measure the inlet and outlet water temperature at 15 second intervals, the amount of hot water generated, and the amount of energy (gas or electric) used to produce the hot water. This data was

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used to calculate the average thermal efficiency of the water heater.

Water heater efficiencies were calculated for the groups of instantaneous gas water heaters, gas storage water heaters, and electric storage water heaters. Five water heaters in each group were operated using unsoftened well water (26.2 grains per gallon, 0.99 ppm iron); and five water heaters were operated using softened well water (0.55 grains per gallon, and 0.27 ppm iron). The efficiencies were calculated using the following energy balance. The energy output delivered from the hot water withdrawn from the tank is:

$$Q_{\text{out}} = mc(T_{\text{out}} - T_{\text{in}}) \quad [\text{Equation 1}]$$

where

$m$  = the measured amount of water withdrawn from the tank,

$c$  = the heat capacity of water,

$T_{\text{out}}$  = the measure outlet water temperature, and

$T_{\text{in}}$  = the measured inlet water temperature.

The energy input into the tank was determined for electric water heaters by directly measuring the kilowatt hours used with a watt-hour meter. For gas water heaters, the energy input was determined using:

$$Q_{\text{in}} = V \times H \quad [\text{Equation 2}]$$

where

$V$  = the measured volume of natural gas used, and

$H$  = the measured Btu content of the natural gas using a gas chromatograph.

The efficiency was then calculated using:

$$E = Q_{\text{out}} / Q_{\text{in}} \quad [\text{Equation 3}]$$

where

$E$  = the efficiency of the water heater.

At the end of the 90 days of testing, each water heater was carefully cut in half and the water side scale removed from the inside surfaces and weighed. A statistical analysis of the data was completed to determine the average performance improvements of the group of water heaters using softened water when compared to the baseline group of water heaters using unsoftened water. Ninety-five percent confidence intervals were calculated based on five water heaters being tested in each group.

In summary, the electric and gas storage water heaters and the instantaneous gas water heaters on soft water performed well throughout the entire testing period. Although the pressure regulators and needle valves were tweaked throughout the testing to maintain constant testing conditions, all of the water heaters on soft water required minimal attention because the conditions were very stable. This is reflected in the efficiency data for these units that show the efficiency remained essentially constant over the duration of the testing with the variations being within the experimental error of the instrumentation and testing protocol. Overall, the softened water did a good job of minimizing scale buildup in the water heaters.

In contrast, none of the electric or gas storage water heaters or the instantaneous gas water heaters on unsoftened water made it through the entire testing period because the outlet piping system consisting of one-half inch copper pipe, a needle valve, and a solenoid valve became clogged with scale buildup. Although the pressure regulators and needle valves were tweaked throughout the testing to try to maintain constant testing conditions, all of the water heaters on unsoftened water were removed from the testing at some point due to the inability to maintain sufficient flow.

The instantaneous water heaters on unsoftened water had to be delimed at 1.6 years of equivalent field service, and the average efficiency of these units dropped from 80 percent at the start of the test to 72 percent, when they were delimed. After deliming, the average efficiency of these units increased to about 77 percent but was still below the 80 percent starting efficiency. The cost implications of these findings are addressed in [the conclusion of] this report.

The average efficiency of the gas storage water heaters on unsoftened water dropped from 70.4 percent at the start of the test to 67.4 percent at two years equivalent field service. These data were used to derive equations to predict the efficiency of gas storage water heaters as a function of water hardness and daily household hot water usage. The average rate of scale buildup in the gas storage water heaters on unsoftened water was about 528 gm/yr (1.16 lb/yr). The average rate of scale buildup in the gas storage water heaters on soft water was about 7 gm/yr (0.01 lb/yr), which is almost negligible.

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The electric storage water heaters on both softened and unsoftened water were able to maintain a constant efficiency throughout the entire test period because the heating elements were completely submerged in the water. However, the life of the heating element in unsoftened water is expected to be shortened due to scale buildup increasing the operating temperature of the element. The average rate of scale buildup in the electric storage water heaters on unsoftened water was about 907 g/yr (2.00 lb/yr). The average rate of scale buildup in the electric storage water heaters on soft water was about 14 g/yr (0.03 lb/yr), which is almost negligible.

[The following] equation can be [used] to predict the efficiency of gas storage water heaters at other water hardness levels, and for other daily hot water usage amount by putting it into the form below:

$$E = E_0 - bt \quad \text{Equation [4]}$$

where

[E = the efficiency at time t,  
E<sub>0</sub> = the initial efficiency of the water heater at t = 0, in this case 70.4 %,  
t = the time in equivalent years defined as usage in gallons divided by 18250 gallons per year.]

$$b = (0.001133)HG, \quad \text{Equation [5]}$$

(Gas Storage Water Heaters Only)

H = the water hardness in grains per gallon, and  
G = the daily household hot water usage in gallons per day.

For the gas storage water heaters on unsoftened water, the water hardness was 26.2 grains per gallon, and a daily hot water usage of 50 gallons per day was assumed. When these values are plugged into Eq. [5], the value for b is 1.485.... The expression for b assumes that if the usage rate doubles, the amount of scale buildup inside the water heater also doubles.

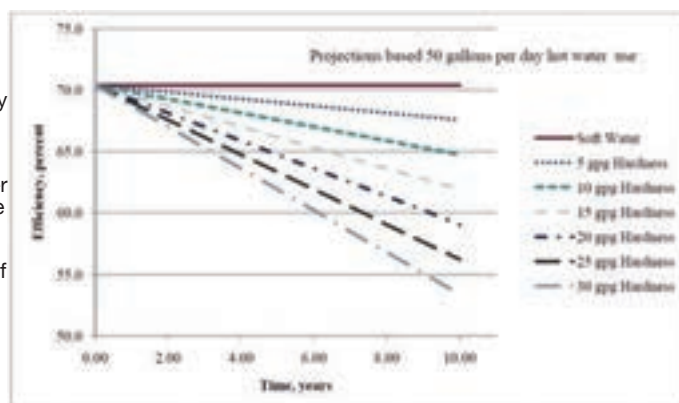
For gas storage water heaters on soft water with a water hardness level of 0.0 grains per gallon, Eq. 2 reduces to a constant value E<sub>0</sub> for the efficiency for all times, which is consistent with Battelle's research findings discussed in Section 5.3.1. Figure 1 shows the [calculated] efficiencies of gas storage water heaters operating on soft water is constant with time, whereas those units operating on unsoftened water experience significant degradation in efficiency over time.

### FIXTURES AND APPLIANCES

Ten low flow showerheads were installed on the hot water supply coming from the instantaneous gas water heaters; five were tested on unsoftened water and five were tested using softened water. The low flow showerheads on unsoftened water were removed from testing as they clogged up to the point of not allowing adjustment to a 1.25 gpm flow rate at any time during the test. All of the low flow showerheads on softened water made it through the testing without any problems. However, the low flow showerheads on unsoftened water clogged after an average of 3,203 gallons of water flow through them.

Six dishwashers (Kitchenaid ) and laundry washers (General Electric) were purchased to test the effect of unsoftened water on the performance of the appliances. The electronic controls for this equipment were integrated into the automated data acquisition and control system designed for the testing. The wash and dry cycles of the dishwashers and the wash cycles of the laundry washers were controlled automatically with the units going through eight cycles every 24 hours. The clothes washers were loaded with 7 lbs of restaurant hand towels. The dishwashers were loaded with eight place settings of dishes and flatware. At the end of the 30 days of testing, the dishwashers and clothes washers were examined before a teardown analysis was initiated. The units using

**Figure 1.** Predicted efficiency of a gas storage water heater operating on soft water (0 grains per gallon) versus one operating on unsoftened water with a hardness of 30 grains per gallon.





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softened water were almost completely free of any water scale buildup. In contrast, the units using unsoftened water (26 grains per gallon) had noticeable water scale buildup on all of the interior surfaces after only 30 days of testing. Although both of the dishwasher and clothes washers completed the same number of wash cycles (240), the appearance of the inside of the units using unsoftened water shows that it needs to be delimed and cleaned due to the buildup of scale and deposits. On the other hand, the units using soft water appeared as if they could be cleaned up to look like new with just a quick wipe down.

### CARBON FOOTPRINT

Battelle assessed that carbon footprint of the water heaters by evaluating the energy consumption within the home and the resulting greenhouse gas emissions. The results parallel those for the energy consumption, in that where there are energy efficiency differences there are also carbon footprint differences. For the storage-type gas water heaters, there was a reduction in carbon footprint of 14.8% over a fifteen year water heater service life with softened water compared to 26 gpg hard water, when considering both the natural gas used for water heating and the electricity used for water softening. For the instantaneous water heaters, there was a reduction in carbon footprint of 4.4% over a fifteen year water heater service life, when considering both the natural gas used for water heating and the electricity used for water softening.

### CONCLUSIONS

For gas storage and instantaneous water heaters, the use of a water softener to eliminate or minimize the scale forming compounds in water will result in the efficiency of the water heater remaining constant over the life of the unit. In contrast, gas storage and instantaneous water heaters using unsoftened water had a noticeable decrease in efficiency over the testing period resulting in higher natural gas use. This natural gas savings associated with the use of softened water will lead to direct energy and economic savings, as seen in the summary results in Table 2. In addition, because of the need to have the instantaneous water heater delimed or cleaned periodically, the economic savings can lead to recovery of the cost of a water softener and operating supplies in a period as short as a year, if the inlet water is sufficiently hard.

Further, there are environmental benefits to the use of a water softener: the lower use of natural gas leads to reductions in the carbon footprint which are related to the decrease in total energy consumption. The increase in total energy consumption (as a result of a reduction in heat transfer efficiency) is related to the hardness: higher water hardness will lead to greater energy consumption without the use of a water softener, and consequently greater energy costs.

**Table 2.** Estimated Savings for Gas-fired Water Heaters Using Softened Water Over 15 Years Life

Cost Elements	Water Hardness (grains per gallon)						
	0	5	10	15	20	25	30
<b>Instantaneous Gas Water Heaters</b>							
Percent Life Cycle Energy Cost Savings, % <sup>1</sup>	NA	5.4	5.4	5.4	5.4	5.4	5.4
Percent Total Life Cycle Cost Savings, % <sup>2</sup>	NA	14.8	22.5	31.2	39.6	48.4	57.0
Estimated Usage Before Deliming Required, Years <sup>3</sup>	NA	8.4	4.1	2.7	2.0	1.6	1.4
<b>Gas Storage Water Heaters</b>							
Life Cycle Operating Efficiency Reduction From Baseline, % <sup>4</sup>	0.0	4.3	8.5	12.8	17.0	21.3	25.5
Percent Life Cycle Energy Cost Savings, % <sup>1</sup>	NA	3.1	6.6	10.3	14.5	19.0	24.2

Notes: <sup>1</sup> Derived from Table 1-2.

<sup>2</sup> Derived from Table 1-1.

<sup>3</sup> Derived from Table 1-1.

<sup>4</sup> Derived from Table 1-4.

Electric storage water heaters did not record any difference in the electricity consumption between units receiving softened or unsoftened water. However, the life of the heating element on the electric water heater receiving unsoftened water would be expected to be shorter.

Low flow showerheads and faucets using unsoftened water clogged in less than seven days of accelerated life testing, whereas those units using softened water made it through the test without any problems.

The dishwashers and clothes washers on either soft or unsoftened water made it through 30 days of accelerated scale testing, but the units on unsoftened water had noticeable scale buildup on all surfaces that had contact with unsoftened water.