Tankless Water Heaters: Do They Really Save Energy?

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ABSTRACT

Tankless water heaters are a highly discussed green building solution, but how much energy do they actually save? Are the publicized drawbacks, such as cold water sandwiches and increased delivery times, a deal breaker?

To address these questions, a recent Minnesota field study installed 16 tankless natural gas water heaters (both condensing and non-condensing) and eight identical conventional storage water heaters in ten homes and alternated operation of different heaters. Data collection equipment installed at each site recorded water flow rate, water heater inlet and outlet water temperature, gas and electrical consumption and ambient temperatures. System efficiencies and energy savings were computed and compared to rated performance (Energy Factor). The *in situ* efficiency of the storage water heaters was nearly 20% lower than rated, while that of the tankless water heaters was only 10% lower. This paper will discuss the causes, consequences, and possible ramifications of this reduced efficiency.

To evaluate user satisfaction, data were analyzed for quality of performance as well as efficiency, and the surveys of homeowners were administered. Hot water usage statistics and patterns were also compiled. Data about typical draw lengths, volumes, flow rates, and spacing provided input to the development of new water heating test standards and improved understanding of how homes use hot water.

Introduction and Background

Water heating comprised 2.11 quadrillion Btus of U.S. energy consumption in 2004. 1.4 quadrillion Btus (1.4 billion therms), or 67% of the energy used for residential water heating, was from natural gas (RECS 2005). Water heating is the second largest end use of natural gas in homes in the United States, accounting for 24% of residential use (D&R International 2006). In 2008, storage water heaters were the primary source of hot water for 76.6 million of the 78.5 million single family homes in the United States. Natural gas supplied water heating to 38.8 million single family homes (RECS 2009). Typical natural gas storage water heaters have efficiency ratings (Energy Factors) around 60%, making water heating one of the least efficient natural gas uses in single family homes. More efficient water heating technology thus has the potential to provide large natural gas savings. Non-condensing natural gas tankless water heaters have Energy Factor ratings around 82%, suggesting a potential for savings of 370 trillion Btus. Condensing natural gas tankless water heaters have Energy Factors greater than 90%, potentially saving more than 470 trillion Btus each year.

Space conditioning is the largest energy use in residential homes. Improved building envelopes reduce the amount of energy required to keep living spaces comfortable, and high performance equipment provide the necessary energy much more efficiently. Tightening a home and replacing a naturally drafted furnace with a condensing furnace can increase the risk of back drafting from a natural draft water heater (Bohac and Cheple 2002). Tankless water heaters are typically installed with sealed combustion, which ducts combustion air directly to the unit and uses a vent fan to exhaust combustion products, eliminating the potential for back drafting associated with natural gas water heating.

The potential benefits of tankless water heaters (TWHs) are encouraging, but natural gas tankless water heaters are relatively new to the U.S. market. Actual installed efficiency and energy savings were unknown, there were several concerns about hot water delivery and user satisfaction, and little was known about how TWHs affect hot water usage volumes and patterns. This project was designed to answer these questions.

Methodology

Ten homes were recruited in the Minneapolis/St. Paul metro area and 24 water heaters were installed, two to three per house. Eight storage water heaters, nine non-condensing TWHs, and seven condensing TWHs were installed. In each home, the heater in use was alternated every month for eighteen months, so that each unit provided hot water to the home through the full range of seasons. The systems were extensively instrumented to collect all the data necessary to characterize water heater performance and hot water usage (Schoenbauer et al 2010).

A range of domestic hot water (DHW) usage was desired to characterize the performance of water heaters across a broad range of loads. The number of occupants is a good predictor of hot water usage, (AWWA 20xx), so sites representative of the occupancy rates of Minnesota single family homes ([BoC] 2000) were selected. Two homes had a single occupant, three homes had two residents, two homes had three occupants, two homes had four occupants, and the final home had five occupants.

Homeowners were surveyed monthly to gauge their satisfaction with each water heater and to determine whether key performance criteria influenced their likelihood to purchase a given water heater.

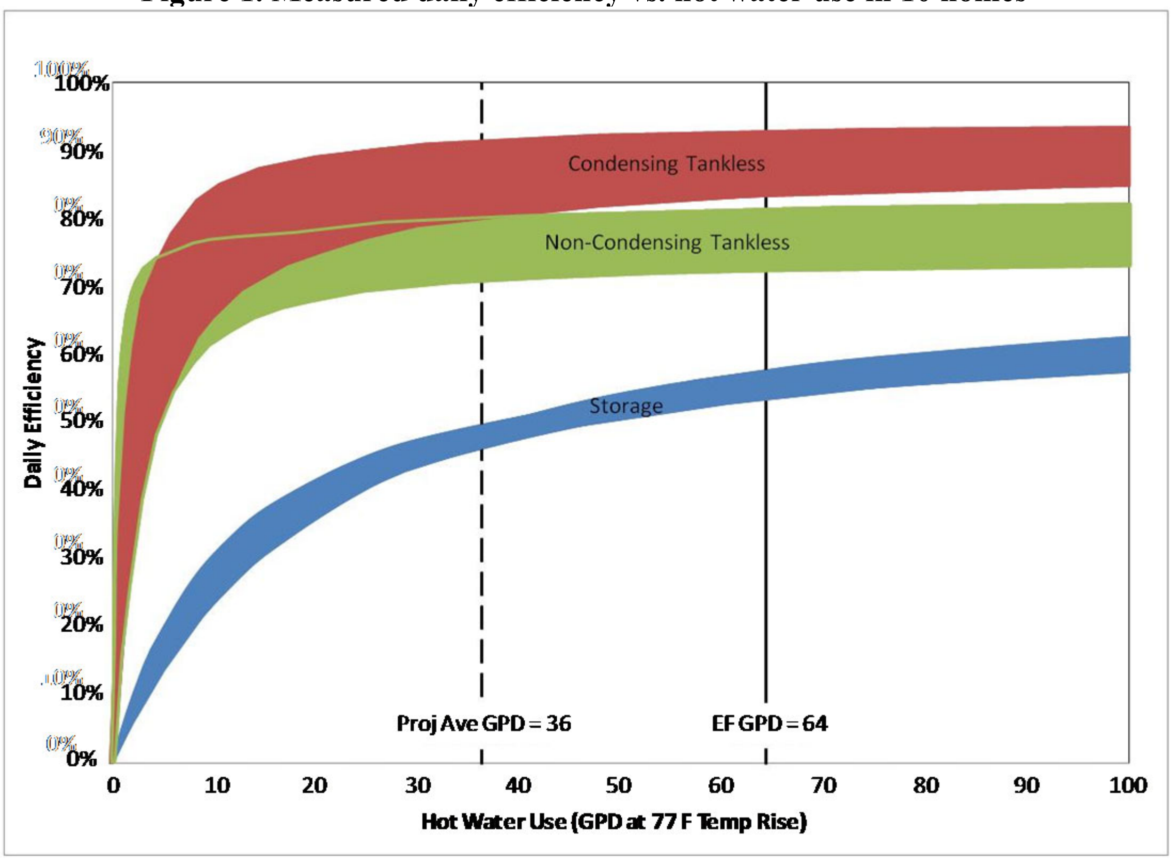
Results

Efficiency. The Energy Factor ([DOE] 2008) provides a means for comparing water heaters, but is not intended to predict their actual installed performance. It was developed when storage water heaters dominated the market. The Energy Factor test procedure measures the energy consumption and hot water energy output from a given water heater for a specific draw profile. Two major factors contribute to the differences between rated Energy Factor and installed efficiency. The first is total daily volume. The EF test uses 64.3 gallons per day, but field monitoring (Thomas 2009) shows that actual average daily volumes are less. The second factor is the draw pattern. The EF test has six draws of 10.7 gallons at three gallons per minute (gpm). This draw pattern is not representative of real world usage. This project found that typical hot water draw patterns consist of many small draws of less than five seconds and 20-30 draws per day of greater than five seconds. Excluding draws less than 5 seconds, average draws were found to be about one minute long and have volumes between one and 1.5 gallons.

Error! Reference source not found. shows the range of daily installed efficiencies for condensing and non-condensing TWHs and natural draft storage water heaters (for detailed data see Schoenbauer et al. 2010). For all heater types, efficiency increases as daily hot water consumption increases. For storage water heaters, more hot water consumption means the useful output is increased while the hours of off-cycle flue and stack loss are reduced. Storage water heaters required draws of approximately 60 gallons per day or more to reach their maximum daily efficiency, while TWHs reached 90% of their maximum daily efficiency at approximately 10 gallons of hot water per day. TWHs heat water as necessary. Small draws heat up the burner and water heater components, reducing efficiencies (Hoeschele 2007), but the relative effect of these cyclic losses is fairly small for larger draw volumes.

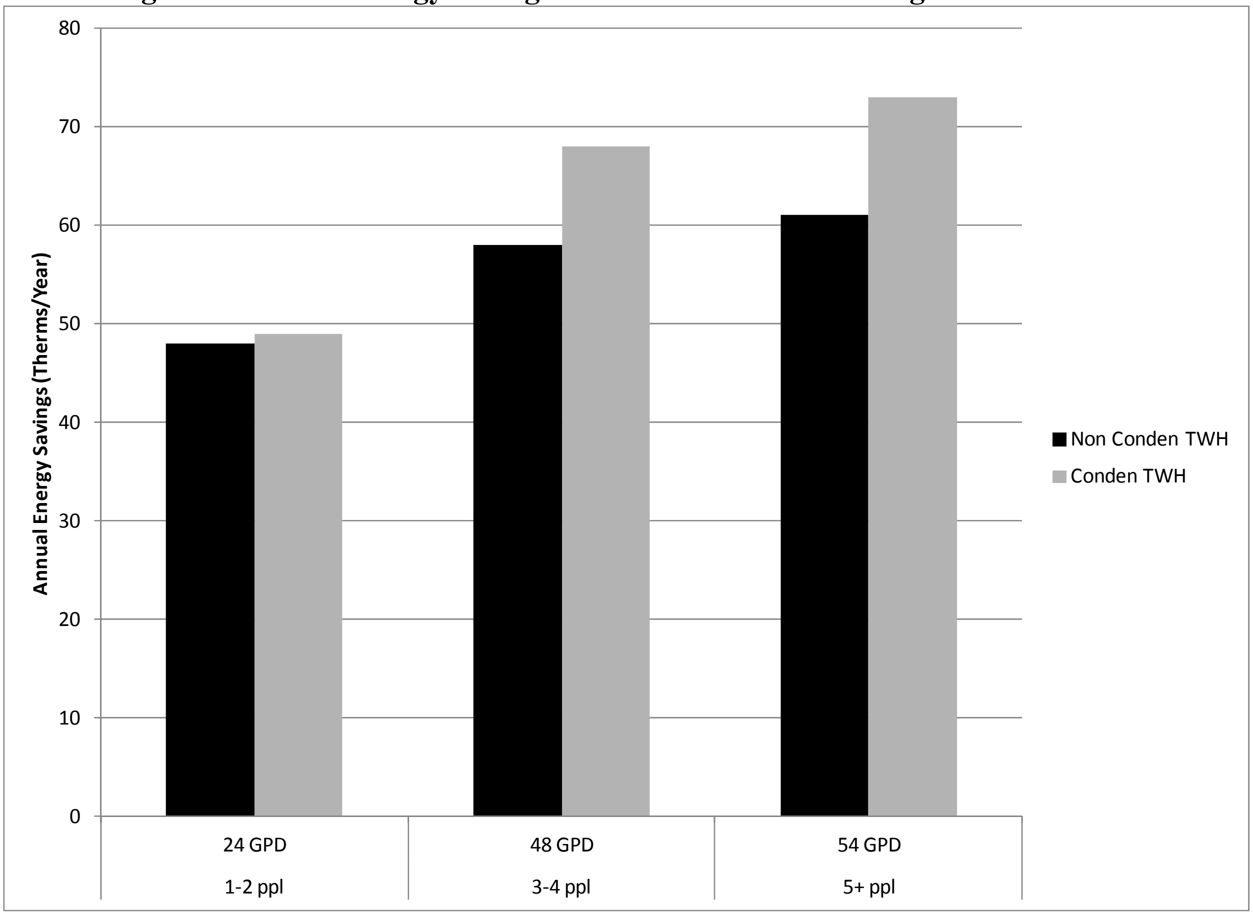
Error! Reference source not found. also shows the hot water volume used for the Energy Factor rating, and the average daily volume of 36 gallons observed in this study. Because of this low draw volume, the storage water heaters' efficiencies fell much further below their Energy Factor ratings than did the efficiencies of the TWHs.

Figure 1. Measured daily efficiency vs. hot water use in 10 homes



The *in situ* efficiency was lower than the Energy Factor rating by 18% for the storage water heaters 8% for the non-condensing TWHs and 10% for the condensing TWHs. This makes the Energy Factor a poor predictor of actual savings. The Energy Factor predicts that a 0.82 TWH would save 27% over a 0.60 EF storage water heater, while the measured results showed a 35% savings.

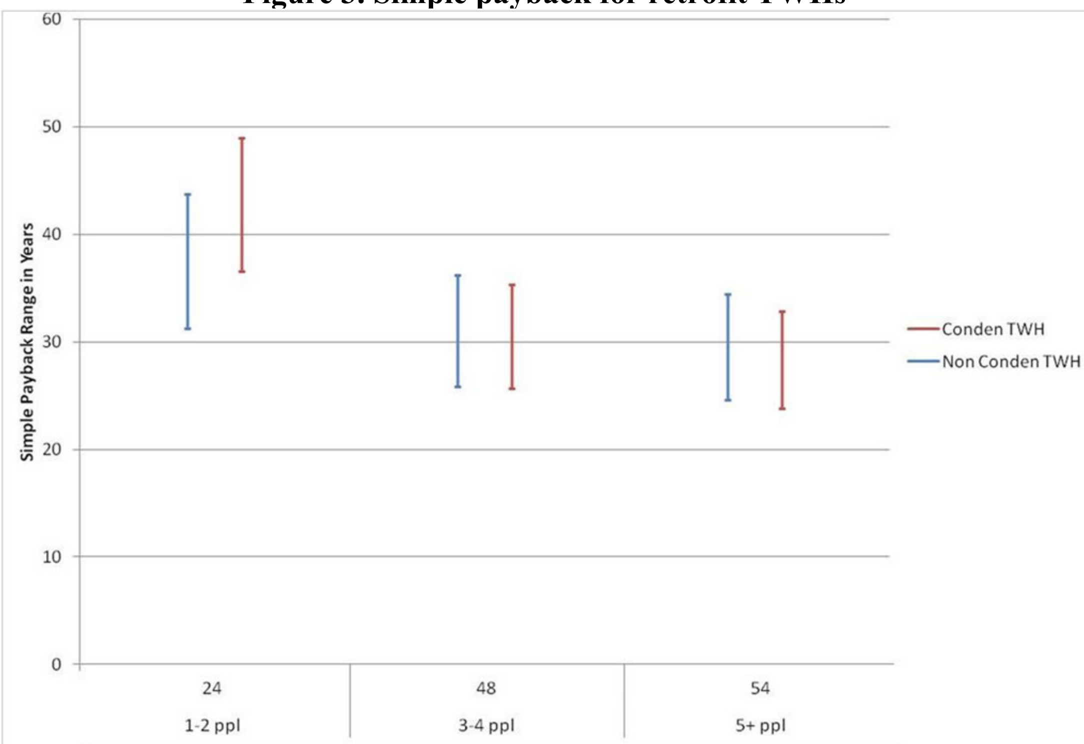
Figure 2. Annual energy savings of TWHs relative to storage water heaters



Energy savings and paybacks. Several factors affect the energy savings potential of tankless water heaters. Condensing TWHs have higher efficiencies and therefore higher savings potential. Homes with larger hot water demand require more heating and more energy to save. Figure 2 shows the annual energy savings of non-condensing and condensing TWHs relative to conventional storage heaters as a function of daily hot water demand. Noncondensing TWHs save 48 to 61 therms/year over this hot water usage range. Condensing TWHs save 4-12 therms more. Savings increase by 20% in high use homes with condensing water heaters. Non-condensing TWHs used between 30 and 170 kWh/year while condensing TWHs used 70 to 250 kWh/year. Electrical energy usage was included in the savings analysis at $0.12 per kWh.

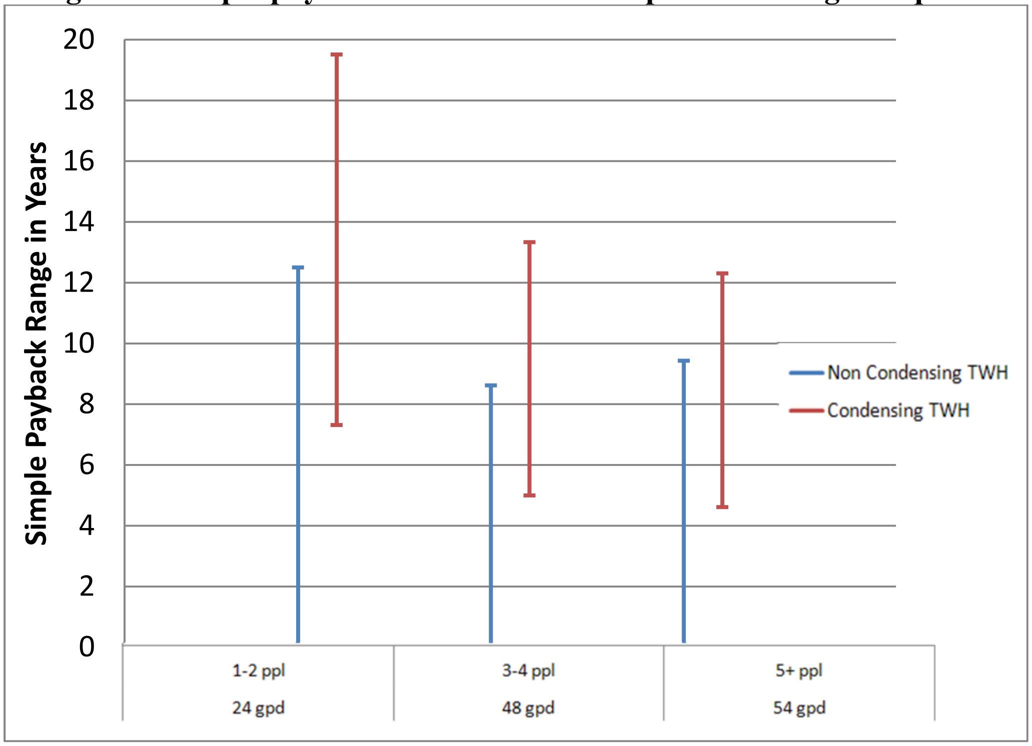
TWH paybacks are difficult to estimate. Installation costs can vary drastically from site to site. TWHs typically have maximum input capacity of 140,000 to 199,000 Btu/hr compared to the 40,000 Btu/hr capacity of a typical storage water heater. Although TWHs rarely operate at their maximum input rate, in retrofit installations it may be necessary to increase the size of the gas piping inside the home. Direct venting required by tankless water heaters has a combustion safety benefit, but can be difficult to install in retrofit applications. Interviews with eight local contractors were used to estimate the typical installed costs for whole house natural gas tankless water heaters as $2,500 to $3,400. The installed cost for a natural draft storage water heater is approximately $1000. These costs imply simple paybacks greater than 20 years for retrofit installations, assuming a $1 per therm cost for natural gas and $0.12 per kWh for the electricity used by TWHs for the vent fan, controls and freeze protection.

Figure 3. Simple payback for retrofit TWHs



Paybacks are shorter when combustion safety issues require direct vent installations. New construction typically uses direct vented condensing furnaces and non-condensing power vented storage water heaters. Non-condensing power vented storage water heaters are the lowest cost power vented units and are often used in retrofits where combustion safety is an issue. They generally have an Energy Factor of 0.65 or 0.67. The incremental cost of non-condensing TWHs is less than $500 in these scenarios where power vent water heaters are required, and condensing TWHs can be installed for about $300 more than non-condensing TWHs in these homes. Figure 4 shows the paybacks for situations in which a power vented storage water heater is the lowest cost option. In this situation the simple payback is less than 12 years for non-condensing TWHs and 4 to 20 years for condensing TWHs.

Figure 4. Simple paybacks for TWHs where power venting is required



User Satisfaction

In addition to efficiency, the study investigated and characterized several performance factors. Because TWHs heat water when needed, instead of storing hot water at all times, the user experience is different. TWHs require a specific amount of water to turn on, once flow is established its takes a bit of time for the water heater to come up to temperature. Storage water heaters keep water hot at all times. In order to reduce off cycle loses storage water heaters allow water temperatures to drop a specific dead band before heating back up. At the end of each month, each homeowner was given a survey on the heater they had been using for the preceding month. The surveys asked homeowners to rate their likelihood to purchase a given water heater based on six different performance characteristics:

- Delay time until hot water arrives at the fixture
- Necessity to increase flow when low flow is desired
- Steadiness and consistency of temperature for a single use
- Steadiness and consistency of temperature for multiple simultaneous uses
- Ability to continuously produce hot water for long times without running out
- Possible reduction in flow rate with multiple simultaneous uses

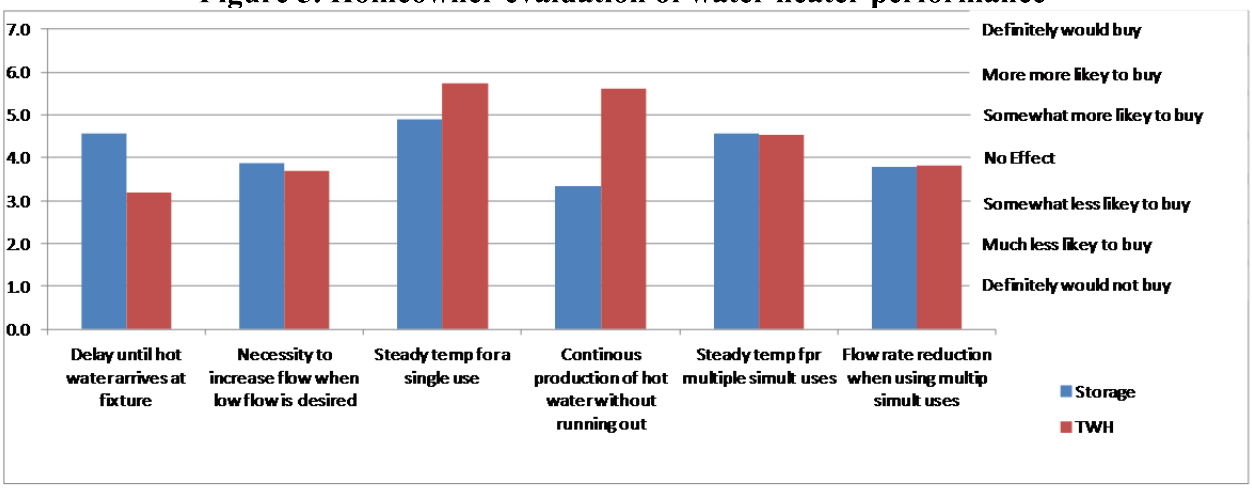
Users rated the water heater with one of seven statements for each characteristic:

- Definitely would not buy because of this
- Much less likely to buy because of this
- Somewhat less likely to buy because of this

- No effect on decision to buy
- Somewhat more likely to buy because of this
- Much more likely to buy because of this
- Definitely would buy because of this

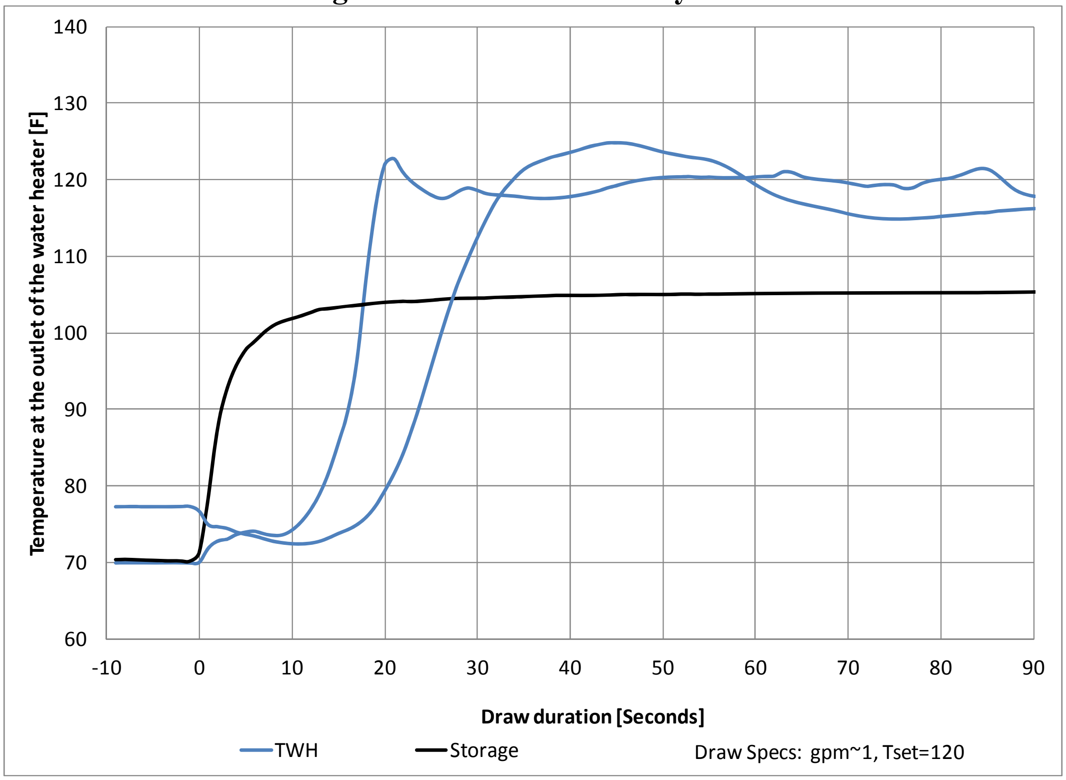
Figure 5 is a graphical representation of the average responses to these questions. The outer ring of the circle represents the statement "definitely would buy because of this," while the smallest circle represents "definitely would not buy because of this." The figure shows that users strongly preferred the storage water heater on the dimensions of delay in hot water delivery and necessity to increase flow for low flow uses. They strongly preferred the TWHs for their ability to produce hot water for long draws without running out and for the steady temperature of single draws. Most users commented that they avoided multiple simultaneous uses for both water heater types.

Figure 5. Homeowner evaluation of water heater performance



Objective performance data supported most of these user preferences. Figure 6 shows the delay in arrival of hot water at the water heater outlet with two typical TWHs. The storage water heater reached 90% of its maximum temperature within a few seconds; TWHs required 20 to 30 seconds. The time required for hot water to travel from the water heater outlet to the mixture must be added to this to estimate delays experienced by the user. Users also preferred the storage water heaters for their performance at low flows. The TWHs require a minimum flow rate of 0.4 to 0.6 gpm to activate the burner.

Figure 6. Hot water delivery time



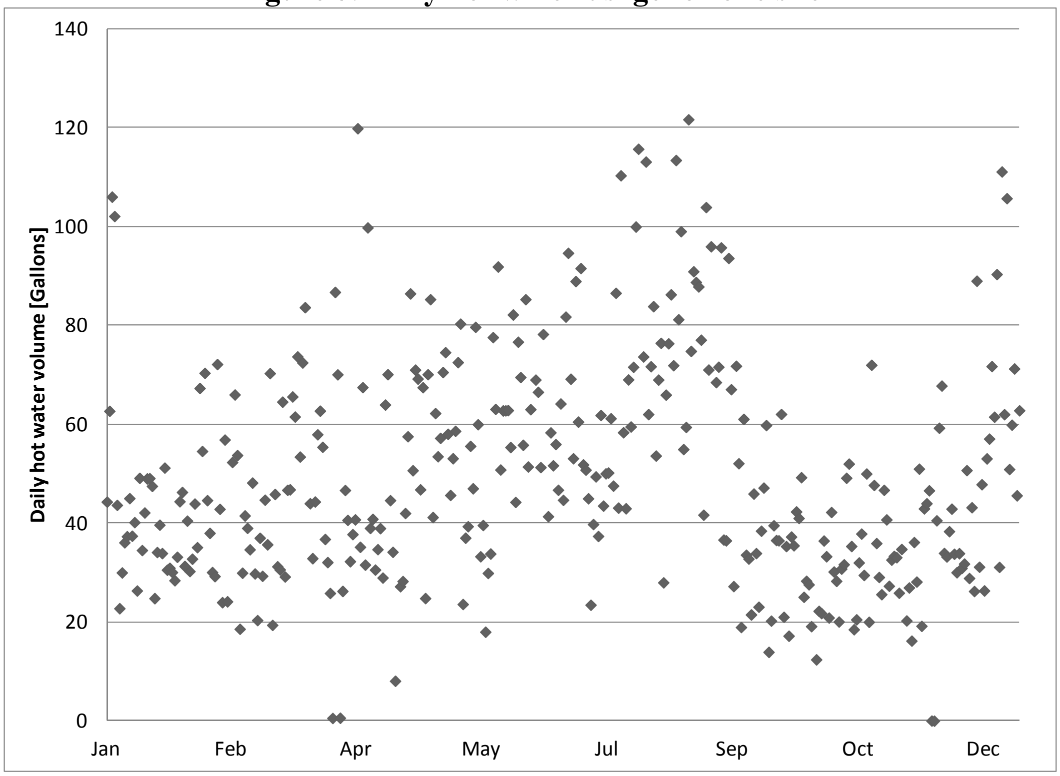
Users preferred tankless water heaters for their ability to provide steady temperature for single uses and to never run out of hot water. Tankless water heaters took longer to reach temperature, but once the temperature became steady it was consistent and very close to the set point. Storage water heaters have a temperature dead band, or a range of temperatures to which the unit is allowed to cool before its burner fires. When a storage water heater had been in standby for a long period of time prior to a draw, the water temperature was well below its set point. Therefore there was a much larger temperature difference from draw to draw with the storage water heaters. Figure 6 shows the draws from three water heaters set to produce 120 °F. Because the storage water heater had not fired recently, the TWHs produced water temperatures closer to the set point.

Homeowners in this project were given the option to keep either the tankless or the storage water heater. Nine of the ten homeowners chose the tankless water heater. The nine homeowners that choose to keep the TWHs either found that the behavior changes required by the tankless were ultimately unimportant, or the energy savings offset the operational changes. The single owner who kept the storage water heater was concerned that the TWH would not store forty gallons of drinkable water on site.

Hot Water Usage

The study measured hot water usage in great detail at each site (Schoenbauer et al 2011). As previously discussed, consumption was observed to differ significantly in both volume and pattern from the Energy Factor test methodology, and hot water volume affected TWH savings. There were additional concerns about the “take back” effect: that TWH users aware of the unit’s efficiency or ability to produce hot water without running out would increase their hot water consumption or would take the longer showers their storage water heaters could not provide. The project compared hot water usage with a storage water heater and a TWH water heater. None demonstrated a statistically significant change in hot water volume per day.

Figure 7. Daily hot water usage for one site

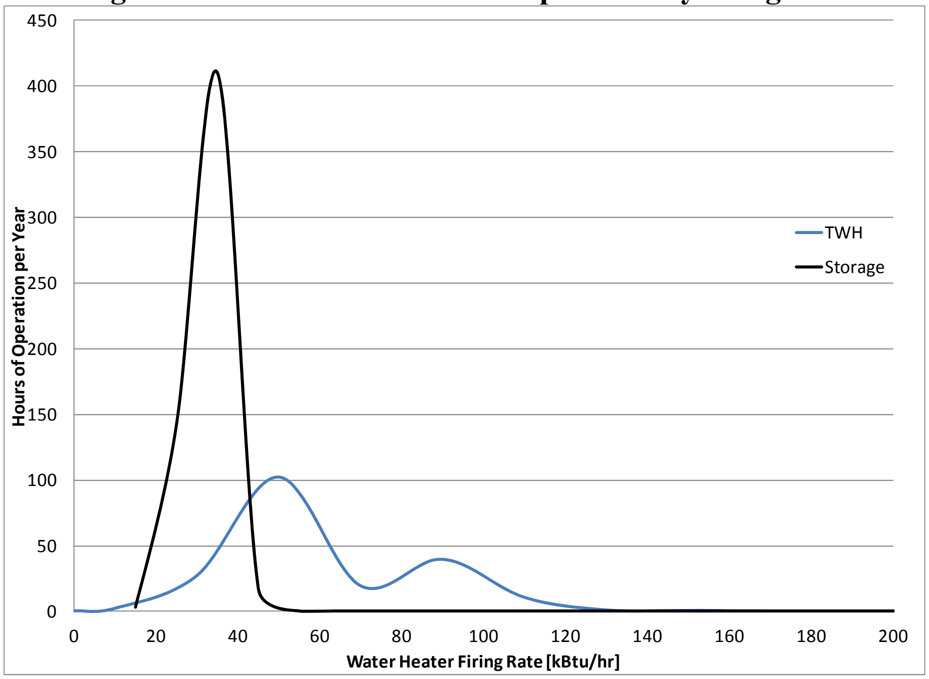


Even in a single house, hot water demand can vary drastically from day to day, as shown in Figure 7. While the study did not find a statistically significant difference in daily hot water volume, it did identify a difference in how hot water was used. Because TWHs require flow rates greater than some minimum amount (typically 0.4 to 0.6 gpm) the number of draws of less than 0.5 gallons per minute were reduced from around 10% of draws (with storage water heaters) to 4% with TWHs. On average, TWH draws were longer and at a high flow rate, and therefore had a greater volume. However, because TWHs had fewer draws per day, they did not change daily volume. Occupants indicated that they grouped several smaller draws into one longer draw with the TWH.

Impact of TWHs on Gas Distribution Systems

TWHs have much higher maximum input capacities that storage water heaters. Gas utilities may be concerned about the ability of the existing gas distribution system to support an area with numerous TWHs. However, TWHs only operated at a high firing rate for a small percentage of time. Figure 8 shows the hours of operation per year at various firing rates for both a TWH and a storage water heater at one site.

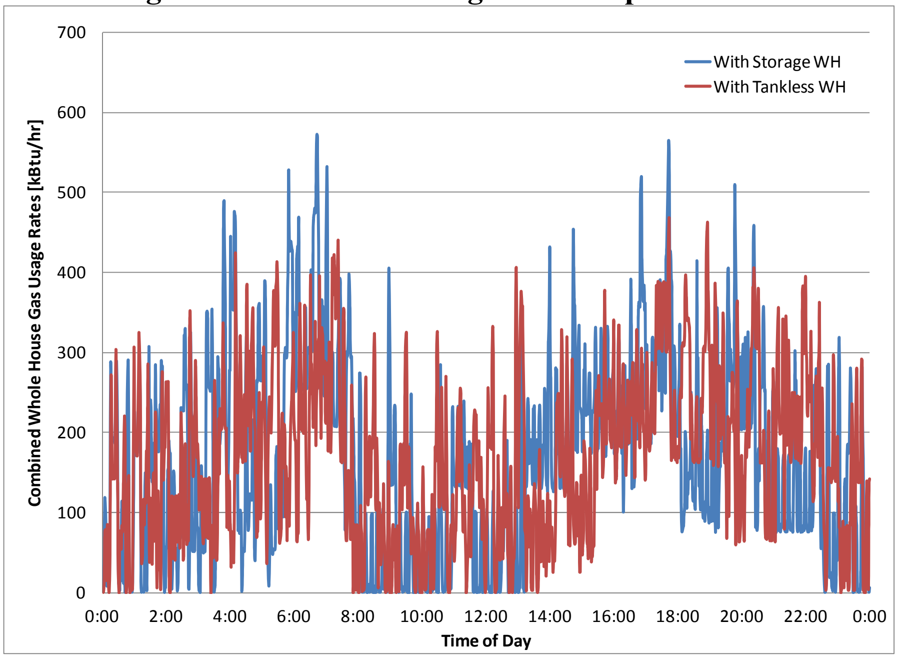
Figure 8. Water heater hours of operation by firing rate



Note: TWHs had firing rates of 20,000 to 190,000 Btu/hr and storage water heaters had firing rates of 40,000 Btu/hr.

TWHs operated at higher peak natural gas consumption rates than storage water heaters, but for a shorter length of time. If several TWHs were installed in the same neighborhood, the neighborhood's one minute consumption rates would not be increased when compared to the same homes using storage water heaters. Figure 9 shows the combined whole house gas consumption measured in five homes on a day with an average outdoor temperature of 0 °F with storage water heaters and TWHs. Whole house gas consumption was only collected at five of the ten homes, only gas consumption of the water heaters was collected at the other five homes. The storage water heater scenario has a higher peak, because its longer firing cycles cause the space heater and water heater to be firing simultaneously at more sites than those served by the TWH.

Figure 9. Average whole house natural gas consumption for 5 homes at 0 °F



Discussion

Endless capacity. Marketing for TWHs emphasizes their endless capacity to produce hot water. The ten sites recruited for this project did not seek out TWHs and showed no difference in use with tankless and storage heaters. Homeowner who specifically purchased a TWH may be more likely to use its endless capacity. This could result in increased hot water usage with TWHs.

Improvements for energy factor rating. Measured *in-situ* performance of water heaters has prompted both the Department of Energy and ASHRAE to improve the test rating procedure. Work is currently underway in both groups to develop a method for rating water heaters which more accurately predicts performance and savings for the range of water heaters available.

Implications for conservation programs. Several factors could improve the economics of TWHs. Programs that rebate TWHs in limited applications could have a great impact. Paybacks are more attractive in new construction or retrofits in which combustion safety necessitates a power vented water heater. Additionally, a large volume of installations may see costs go down. Contractors may be able to reduce costs over a large number of installations. Lots of installs would also make TWHs a more common job, and potentially reduce the premium status for many contractors.

Some TWH manufacturers claim they have 15-20 year lifetimes compared to the average storage water heaters lifetime of 10-12 years. This generation of whole house natural gas TWHs has not been installed long enough to confirm TWH lifetimes. If the claims are correct, their simple paybacks will be substantially lower since one TWH will last as long as 1¼ to 2 storage water heaters.

Providing both space and water heating with a single high efficiency appliance would reduce total equipment costs and is currently being examined in a follow-on project.

Conclusions

Tankless water heaters provided measured savings of 50 to 85 therms per year, a significant amount of energy. They produce hot water differently than storage water heaters, creating some changes in user behavior. These changes do not force users to increase hot water consumption. Homeowners considered TWHs' ability to provide endless hot water and their consistent and steady temperatures as performance benefits. Users disliked their delayed delivery time and need to increase flow for low flow operations. Most homeowners found the positives outweighed the negatives, and nine of the ten homes opted to keep the TWH.

The economics of TWHs are poor for retrofit applications where a conventional storage heater can operate safely. In these scenarios, TWHs will not pay for themselves in their lifetimes without significant reductions in installed costs or a major increase in natural gas prices. Homes with higher usage rates have improved paybacks. The economics of TWHs are more favorable for new construction and for retrofit applications where power vented water heaters are required to ensure adequate venting. In these applications, incremental costs for TWHs can sometimes be reduced to $0 and paybacks range from 0 to 18 years.

This research demonstrates the inability of the Energy Factor test to compare water heater performance for different technologies. The Energy Factor underpredicted savings for TWHs, projecting a 25% savings where a 37% savings was measured.

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