Pacific Gas and Electric Company

PY2008 Emerging Technologies Program

Application Assessment Report #0613

Laboratory Testing of Residential Gas Water Heaters

(San Ramon, CA)

Issued:	**December 2008**
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EXECUTIVE SUMMARY

A laboratory dedicated to water heating was designed and built at the PG&E San Ramon Technology Center. The overall goal of the water heater lab is to identify energy efficiency opportunities and verify the energy savings potential as related to both residential and commercial water heating systems.

The first phase of testing was conducted to evaluate the performance of residential gas water heaters under different load profiles. The objective was to generate information that could be used in the development of a new tiered rebate program for residential water heaters offered by PG&E.

The test apparatus was designed to meet the conditions of DOE test standards for water heaters. The capabilities of the lab were verified by running tests as defined by DOE. The six water heaters tested in this phase of testing were selected to represent the range of water heating technologies and their corresponding efficiencies currently available on the market.

The performance of the water heaters were also tested under load profiles selected to simulate high, medium, and low hot water usage households, as well as the hot water usage profile included in ASHRAE Standard 90.2 (Reference 1). The various hot water usage load profiles were obtained from the results of field testing previously conducted by the Gas Technology Institute (GTI).

Generally, all six water heaters demonstrated increased efficiencies with increased hot water consumption from the reduction of standby losses due to less time on standby. The Heat Transfer Products Phoenix modulating burner condensing water heater outperformed all of the other units, achieving the greatest efficiency at most levels of use. The average test results are included below in **Table 1**. (For a more thorough description of the table contents, refer to the description of **Table 8**, of which this is a subset.). Also, see **Table 10** for annual energy use estimates.

Table 1: Summary of Energy Factor / Thermal Efficiency Results

			Manufacturer Ratings		Average Energy Factor Results from Testing				
Manufacturer	Product Line	Product Description	Thermal Efficiency	Energy Factor	Energy Factor Test*	High Use (123 gal)	Med Use (57/68 gal)	Low Use (30 gal)	ASHRAE 90.2 Profile (52 gal)
Kenmore	Power Miser 6	Basic	-	0.59	0.571	0.651	0.577	0.443	0.541
A. O. Smith	ProMax+	Additional Insulation	-	0.62	0.580	0.661	0.565**	0.472	0.563
Bradford-White	Defender	Power Vent	-	0.66	0.612	0.674	0.605**	0.493	0.552
A. O. Smith	Cyclone	Condensing	90%	-	0.722	0.780	0.666	0.611	0.682
Heat Transfer Products	Phoenix	Modulating Condensing	94.8%	-	0.833	0.903	0.865**	0.786	0.816
Takagi	Flash T-H1	Tankless Condensing	92%	0.91	0.843	0.843	0.801	0.762	0.731

*Average of four tests
** Medium Use Test; only 57 gallons of water drawn

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INTRODUCTION

Background

Domestic water heaters consume a significant portion of the annual natural gas energy in typical homes, so it is important for PG&E customers to have the resources available to choose the best water heater for their needs. Water heating technologies have not evolved much over the past 70 years, and the standard storage natural gas water heater that dominates in PG&E's service territory remains very inefficient. Due to the dominance of inefficient systems for producing hot water and a lack of information regarding the energy impacts and availability of more efficient products, there exists a large opportunity for energy savings related to water heating. From this opportunity, new types of water heaters have been introduced into the market. Currently, there are a number of advanced water heater technologies showing up on the consumer market that claim to save significant amounts of natural gas, such as high efficiency tankless and condensing storage tank units.

Until now, the PG&E Mass Market program claimed savings for all units based on the Database for Energy Efficiency Resources (DEER), claiming only eight therms per unit installed. It is estimated that more efficient water heaters could save on average 50 therms/year per unit, but it depends on hot water usage and efficiencies of the water heaters considered. Results from testing found savings of up to 125 therms/year per unit for a high water usage household when comparing the Takagi TH-1 to the Kenmore PowerMiser 6, an example minimum efficiency heater regulated under California's Title-24. In the United States, 5.5 million gas water heaters are sold each year. There are about 10 million natural gas water heaters in California of which approximately six million units are in the PG&E territory. Ten percent of the stock is replaced each year. Some of the advanced water heaters have installation requirements that make only 10% of existing sites feasible while others can access a larger share of the market. For the PG&E territory alone, with a savings of 50 therms/year per site and a market penetration of just 10%, it is possible to save 30 million therms per year.

Research by PG&E and the California Energy Commission's (CEC) Public Interest Energy Research (PIER) program has raised questions about the actual performance of new water heaters available in the residential market. Most have Energy Factor (EF) ratings, but some do not; and PG&E sponsored research has raised the concept of a Load Dependent Energy Factor (LDEF). Energy Factor ratings may not capture the real world efficiencies of the water heaters, since variations in total daily hot water load and the hot water draw schedule change the efficiency dramatically. Different types of water heaters are impacted differently. In addition, most advanced gas water heaters use some electric power, and it is suspected that the Energy Factor may hide the true cost of operation for these systems.

In order to compare various types of water heaters, the PG&E Emerging Technologies (ET) program contracted with PG&E Applied Technology Services (ATS) to develop a water heater test laboratory at the San Ramon Technology Center. By simulating real-world conditions, the test facility can evaluate the actual energy savings potential of hot water heaters. The objective behind the residential natural gas water heater testing program is to enhance PG&E's Mass Market program by providing supporting data for promotional literature and to justify a possible increase to the current $30 rebate[*]. The goal is to create a tiered rebate program based on a system's rated efficiency, with the amount of the rebate for each tier linked to an average expected annual energy savings. If the advanced water heaters prove to have a significantly higher efficiency over the standard storage natural gas water heaters, rebates may need to be increased for these units to offset their higher costs. The testing work is involved with trying to relate the published water heater efficiency ratings to their annual energy consumption with typical use patterns

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[*] Qualifying gas water heaters have an Energy Factor rating ≥ 0.62 for storage tanks ≥ 30 gallons. See: http://www.pge.com/myhome/saveenergymoney/rebates/appliance/waterheater/index.shtml

(which is complicated by different rating factors depending on the heater size). The results should also be useful for helping consumers determine what type of heater would be the best fit for their needs.

This report describes the first phase of testing.

Prior Research

This is the first laboratory testing project regarding residential natural gas water heaters conducted within PG&E. This project builds upon the 2004 PG&E Emerging Technologies tankless water heater feasibility study, completed by Davis Energy Group, Inc. and updated in 2007, which assessed a possible incentive program for tankless water heaters. Another study similar to this project investigated the performance implications of hot water draw patterns on tankless gas water heaters: "Field and Laboratory Testing of Tankless Gas Water Heater Performance" (Included in Reference 8) conducted by the Davis Energy Group and sponsored by the CEC.

Objectives

The objective of the initial phase of water heater testing was to determine the load-dependent efficiency of six different water heaters by assessing their performance under various load profiles simulating high, medium, and low hot water usage households. The results from the study address the following:

- The use of Energy Factor or Thermal Efficiency as an adequate representation of actual efficiency
- Considerations for the development of a new tiered rebate program
- Selection of the most efficient water heater with regards to hot water usage (best match)
- Potential energy savings of more efficient water heaters

METHODOLOGY

Testing Standards

There are a number of different parameters to describe the energy performance of domestic water heaters and those that apply depend on the burner firing rate. For natural gas water heaters with a burner firing rate of 75,000 Btu/hr or less (which includes most residential systems), the applicable test standard is the USDOE Code of Federal Regulations 10CFR430, Subpart B, Appendix E (Reference 8). In this standard are procedures for determining the first hour rating and the recovery efficiency, plus a 24-hour simulated use test that gives the Energy Factor, and from which the "Energy Guide" label annual consumption is calculated. For systems with larger burners, the applicable standard is ANSI Z21.10.3 (Reference 4), which provides the method for calculating thermal efficiency in addition to regulations regarding their construction. According to the DOE standard, residential water heaters are rated according to three parameters, defined as follows:

- "*First Hour Rating* means an estimate of the maximum volume of hot water that a storage-type water heater can supply within an hour that begins with the water heater fully heated (i.e. with all thermostats satisfied). It is a function of both the storage volume and the recovery rate."
- "*Recovery Efficiency* means the ratio of energy delivered to the water to the energy content of the fuel consumed by the water heater." Standby losses are a minor component of this factor, and it is roughly equivalent to the Thermal Efficiency rating for large water heaters.
- "*Energy Factor* means a measure of water heater overall efficiency."

Energy Factor is not normally found on the yellow "Energy Guide" labels applied to residential consumer products, but it can be easily calculated from the reported annual energy consumption. The energy contained in the water drawn during the standard DOE test expanded to an annual basis is:

Delivered Energy = 64.3 gallons/day × 77°F rise × 8.3 lb/gallon × 1 Btu/lb-°F × 365 days/year
/ 100,000 Btu/therm
= 150 therms/year

The Energy Factor can then be found by dividing the labeled therms/year energy consumption into 150.

ASHRAE Standard 118.2 (Reference 2) currently lists most of the same information that is in the DOE standard, although with different adjustment methods for the Energy Factor. ASHRAE Standards serve as a path to try out different rating methods before they are adopted into the Federal standards.

Test Apparatus

To meet the objectives of determining how Energy Factor varies with draw pattern and usage, the test facility was designed such that the standard Energy Factor tests could be conducted. Thus, the guidelines in the DOE and ASHRAE standards were followed as to the construction of the individual water heater test stands (**Figure 2**). The objectives of the test also included side-by-side testing of different systems under the same environmental and load conditions, which meant multiple but identical test stands that draw from the same source of water. The lab was also constructed in a room with its own space conditioning system to achieve the desired consistent environment and not affect other spaces in the building.

Figure 1: Water Heater Test Laboratory

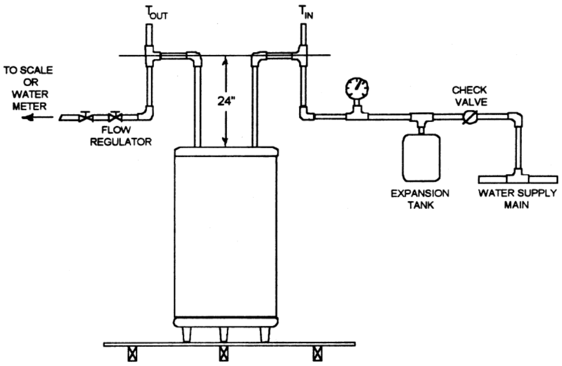

Figure 2: DOE Standard Test Stand

The conditions of the standard Energy Factor test also influenced the test apparatus. The standard Energy Factor test requires a water supply temperature of 58°F, which means a method of tempering the supply water to maintain that temperature was needed. Since the water draws are a short-term event process rather than continuous, the test apparatus was designed with a storage tank that was normally maintained with a supply of chilled water by an external chiller (**Figure 3**). The supply water is typically near room temperature because the line enters the room along the ceiling, which is usually higher than 58°F and needs to be cooled. Before entering the supply header to the test units, the water passes through a 3-way mixing valve to mix tap water with chilled water to achieve the desired supply temperature. The storage tank is actually an electric water heater, so that if a higher supply temperature is desired (e.g. to simulate a solar or other preheat system), the chiller can be turned off and the heating elements activated.

The testing standards recommend using a weigh tank to measure the quantity of water drawn from each tank, but in the interest of simplicity, space, and to enable automated testing, a single high-accuracy mass flow meter was used instead. (This is an accepted alternative in the standards). The outlet from each test water heater was controlled by a solenoid valve, and fed into a common outlet header. This header passed through the common flow meter, and then to an array of flow rate control valves (**Figure 4**). There were a set of four control valves in parallel (although only three of them were used during these tests), with each set to a different flow rate and activated by a solenoid valve at their outlets. The DOE standard flow rate for the Energy Factor, First Hour Rating, and Recovery Efficiency is 3 gallons per minute (gpm), so one of the valves was set to this flow rate. The other two were set to half and one quarter of this flow, such that by activating the individual solenoid valves, seven evenly spaced flow rates could be applied.

The installation of a water recovery system was considered as an option to conserve water used in testing rather then sending it down the drain. The cost of the water that would be saved is insignificant compared to the cost of installing the water recovery system (particularly considering the limited testing duration), and is not enough of an incentive for installing a water recovery system. There is also a trade-off between water conservation and energy use because water heater testing produces hot water and requires cold water at the inlet. The water recovered from testing would require cooling prior to reuse which requires energy and time. With the demands of the lab during testing, it would be difficult to wait for the water to be cooled. Considering every factor, installing the water recovery system was not feasible at this time. However, this will be re-visited in the future in light of other possible water needs.

Figure 3: Water Tempering System

Figure 4: Flow Control Valve Array and Mass Flow Meter

Measurements and Instrumentation

The measurements are mostly those required by the DOE test standard, and includes those necessary to measure the energy removed in a hot water draw (flow and temperatures in and out of the tank), the energy consumed by the water heater (gas and electric energy input), the change in stored energy in the tank (tank temperatures), and the ambient conditions (air temperature, humidity, and pressure). Additional measurements were needed for the feedback control system. The complete list of measurements and the instruments used for them is shown in **Table 9** in the Appendix.

Prior to testing, all of the RTD temperature probes were calibrated against a laboratory standard temperature sensor in an ice bath (32°F), a gallium melting point cell (85.6°F), and in a flask of hot water (~120°F). Pressure sensors were calibrated against a portable pneumatic calibrator.

Data Acquisition System

The instrumentation was connected to multiple rack-mounted Compact FieldPoint modules from National Instruments, depending on the signal type. The signal conditioning modules included different units for RTDs, thermocouples, voltage and pulse count (water and gas meters) inputs, plus both analog and digital output modules for the mixing valve and solenoid valves, respectively. Each rack includes an Ethernet communications module that enables the system to accessed from anywhere on the local network.

A local computer connected to the Ethernet network ran a program written in National Instrument’s LabVIEW graphical programming language. This program was developed to read all the measurement devices, display the readings and additional calculated values on screen, and save the data to disk for later analysis, as well as control the water draws and inlet temperature. The system was programmed such that only one water heater could be active and sending water through the common flow meter. The scan rate for sampling from the FieldPoint modules and updating the screen was set at 2 Hz, although the internal scan rate of the modules was 10 Hz.

The frequency at which data was averaged and recorded to disk depended on the status of the water heater. During a water draw, readings for the active water heater were recorded at the highest frequency; typically 5 seconds in accordance with the DOE test method, but often faster if more resolution was desired. When the water flow was stopped and the heater was still drawing energy (either showing gas flow or an elevated electric demand), the logging rate would be reduced to some multiple of the base frequency. Normally this multiplier was set at 3, resulting in a log rate of 15 seconds. Finally, when the heater was in standby (minimal gas flow or electric demand), another multiple of the intermediate rate was applied. Again, the normal factor was 20, which results in a log every 5 minutes. Separate log files were maintained for each water heater under test (since the log rate varied for each), plus and additional file for the environmental conditions and other slow parameters, which was updated at the standby log rate. A Microsoft Excel macro was created to combine these separate log files into a single workbook for analysis.

Test Conditions

Most of the test conditions for the Energy Factor test are defined in the DOE standard, and these are summarized in **Table 2**. In addition, the standard draw quantity is 64.3 gallons in six equal draws of 10.7 gallons. The Recovery Efficiency is supposed to be derived from the first of these draws during a standard Energy Factor Test.

Table 2: DOE Standard Energy Factor Test Conditions

Ambient Dry Bulb Temperature	67.5 ± 2.5 °F
Heater Inlet Water Temperature	58 ± 2 °F
Average Storage Tank Temperature	135 ± 5 °F
Water Flow Rate	3 ± 0.25 gpm
Natural Gas Supply Pressure	7 – 10 IW
Supply Water Pressure	40 PSIG - max spec
Line voltage	± 1% of spec

Test Procedure

The standard rating parameter tests were conducted in accordance with the methods described in the DOE test standard. In summary:

- *First Hour Rating:* One or more pre-draws are taken from the tank, which means releasing water until the main burner is activated. After the thermostat is satisfied and the burner shuts off, the average tank temperature is watched until a maximum is reached, and this number is recorded. A draw at 3 gpm is then initiated and marked as time zero. The draw continues until the tank outlet temperature drops to the recorded temperature less 25°F, at which point the flow is stopped. The burner is then allowed to bring the tank back to temperature, and after cut-out the cycle is repeated. At the end of one hour, if a draw is occurring it is allowed to finish according to the previous criteria. If a draw is not occurring, one is started and allowed to continue until the outlet temperature reaches the shut-off temperature from the previous draw. The first hour rating is the total volume of water released from the start of the first draw.
- *Energy Factor* is the result of a 24-hour simulated use test beginning immediately after the water heater is fully heated (burner cut-out after drawing enough to activate it). It divides a total draw

of 64.3 gallons of hot water into six draws each an hour apart, with the remainder of the 24-hours with the unit in standby. The Energy Factor is the energy in the hot water delivered with a 77°F temperature rise divided by the total energy consumed in the 24-hours. The calculation of the factor includes adjustments for off-standard test conditions and for the change in stored energy in the tank as the result of starting and ending the tests at different average tank temperatures.

- *Recovery Efficiency* is based on the ratio of the energy contained in the first 10.7-gallon draw in the Energy Factor test divided by the energy consumed to bring the tank back to the fully heated state (burner cut-out). Standby losses are a minor component of this factor, and it is roughly equivalent to the Thermal Efficiency rating for large water heaters.

The data acquisition and control computer was programmed to conduct tests automatically according to a script. At the start of a draw event, a bypass valve was opened at the end of the heater supply header, and the mixing valve was controlled to supply the proper water temperature to the header. Once the temperature criteria was satisfied at the bypass valve, the test heaters were activated in sequence starting from the unit closest to the bypass valve and working back along the supply header towards the tempering valve to ensure a consistent supply temperature.

RESULTS

Test Units

The water heaters selected for the first round of evaluation testing were selected to cover a wide range of configurations and efficiency ratings. Even with six test units, there remain some gaps in the varieties available, but the selections do show most of the progressive steps by which higher efficiency systems are developed. The units were selected based on the minimum that would meet the needs of a typical four-person household in California, which for tank-type systems meant a minimum 40-gallon capacity. **Table 3** below contains a summary of the specifications for the test units, and **Table 4** contains a listing of their rated performance characteristics. Following the tables are detailed descriptions of each water heater.

Table 3: Summary of Test Units

Manufacturer	Product Line	Model Number	Product Description	Build Date	Tank Capacity (gallons)	Dimensions (inches)	Condensing?	Ignition
Kenmore (1)	PowerMiser 6	153.336466	Basic	7/28/2006	40	55½ H × 18½ Dia	No	Pilot
A. O. Smith	ProMax+	GVR-40 100	Additional Insulation	4/10/2007	40	55½ H × 20½ Dia	No	Pilot
Bradford-White	Defender	M2TW50T6FBN	Power Vent	N/A (S/N: CJ8206265)	48	56▯ H × 22 Dia	No	Elect.
A. O. Smith	Cyclone	BTX-80 100	Condensing	9/26/2006	50	58 (2) H × 22 Dia	Yes	Elect.
Heat Transfer Products	Phoenix	PH130-55	Modulating Condensing	6/21/2007	55	52 H × 23 Dia	Yes	Elect.
Takagi	Flash	T-H1	Tankless Condensing	10/27/2006	Tankless	28▯ H × 18.9 W × 11.8 D	Yes	Elect.

(1) Made by A. O. Smith for Sears (2) A plastic cap that hides the blower adds another 10-inches in height

Table 4: Test Unit Rated Performance

Manufacturer	Product Line	Maximum Burner Input (Btu/hr)	First Hour Rating (gallons)	Thermal Efficiency	Energy Factor	Energy Guide Label (therms / year)
Kenmore	PowerMiser 6	35,500	62	-	0.59	254
A. O. Smith	ProMax+	40,000	71	-	0.62	242
Bradford-White	Defender	67,000	108	-	0.66	227
A. O. Smith	Cyclone	76,000	123	90%	-	-
Heat Transfer Products	Phoenix	130,000	205	94.8%	-	-
Takagi	Flash	199,000	-	92%	0.91	164

Kenmore PowerMiser 6

A. O. Smith ProMax+

Bradford-White Defender


A. O. Smith Cyclone


Heat Transfer Products Phoenix


Takagi Flash TH-1

Kenmore PowerMiser
California's 2007 Title-20 Appliance Efficiency Standards (Reference 5) and 2005 Title-24 Residential Compliance Manual (Reference 7) both list the same minimum Energy Factor for small water heaters. This is the minimum that a water heater must achieve to be legally sold in California, and is given as a function of rated storage volume. A subset of the standards listing just the gas-fired systems is shown in **Table 5**. (Instantaneous water heaters are classified as ones with an input rating of at least 4,000 Btu/hr per gallon of storage, and includes most tankless.)

Table 5:
California Efficiency Regulations for Small Gas-Fired Water Heaters

Type	Size	Minimum Energy Factor (EF)
Storage	≤ 75,000 But/hr	$0.67 - (0.0019 \times V^{*})$
Instantaneous	≤ 200,000 But/hr	$0.62 - (0.0019 \times V^{*})$

[*] V is the storage volume in gallons

The minimum Energy Factor allowed in California for the minimum storage volume chosen for this test program (40 gallons) is then 0.59. Thus, it was decided to include a system with this rating to provide a baseline for comparing against higher efficiency systems.

The selected minimum efficiency unit chosen was a Kenmore PowerMiser 6. This system is commonly available at most Sears and Orchard Supply Hardware stores, and is probably representative of the most common variety of water heater installed in single-family residences. (Actually it's better, because lower standards applied in the past.) This system is manufactured by A. O. Smith for resale by Sears.

A. O. Smith ProMax+
The investor-owned gas utilities in California (including PG&E) all have a small incentive available for more energy efficient products than what the State requires. The minimum efficiency required to qualify for the incentive is a rated Energy Factor of 0.62. (Coincidentally, this is the initial minimum efficiency to qualify as an EnergyStar™ product when it rolls out in January 2009.) Thus, the second test unit would be one that achieved this minimum efficiency.

The system chosen is an A. O. Smith ProMax+ unit of the same 40-gallon volume as the baseline Kenmore. As both products are built by A. O. Smith, their construction and burner controls are virtually identical, although this product has a slightly higher burner firing rate (40,000 Btu/hr versus 35,500). The one obvious difference between the two is that the A. O. Smith is 2-inches larger in diameter than the Kenmore. This suggests that the method by which the Energy Factor was improved for this system was by adding another inch of insulation around the tank.

Bradford-White Defender

The initial EnergyStar™ minimum efficiency of 0.62 is set to last only until September 2010, when it is scheduled to be increased to 0.67. Thus, the next system chosen would be one that achieves about this level of efficiency. There are very few products at this level, and A. O. Smith has many of them; but it was decided to choose a different manufacturer for variety. The Bradford-White Defender actually has an Energy Factor rating of 0.66, but it is suspected that some minor adjustments may be made to bring it up to the new EnergyStar™ level.

The incremental improvements to achieve the higher efficiency include adding electronic ignition to eliminate the standing pilot light, and a power vent with damper to reduce stack loss when the system is in standby. The power vent fan also mixes outside air with the flue gases to cool them enough to use PVC as an exhaust pipe. Because this may cause the flue gases to drop below the dew point, the fan also includes a condensate drain.

A. O. Smith Cyclone

As more heat is drawn from the products of gas combustion, eventually the temperature will be lowered to the point where the water vapor will begin to condense to a liquid (dew point). Continued cooling releases the latent heat of vaporization from the water, which is a valuable energy resource. Unfortunately, this condensate is usually corrosive and most water heaters are designed to prevent this from happening and causing damage to metal flue parts. However, as natural gas has become more expensive, many manufacturers are looking into capturing this available energy. These water heaters will have much higher costs due to the need to use materials that resist corrosion and additional heat exchange surface area.

The tested A. O. Smith Cyclone BTX-80 is actually a commercial product, but is virtually identical to their Vertex GPHE-50 residential unit (which is also branded as the State Premier GP6-50). It uses an open bottom-fired burner like the previous systems, but the center flue only goes up about ¾ of the way into the tank. At this point, it splits into several smaller tubes that spiral back down towards the bottom (hence the Cyclone name) before they recombine and exit through a side vent. The descending path creates counter-flow heat exchange with the water in the tank, where the coolest water at the bottom is in contact with the coolest exhaust. The condensed liquid water from the flue gas is separated out at the bottom of the side vent and plumbed to a drain, and the cool exhaust vapor is drawn upwards using a power vent. The power vent becomes more essential with this type of heater because the cool exhaust does not create the same stack effect to drive flow. This is an advantage more than a problem, because there are virtually no stack losses while the system is in standby. This unit also included a muffler to reduce the outlet noise associated with the fan.

Heat Transfer Products Phoenix

As the water heater appliance becomes more and more efficient, and if the burner size is large enough, it becomes economical to use it for hydronic space heating as well. This product is designed specifically for this dual role (although the previous two systems are also equipped with side taps to provide some space heating or for a hot water recirculation loop). Unlike all of the previous systems that had constant firing rate burners, this system has a modulating burner to provide only as much heating as is necessary for the current demand. Rather than an open burner on the bottom of the tank, a forced-draft burner is located at the front of the tank and discharges into a chamber in the center. Like the Cyclone, the exhaust leaves the top of the central chamber in several tubes that spiral down around the chamber, but in this system exit the tank at a point actually below the burner. With the thermostat located high in the tank, the water remains stratified with hot water at the top and very cold water in the bottom to improve the counter-flow heat exchange and extract more energy from the combustion products. With all stainless-steel construction of the tank and combustion surfaces to avoid corrosion from the exhaust condensate, there is no need for the sacrificial anode rod that all of the other storage tank systems have. Like the burner, all of the water taps to the tank are also through the side. This has eliminated any penetrations through the top of the tank where much of the heat is lost in conventional water heaters. (Particularly considering that the water pipes at the top of conventional water heaters can act as cooling fins or heat pipes.) The lack of top penetrations and a bottom burner allows this system to reach a level of tank insulation unavailable in conventional construction, resulting in very low standby losses.

Takagi Flash TH-1

Although the other systems showed progressive improvements to reduce standby losses, so long as there is a stored volume of hot water, there will be some heat losses and extra energy used to maintain the water temperature. One approach to reducing the standby losses is to eliminate the tank altogether. There have been recent developments and an upsurge in popularity in whole-house tankless water heaters that produce hot water on demand. These systems require very large capacity burners to meet full flow, and sophisticated controls to modulate the burner firing when the flow is less. In addition to the attractiveness of unlimited hot water, these systems also have the advantage of compact size.

The Takagi TH-1 is a high efficiency example of this type of water heater. Although most of the tankless products available on the market are non-condensing (like most conventional water heaters), this is a recent development that increases the heat transfer area to achieve flue gas condensing. This product also includes an internal tempering valve to allow the burner system to overheat the water under low flow and temper it down to the proper outlet temperature.

First Hour Rating

The First Hour Rating is calculated as the total volume of useful hot water extracted during an approximately one-hour test. At the end of one hour from the start of the first draw, if a draw was not occurring and had to be initiated, the volume of the final draw is multiplied by the ratio of the difference between the average outlet temperature of the final draw and the minimum outlet temperature of the previous draw to the difference between the average and minimum outlet temperatures of the previous draw. This value is then added to the other draw volumes to determine the First Hour Rating. If a draw did have to be initiated and did not extend beyond 30 seconds, typically the water heater did not have time to recover from the last draw so the average outlet temperature was low. Therefore, there was not a significant impact on the first hour rating.

The first hour rating test was conducted three times on each heater and the ratings were consistent. The results of the first hour rating test are found in **Table 6**. The Department of Energy does not specify first hour rating test procedures for tankless water heaters, or "instantaneous water heaters" as described by DOE, because of their characteristic continuous supply of hot water. Therefore, the Takagi Flash T-H1 was not tested.

Table 6: First Hour Rating Results

Manufacturer	Product Line	First Hour Rating (gallons) Manufacturer Ratings	First Hour Rating (gallons) Measured*
Kenmore	Power Miser 6	62	65
A. O. Smith	ProMax+	71	70
Bradford-White	Defender	108	90
A. O. Smith	Cyclone	123	147
Heat Transfer Products	Phoenix	205	178

The first hour rating results for the Bradford White Defender, A. O. Smith Cyclone and the Heat Transfer Products Phoenix were very different from the manufacturer's values. The largest divergence is seen with the Phoenix. Although the first hour rating test calls for draws of three gallons per minute, which limits the total volume to 180 gallons per hour, the manufacturer of the Phoenix provides a first hour rating of 205 gallons. Because of its high burner capacity, at three gallons per minute the Phoenix never reached the minimum temperature and ran the entire hour. Three gallons of hot water per minute at a temperature rise of 77ºF is equivalent to 115,000 Btu/hr and does not exceed the burner's capacity of 130,000 Btu/hr. In theory, with a burner capacity of 130,000Btu/hr, the burner could meet the demand of hot water drawn at a rate of almost 3.4 gpm, which is the rate at which the manufacturer generated the first hour rating of 205 gallons.

The cause for the discrepancy between the first hour ratings of the other water heaters is unclear. However, the procedures of the first hour rating test leave room for significant variances in ratings. Most evidently, the first hour rating test is not a one-hour long test due to the process of either continuing or initiating a draw at the end of the hour. In some cases, a draw could begin seconds before the end of the hour and continue until way beyond 30 seconds, and the entire volume of the draw would be included in the first hour rating. In contrast, if a draw was initiated at the end of the hour and did not reach the minimum before 30 seconds, the volume is not included. Comparing the runs for each water heater individually and looking at the start and stop times of the draws, although similar, they were never consistent which could lead to different ratings.

Another downside of the first hour rating is that it does not present very useful information for the consumer because it only represents the quantity of hot water provided in one hour, but does not explain when it will be available or how many draws are included. A test that monitors a single draw at a certain flow rate to determine the quantity of hot water delivered before it reaches the minimum outlet temperature and notes the recovery time once the draw is terminated would be more telling. Evaluation of this testing procedure is beyond the scope of this project, as it does not directly relate to energy efficiency.

Load Profiles

The objective of the test program was to test the daily efficiency of different types of water heaters under different load profiles, and compare the results against what is produced through the DOE standard Energy Factor test. Thus, the first step was to put the units through a standard Energy Factor test to determine a value for the particular test units. This removes some of the uncertainty that would be produced if the results were just compared with the manufacturer's listed ratings. In addition, half of the test units do not have an Energy Factor rating because of their burner capacity. Running the standard tests was also a way to gain testing experience with the new apparatus. In the Appendix, **Figure 5** shows the draw profile for the DOE standard test for comparison with the other profiles. (The time scale is a 24-hour duration, and not absolute time; it does not have to start at midnight.)

The results from the DOE standard Energy Factor tests were expected to be lower than the manufacturer's ratings. The main reason for this is that this was to be a test of "off-the-shelf" units that were not tuned in any way to maximize their performance. The test standards do allow the burner firing rate to be adjusted to within 2% of the manufacturer's specification, but this was not done. The listed firing rate is based on a natural gas higher heating value (HHV) of 1050 Btu/scf. The local natural gas is typically about 1020 Btu/scf, which is about 3% below the basis. The effect of this is an increase in the recovery time to heat the water in the tank, and a lower combustion chamber temperature, which can affect the heat transfer rate to the water.

There are not many studies of hot water usage for residential homes that provide practical high-resolution data representative of actual households. Many of the studies offer average use data in hourly bins, but the greatest challenge is in defining what is typical. Hot water usage varies dramatically not only based on the size of the home, location, and number of occupants, but also based largely on the demographics of the household. For example, a household with children and a non-working parent would typically use more hot water than working adults that spend less time at home, do less laundry, and take shorter showers. A home using more water efficient appliances, such as front-loading washer machines, would reduce hot water usage. Varying the load profile could have an effect on the water heater efficiency. Due to the many factors that influence hot water usage, it is difficult to generalize energy savings potential by using average profiles.

For the purpose of water heater performance testing under various load profiles, it was necessary to obtain high-resolution hot water usage data of actual homes. The Gas Technology Institute (GTI) conducted a field test in 2007 of twenty-nine sites that utilized a new natural gas condensing water heater in a combination space and water heating system. The sites represented five different climatic heating-design zones located in the states of Washington, Oregon, Oklahoma, Alabama, Florida, and the province of Ontario, Canada. The homes included 93 people of varying demographics. With regards to collecting domestic hot water usage data, GTI monitored the water heater inlet and outlet temperatures, and the hot water flow. Data were recorded every 15 minutes while in standby, and every 30 seconds during hot water draws.

From this data, GTI provided PG&E with actual hot water usage data of seven consecutive days for three different homes representing high, medium, and low usage households. The data listed the gallons of domestic hot water drawn at 30-second intervals. On average, the high usage household used 104.7 gallons/day, the medium usage household used 67.4 gallons/day, and the low usage household used 30.3 gallons/day. One characteristic day from each home was selected to run performance tests. The three 24 hour load profiles were each programmed to run automatically using the event schedule in the control computer to initiate draws on the six water heaters consecutively. Each draw opened the flow control valves for a set duration to best simulate the draw's flow rate and volume of hot water derived from the GTI profiles. The GTI profiles are shown in the Appendix as **Figure 6**, **Figure 8**, and **Figure 10**, and the performance testing profiles derived from the characteristic day are shown as **Figure 7**, **Figure 9**, and **Figure 11**. The test profiles show the draw start, duration, and flow rate as a profile in blue, while the total quantity drawn for each event are shown as red dots.

Another popular hot water usage profile is included in ASHRAE Standard 90.2 (Reference 1). This profile is based on hourly totals for several residences averaged together, and is not representative of the actual use for a single house. Its use is primarily for modeling the energy demands for design purposes. Despite this, another draw profile was created based on this usage. The profile as given in the ASHRAE Standard is shown in **Figure 12**, and the input profile derived from it is shown in **Figure 13** using the total daily draw amount from the standard DOE test. Rather than having single draws at the start of each hour like the profile might indicate, the draws were split up into 30- or 15-minute windows when the total quantity for the hour was more than 2 gallons.

Figure 14 gives a statistical bin analysis view of the draws from each of the profiles. In each chart, the bins showing the maximum gallons per draw are listed along the horizontal axis. The plots show both the fraction of the total number of draws taken in each bin, and also the fraction of the total volume. This shows that while there may be a large number of draws taken at low quantities, they do not necessarily add up to a large fraction of the total. The total draw volume and number of draws are also given.

Load Profile Test Issues

In practice, the planned profiles were not always implemented as planned, and were not always consistent across the six test units. Part of this is the result of the learning curve in operating the testing apparatus according to a very complicated draw structure in relation to the relatively simple DOE profile, and many factors can be corrected in the future. The DOE profile consists of a low number (6) of equal draws at a constant flow rate and separated by equal intervals. The more realistic profiles vary each one of these, and getting a consistent result is much more difficult. Some of the problem areas are as follows:

1. Extra draw quantity: The control computer runs flow through each heater until the specified quantity is reached, and then signals the solenoid valves downstream of the flow control valves to close. There is some delay inherent with the half-second scan rate, and the solenoid valves do not react instantaneously, so some additional amount is passed after the end of the real draw. This was first noticed in some trial Energy Factor runs, and easily compensated for by reducing the draw amounts by an equal fraction (~2%). The other draw profiles are not as easily adjusted because of the higher number of draws, and the often higher fraction of the particular draw amount.
2. Flow rate drift: The flow control valves were usually set before the start of each test to specific expected values (0.75, 1.5, and 3.0 gpm; the fourth valve was not used during these tests). While generally stable, the valves have shown a tendency to drift slightly with changes in temperature. This means that the expected flow rate was not always achieved, although the 3.0 gpm draw for the Energy Factor tests was usually within the DOE specified range. Since the draw control is based on a specified volume, a draw could take more or less time than expected if the flow rate was different.
3. Draw sequence overlap: The DOE test procedure is only concerned with testing one heater at a time, while in this project the plan was to evaluate six units side-by-side in sequence. Each DOE draw is 10.7 gallons at 3 gpm, which would take 3.56 minutes for each heater. Thus, sequencing six heaters, plus additional time padding to capture the extra flow after the valve closure, will take about a half hour. With the draws spaced an hour apart like in the DOE procedure, this is not a problem. It does become a problem when the draw events are both long and frequent. After developing the planned draw profiles, it was soon discovered that not all six heaters could be sequenced without overlap. (If a draw event is still running when another event is scheduled to occur, then that second event will not happen.) The result of this finding was that the heaters were usually split into groups of three in order to follow the profiles better.
4. Inconsistent idle time: When the draw quantities and start times are variable, then the idle time between draws can vary between heaters. For example, at Hour 1 the heaters are run through a draw event of 5 minutes each; if at Hour 2 another sequence is started with draw events of 10 minutes each, the first heater will start its draws one hour apart, while the sixth heater will start its draws 1 hour and 25 minutes apart. Thus, while the number, volume and duration of each event may be the same, the spacing will be different and the heaters will not follow the same profile. A way to compensate for this is to pad each draw event with time delays when no flow is happening, and apply a constant event duration throughout the sequence.

Figure 15 shows the total daily gallons drawn from all of the long-term tests performed for this project. As shown, there were multiple tests conducted for each profile to help with consistency. (This was also the result of programming a test sequence on a Friday such that there would be two completed test days by Monday.) The chart shows the 24-hour draw quantity for each individual heater, and also shows the target quantity that was programmed into the sequence. The five DOE Energy Factor tests showed consistent results and were all well within the tolerance band set by the standard. (The fifth test was a special case run just for the tankless unit, because the DOE standard specifies that the first three draws be done at its maximum flow rate, and the second three draws be done at the minimum flow rate that will cause its burner to fire.)

Some of the identified problem areas are apparent in these results. The first high usage profile run was attempted with all six heaters, which resulted in the sequence overlap problem and a lower than planned volume. The subsequent high usage profiles were done in groups of three, with two test runs for the first group (ProMax, Cyclone, Takagi), and one test run for the second group (Kenmore, Defender, Phoenix). Most of the other tests show indications of the extra flow at the end of a draw with totals exceeding the target. The volume for the first group in the first medium usage profile test is low from a combination of the flow setting drifting low and the resulting increased overlap. For the tests done at the 90.2 profile, an attempt was made to compensate for the inconsistent idle time between draws, but the result was an increase in the event overlap due to flow rate drift and far fewer draws than planned (36 out of 48). The drawn quantities within each test group were all relatively consistent as the result of running the same operation script and flowing through a common flow measurement device. This was a goal for the test program to achieve comparable results.

The other major factor in determining the amount of hot water delivered is the outlet supply temperature. The inlet temperatures to each heater were all relatively consistent since they were fed from a common header that was pre-flushed with water tempered to the design specification. The outlet temperature varied with each individual heater's thermostat setpoint, and the time since the burner shut off after the previous recovery. The DOE standard is lenient as to the outlet temperature, allowing it to fall inside of a 10°F window around 135°F, although this is actually specified as an average tank temperature and not as an outlet temperature. (This creates a problem for the Phoenix because of its highly stratified tank.) The Kenmore, ProMax, and Defender units all have analog (knob) control over the thermostat setpoint, and these were easily adjusted to achieve the desired condition. The Phoenix has a sophisticated digital control, to which a numeric temperature value can be entered. The actual outlet temperature was often higher than the entered value, however. Both the Cyclone and Takagi have digital controls with specific setpoints selected by switches. Unfortunately, the selections are few and spread far apart, and the closest to 135°F for each was around 140°F.

Figure 16 is a chart of the total hot water energy drawn, which combines the flow volumes shown in Figure 15 with the temperature rise across the heater. The results from the Energy Factor tests show more variability than the drawn volumes would indicate, but they are still within the DOE standard tolerance (as calculated based on the allowed tolerances for volume and inlet and tank temperatures). Other than the thermostat setpoint, there are a couple of other problem areas that occur with the non-standard usage patterns:

1. The ¼-inch RTD probes used for the water temperature measurements respond fast enough for the DOE standard test, but may be too slow for draws with short durations. The DOE test procedure says to ignore the temperature readings for the first 15 seconds of the draw, and average the readings from this point until the draw conclusion. This cannot be done for draws of less than a minute without incurring significant error. The values in the chart are all based on using flow-weighted-average temperatures beginning from the start of the draw. (A flow-weighted-average is found by summing the product of the measured average temperature and flow quantity for each interval in the draw, and then dividing by the total volume.) A slow responding sensor imparts its own error and undervalues the energy draw.
2. Tankless water heaters (like the Takagi) create a unique situation with the low flow rate draws since there is a minimum flow rate required for to activate the burner. For this unit, this low limit was measured at about 0.83 gpm, which is higher than some of the draws using the lowest range control valve. Thus, there were a few draw events when the unit did not produce any hot water,

resulting in a lower delivered energy than the other systems. In practice, this may actually be an advantage, since if the low flow rates are also low duration events (like opening a sink faucet to wash hands), then the hot water would probably not reach the end use anyway and any drawn hot water would thus be wasted.

Energy Factor

The simplest interpretation of the Energy Factor is the daily hot water energy output divided by the total energy consumed (with the natural gas volume and any auxiliary electrical consumption converted to a Btu equivalent). The DOE and ASHRAE testing standards include alternative procedures to correct the measured test results to the standard volume and temperature conditions, and to compensate for changes in the stored energy (as the result of the average storage tank temperature being different at the beginning and end of the 24-hour period). These procedures are designed to be applied to the limited number of draws in the standard test method, and are not easily applied when there are more frequent and shorter draws. Thus, for most of the following discussion, the simple, uncorrected version of the Energy Factor is discussed.

Figure 18 through **Figure 23** show the measured Energy Factor results for each of the water heaters individually, to show how each one is affected by the different load patterns. The values are also listed together in **Table 8**. The DOE standard Energy Factor tests are shown first on the left side of the charts and include the simple, uncorrected value plus the results corrected according to both the ASHRAE and DOE procedures. For the majority of cases, the corrections do not change the results by much, indicating good conformity with the standard conditions. However, the DOE standard procedure was not followed exactly. The standard procedure is to start the 24-hour simulated use test immediately following burner cut-out after a removing a volume sufficient to cause the burner to start. This is intended to leave the heater at what should be a consistent starting point (as set by the thermostat). The procedure used here was to run tests automatically over more than one day, with the goal of having the condition of the storage tank (average temperature) be relatively close at the beginning and end of the 24-hour period. This may be a better method since there should then be little correction needed for the change in stored energy.

For the first three heaters, their rated Energy Factor is shown as a line above the measured results. As previously discussed, the test results were expected to come out less than the rated numbers because there would be no adjustments made to the off-the-shelf units. This turned out to be the case, but the difference was not too large (about 4% low for the Kenmore and ProMax, and 8% for the Defender; measured as a fraction of the rated Energy Factor and not as an absolute difference).

The right side of the charts show just the simple, uncorrected Energy Factor derived from the non-standard draw profiles. As an upper limit, the average recovery efficiency derived as part of the standard Energy Factor tests is shown as a line. This may be considered an upper limit, since it represents the ability of the unit to transfer heat from the burner to water. The difference between the recovery efficiency and the measured Energy Factor is mainly due to standby heat losses. Since the standby loss through a day’s time is relatively constant (depending on the stability of the difference between the average tank temperature and the ambient air), it represents a smaller portion of the total energy consumed as the draw amount increases. Thus, systems that have larger standby losses will show a larger difference between the high and low usage profiles than systems with low standby loss.

For the three larger units, their rated thermal efficiency is also shown along with the measured recovery efficiency. These results should be roughly equivalent, although the exact procedure for calculating the thermal efficiency according to the ANSI standard was not researched. The interpretation is that thermal efficiency is a steady-state measure, while recovery efficiency is event based (draw 10.7 gallons, and measure the energy consumed until burner cut-out).

The Phoenix presented some interesting effects as the result of its utilizing temperature stratified storage. It already created issues with following the DOE standard procedures, because setting the prescribed average tank temperature of 135°F would create an unreasonably high outlet temperature. The stratification created a large variation in the calculated stored tank energy, and correcting the Energy Factor results according to the standard test procedures usually resulted in a larger difference from the simple value than the other systems. The results from testing under the different load profiles showed mostly better performance than with the standard Energy Factor test, even for the tests with less total draw volume. The reason for this is that in the standard test, the unit sits idle for almost 19 hours following the sixth draw, and the tank thermal stratification begins to break down due to conduction through the water and the internal heat exchanger. As the thermal energy is redistributed through the tank, the upper part of the tank cools to the point where the thermostat acts to activate the burner. For most of the standard Energy Factor tests, the burner was activated twice over the course of the long idle period. (The unit was also unique in that it had enough storage capacity such that for at least one of the six 10.7 gallon draw events the burner was not activated.) Because of the structure of the standard DOE test, the energy consumed because of the thermal redistribution is viewed as a standby loss, while it is actually mostly a stored energy gain. In the non-standard profile tests, the draws are distributed throughout the 24-hour period, and the tank stratification is not given a chance to break down.

The energy efficiency of a water heater is the combined effects of how well it heats the water that is used (recovery efficiency) and how much is used to compensate for heat losses to the environment (standby loss). Thus, as the daily draw amount increases, the overall efficiency of the system should also increase. This effect is examined graphically in **Figure 24** and **Figure 25**. The first of these is based on the total volume drawn (corresponding to the amounts in Figure 15), and the second is based on the total energy content of the water drawn (as in Figure 16), which is also the numerator of the simple Energy Factor. All of the efficiency trends approach zero as the total draw amount goes to zero. The results show an ordering of the six water heaters that actually does correspond to their respective energy ratings, even with the difference between thermal efficiency and Energy Factor.

Annual Cost of Operation

Energy efficiency rebates must be based on an average energy cost savings over a baseline system. How much a system costs to operate will vary with the local energy costs, which also can vary over time. For the cost analysis, representative energy cost values were drawn from online PG&E rate statements. Natural gas rates are relatively volatile due to deregulation of the commodity, and a value of $1.50/therm was derived from a historical average over the first five months of 2008 for the GNR-1 residential rate. For electricity, a value of $0.165/kWh was taken from the “average” total rate for the E-1 residential schedule effective May 1, 2008.

The energy consumed through all the tests is summarized in **Table 10**. The measured daily consumption values have been converted to an annual equivalent by multiplying by 365. However, no correction has been made to adjust the consumption to a consistent hot water load across each test (correction for temperature and volume differences), so system comparisons are rough. The table first gives the manufacturers’ performance ratings, including the “Energy Guide” label estimated annual usage when available. In each group, which are averaged values from all the tests conducted under the listed test profile, the energy use is given first as the gas consumption in therms (standard gas volume multiplied by the gas higher heating value), then the kWh of electricity used, and then the total energy input after the electrical energy has been converted to a therm equivalent. It is this column under the Energy Factor test results that should be compared against the listed “Energy Guide” value.

The estimated cost for this energy is listed in **Table 11**, and shown graphically in **Figure 17**. The previous discussions about the amount of hot water produced must be taken into account. For instance, while the tankless unit shows significantly lower operating cost across the tests, some of the reason behind it for the non-standard profiles is the result of operating below the minimum flow threshold and not actually producing any hot water or consuming energy. In addition, these results also reflect the differences in the thermostat setpoint and the resulting outlet temperature, as they have not been corrected or normalized to a consistent hot water draw amount.

The initial thought was that the reported Energy Factor numbers for advanced water heaters may disguise the true cost to operate a water heater because the electrical energy used to operate auxiliary equipment is simply converted to a Btu equivalent, ignoring the fact that those Btus cost more than the Btus from the natural gas. While partially true, the results show that the electrical energy cost is a relatively insignificant portion of the total cost to operate. It is apparent from Figure 17 that the Phoenix unit had the largest power usage of any of the heaters. This is not the result of the power consumed while the system was operating, which was actually the lowest of all the heaters that require power. It is mainly the result of a high standby power, and is suspected to be mainly due to a numerical LED display of tank temperature. The system could be improved by only activating this display as requested and turning it off after a period, or by using a lower power display (e.g. LCD).

Table 7 below gives a summary of the energy consumption rates measured for the different heaters, including the average burner firing rate in relation to the rated value. The Kenmore and ProMax both have pilot lights that run continuously, resulting in a burner firing rate during standby. The energy from the pilot light is not all lost and actually keeps the tank warm during standby, which reduces cycling. The other water heaters have electronic ignition and components that require electricity such as the power vents of the Cyclone and Defender and the forced-draft burner of the Phoenix. The Cyclone did not use any measureable power when the burner was off. In the case of condensing water heaters, some systems may require a supplemental condensate pump resulting in additional energy use that was not considered in this phase of testing.

Table 7: Summary of Energy Consumption Rates

	Rated Maximum Burner Firing Rate (Btu/hr)	Average Measured Burner Firing Rate (Btu/hr)	Pilot Firing Rate (Btu/hr)	Average Measured Power Use Burner On (W)	Average Measured Power Use Idle (W)
Kenmore PowerMiser 6	35,500	32,960	440	-	-
A. O. Smith ProMax+	40,000	36,640	470	-	-
Bradford-White Defender	67,000	62,170	-	165	1
A. O. Smith Cyclone	76,000	68,880	-	141	0
Heat Transfer Products Phoenix*	130,000	41,810	-	37	16
Takagi Flash T-H1*	199,000	134,430	-	60	6

* Units with modulating burners; results are averaged from the Energy Factor tests only.

CONCLUSIONS

In this test program, an apparatus was designed and operated to perform side-by-side comparison testing of various types of natural gas water heaters. The testing was a learning experience for the challenges involved with testing under more realistic load profiles. This information will be used to make improvements to the test apparatus and develop better testing procedures for our laboratory, and can also be utilized by other organizations as they plan testing of their own. For example, the information will be very helpful in the development of the new ASHRAE Standards for water heater testing as they consider the application of more complicated load profiles.

The following conclusions may be drawn from this testing:

1. Much greater savings can be expected over DEER values, given the wide range of efficiency options currently available.

2. Energy factor ratings provide a reasonable measure to compare different systems, but care must be taken in using it to predict energy consumption because it is a function of the total quantity drawn.
3. A tier-structured rebate is appropriate for water heaters because many levels of efficiency and increased cost for more efficient technology.
4. As a first attempt at creating a tiered rebate, there appears to be a distinct step increase in efficiency between non-condensing and condensing water heaters.
5. High efficiency products are few and not readily available. Increasing the awareness of higher efficiency systems by offsetting part of their higher cost through tiered rebates should help bring more systems into use.
6. Training and incentives for retailers or installers could encourage stocking or dealing in higher efficiency systems.
7. In order to determine energy savings potential for PG&E territory, better hot water usage information is needed for our customers.
8. While the purpose of conducting side-by-side testing was to achieve consistent results across the test units, differences in their thermostat setting and mode of operation led to significant differences between the hot water energy drawn and estimates of operating costs. A methodology for normalizing the results for the non-standard profiles needs to be developed from the DOE and ASHRAE methods.

Recommendations for Follow-on Activities

Some of the data reflects the challenges encountered and there is an interest in rerunning certain tests such as the medium use profile and the one derived from ASHRAE Standard 90.2. Another sample profile has recently been obtained from Consumer Reports®, which they used for their own examination of tankless water heaters reported in their October 2008 issue.

Manufacturers of commercial-rated water heaters report thermal efficiency, but must also measure standby loss. A future endeavor would be to derive a formula for large burner systems that could be installed in a home for converting the rated thermal efficiency and standby loss into an Energy Factor that can be used for comparison with residential systems having that rating.

With further investigation into the makeup of high, medium, and low hot water usage households in the PG&E territory, the load dependent efficiency data could be used to provide a better approximation of energy savings potential for PG&E Customer Energy Efficiency programs. The second phase of residential water heater testing will include combined hydronic, solar pre-heat, and possibly heat pump systems. This phase will examine the effect of preheat systems on water heater efficiency, especially concerning condensing units.

The capabilities of the Water Heater Lab generate opportunities to conduct testing to support further research by other organizations outside of PG&E. For example, the lab may work as a possible subcontractor under GTI proposal for PIER RFP 500-07-503 lab validation of modeling tool and test methods for residential water heaters. This report focuses on residential water heaters; however, the water heater lab will be expanded in the near future to include testing of commercial water heaters. In collaboration with the Food Service Technology Center (FSTC), the commercial testing will begin with laboratory investigation of the results of field tests conducted in the food service industry.

The engineers and program managers working on water heater testing have presented findings at local and national conferences, including the ACEEE Forum on Water Heating. They also participate on multiple CEC PIER Project Advisory Committees related to water heating such as the research project investigating domestic hot water distribution systems, and the research project to characterize commercial water heater energy use in food service kitchens for California. Continued involvement in such programs will assist in developing and installing more efficient water heating systems and provide recognition for PG&E's efforts toward energy efficiency.

Some supplemental testing was done with the apparatus and the first group of test units, but the results have not been included because either they were outside the scope of the original project or the results were inconclusive. These included:

1. Emissions rates.
   Most water heaters sold in California are required to meet specific limits for NOx emissions, and it is suspected that the regulations might encourage the use of higher efficiency systems because the measured recovery efficiency enters into the emissions rate calculation. Some emissions testing was done, but not under the standard conditions for these tests.
2. Examination of the operational differences with tankless water heaters.
   Several tests were done with the Takagi unit to look at the time delay from when flow is initiated until the water temperature reaches its setpoint relative to storage heaters, to examine the so-called "cold water sandwich" effect between draws, and also pressure drop as a function of flow rate. Some of these are inconclusive due to slow responding temperature sensors.

These may be re-examined in a supplemental study.

Improvements to facility and testing

This first phase of testing also identified some problem areas in the testing apparatus, and these can be addressed in future system and procedural improvements:

1. Use faster responding sensors for water outlet temperatures
2. Carefully plan the programming of load profile schedules to avoid event overlap and spacing inconsistencies.
3. Investigate more stable control valves
4. Re-evaluate water recovery system, or capture for other use.

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APPENDIX

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Table 8: Average Energy Factor/Thermal Efficiency Results

		Manufacturer Ratings		Average Energy Factor Results from Testing					
Manufacturer	**Product Line**	**Thermal Efficiency**	**Energy Factor**	**Calculation Method**	**Energy Factor Test***	**High Use (123 gal)**	**Med Use (57/68 gal)**	**Low Use (30 gal)**	**90.2 Prof. (52 gal)**
Kenmore	Power Miser 6	-	0.59	Simple	0.571	0.651	0.577	0.443	0.541
				ASHRAE	0.579	-	-	-	
				DOE	0.574	-	-	-	
A. O. Smith	ProMax+	-	0.62	Simple	0.580	0.661	0.565**	0.472	0.563
				ASHRAE	0.602	-	-	-	
				DOE	0.598	-	-	-	
Bradford-White	Defender	-	0.66	Simple	0.612	0.674	0.605**	0.493	0.552
				ASHRAE	0.615	-	-	-	
				DOE	0.610	-	-	-	
A. O. Smith	Cyclone	90%	-	Simple	0.722	0.780	0.666	0.611	0.682
				ASHRAE	0.735	-	-	-	
				DOE	0.734	-	-	-	
Heat Transfer Products	Phoenix	94.8%	-	Simple	0.833	0.903	0.865**	0.786	0.816
				ASHRAE	0.826	-	-	-	
				DOE	0.817	-	-	-	
Takagi	Flash T-H1	92%	0.91	Simple	0.843	0.843	0.801	0.762	0.731
				ASHRAE	0.885	-	-	-	
				DOE	0.879	-	-	-	

*Average of four tests

** Medium Use Test; only 57 gallons of water drawn

Table 9: Instrumentation List

Performance Parameter	Units	Sensor Type
Temperature		
Ambient Dry Bulb	°F	1/4" RTD Probe (3)
Heater Inlet Water	°F	1/4" RTD Probe (1 per unit)
Heater Outlet Water	°F	1/4" RTD Probe (1 per unit)
Gas meter	°F	1/4" RTD Probe (1 per unit)
Cold water supply	°F	1/4" RTD Probe
Tempering tank outlet	°F	1/4" RTD Probe
Tempering valve outlet	°F	1/4" RTD Probe
End of supply header	°F	1/4" RTD Probe
Coriolis meter	°F	1/4" RTD Probe
Storage Tank	°F	Type T thermocouple (6 per tank)
Exhaust	°F	Type K thermocouple (1 per unit)
Relative Humidity		
Ambient	% RH	General Eastern MRH-1-V-OA
Pressure		
Barometric	in Hg	Qualimetrics 7105-A electronic barometer
Natural gas supply	IW	Rosemount 3051C gage transmitter
Supply water	PSIG	Rosemount 3051C gage transmitter
Tankless unit pressure drop	PSID	Rosemount 3051C differential transmitter
Flow		
Common outlet water flow rate	pph	MicroMotion R050S Coriolis mass flow meter
Individual tank inlet water flow rate	gpm	Omega FTB4707 Single-jet paddle wheel flow meter (6)
Natural gas	ft³	American Meter AL-250 diaphragm meter with IMAC 400-1000 gas meter pulser (6)
Power		
Power	W	Scientific Columbus XLGW10E1-A1 watt transducer (2) Yokogawa 2475 Power Line transducer (2)
Line voltage	V	Scientific Columbus VT110A2 voltage transducer
Other		
Gas higher heating value	Btu/SCF	MTI M200D gas chromatograph (in Chemistry Lab)
Emissions (NOx, CO)	%, ppm	Land Instruments LANCOM III portable flue gas analyzer
Flow control valves	gpm	Kates MFA1-1 (3)
Tempering water tank		Bradford-White M-2-50TSDS electric water heater
Tempering water tank chiller		Advantage M1-1.5AR

Figure 5: DOE Standard Energy Factor Draw Profile

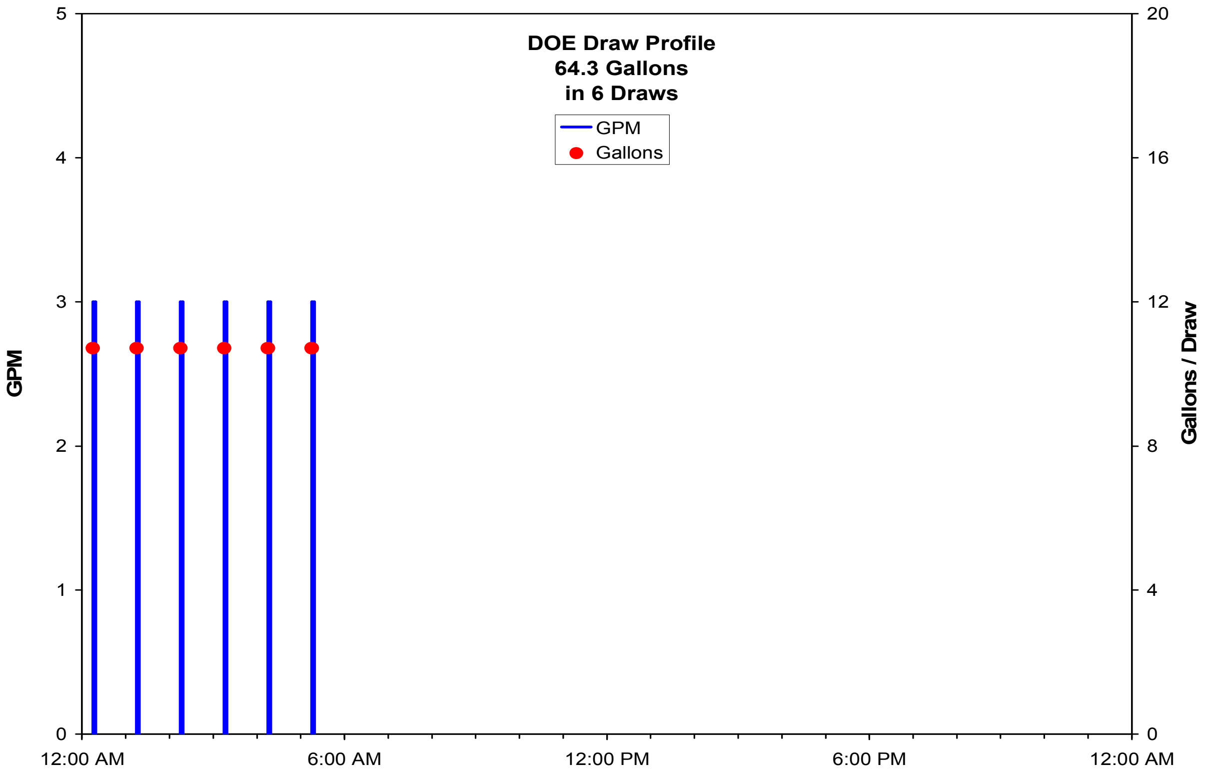

Figure 6: Seven-Day High Hot Water Usage Profile from GTI

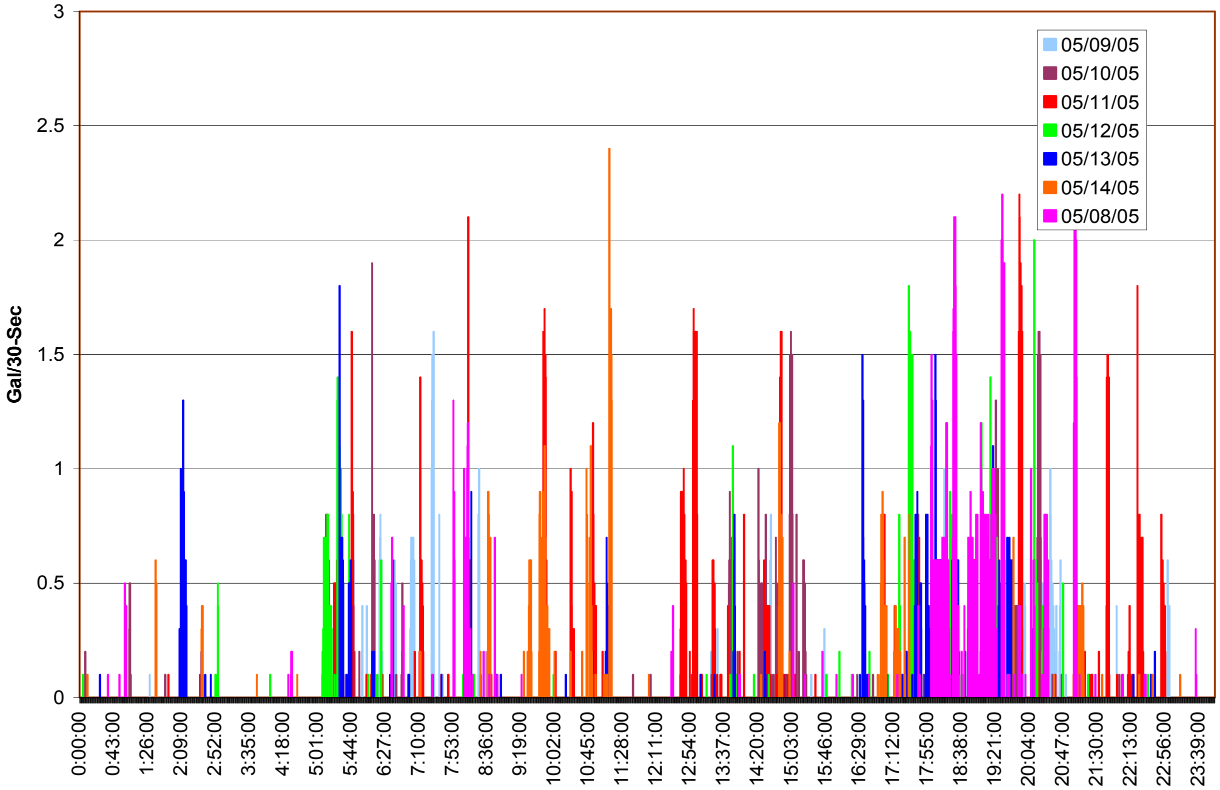

Figure 7: High Hot Water Usage Profile Used in Performance Testing

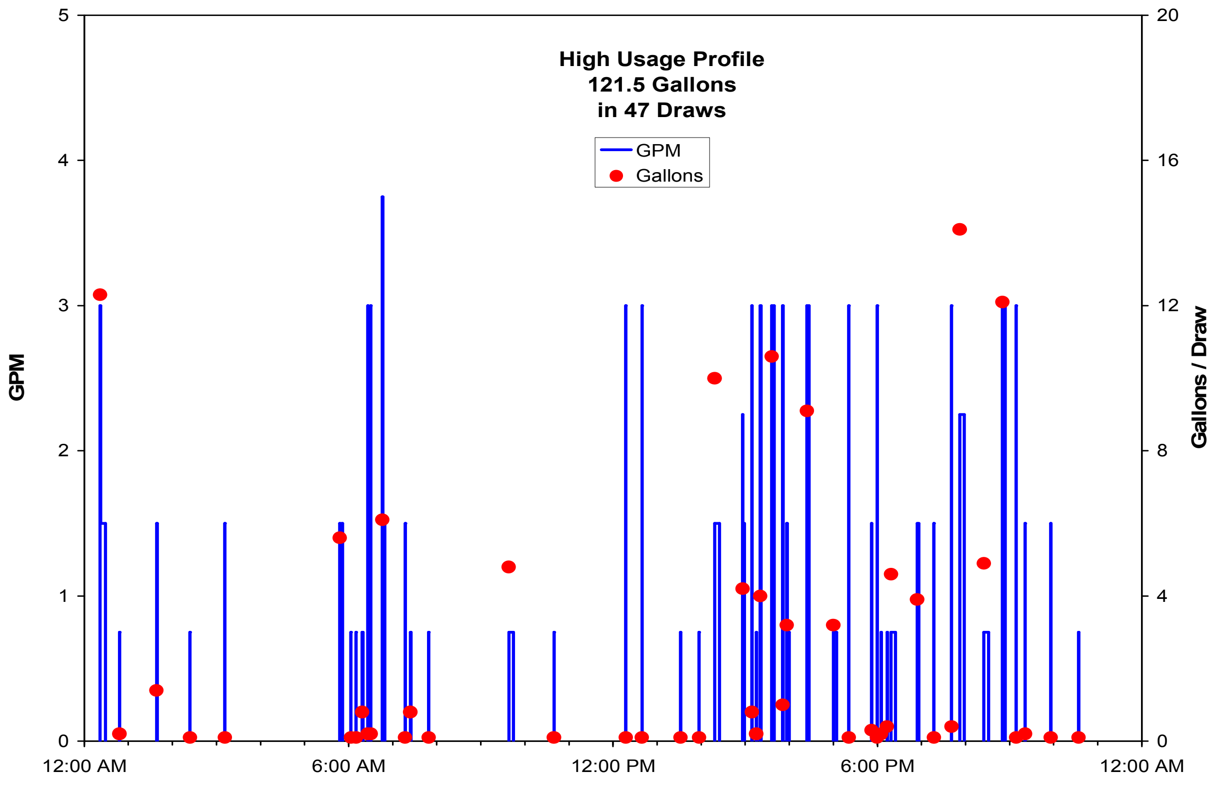

Figure 8: Seven-Day Medium Hot Water Usage Profile from GTI

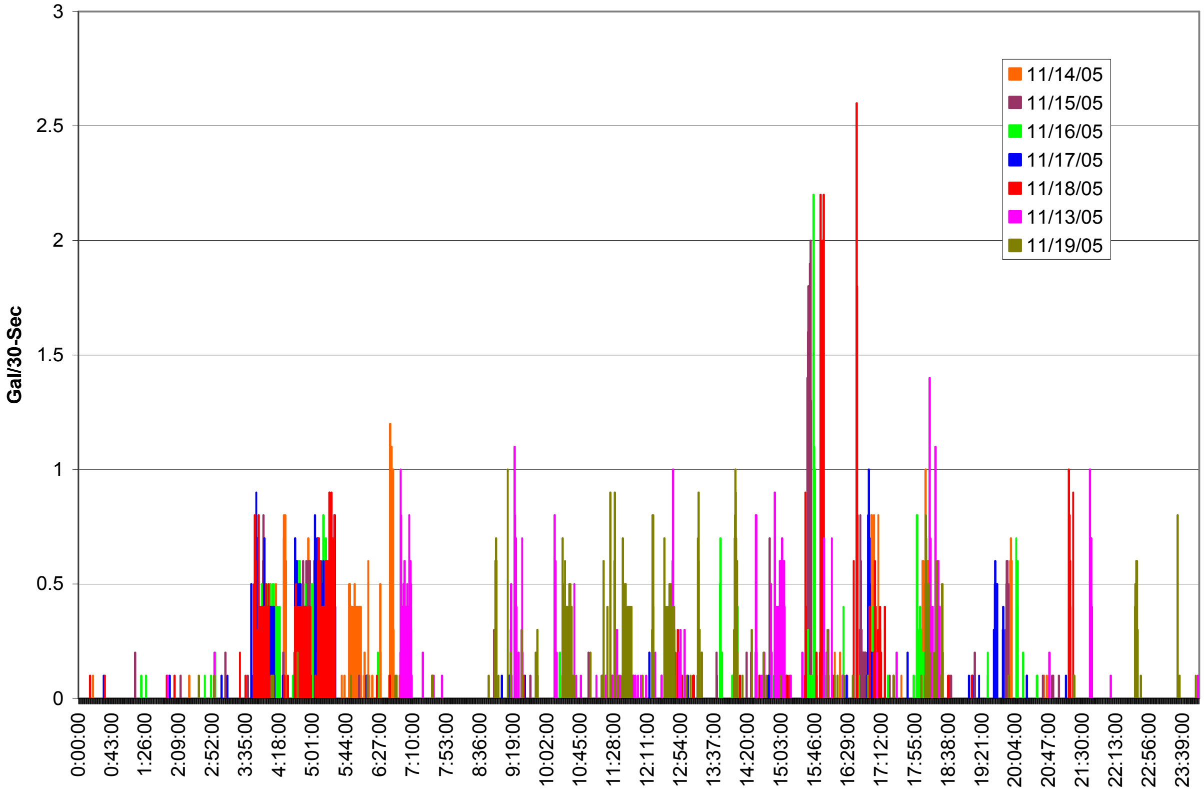

Figure 9: Medium Hot Water Usage Profile Used in Performance Testing

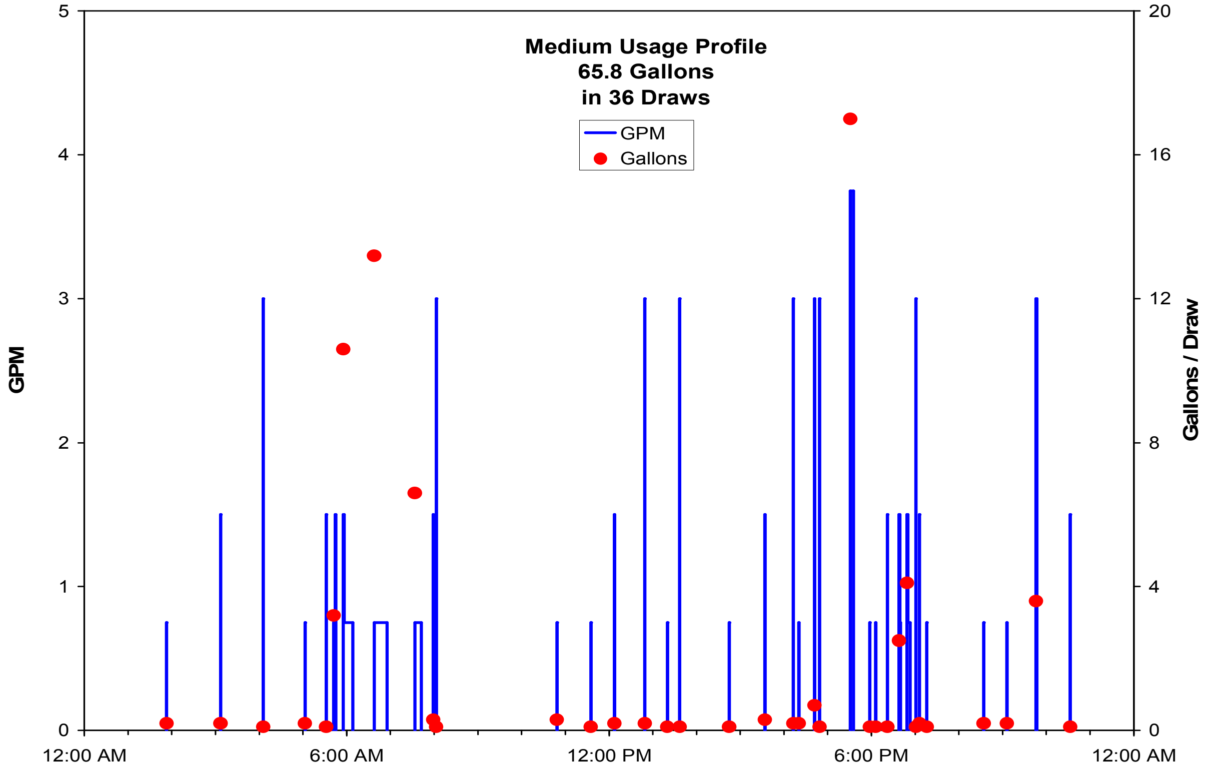

Figure 10: Seven-Day Low Hot Water Profile from GTI

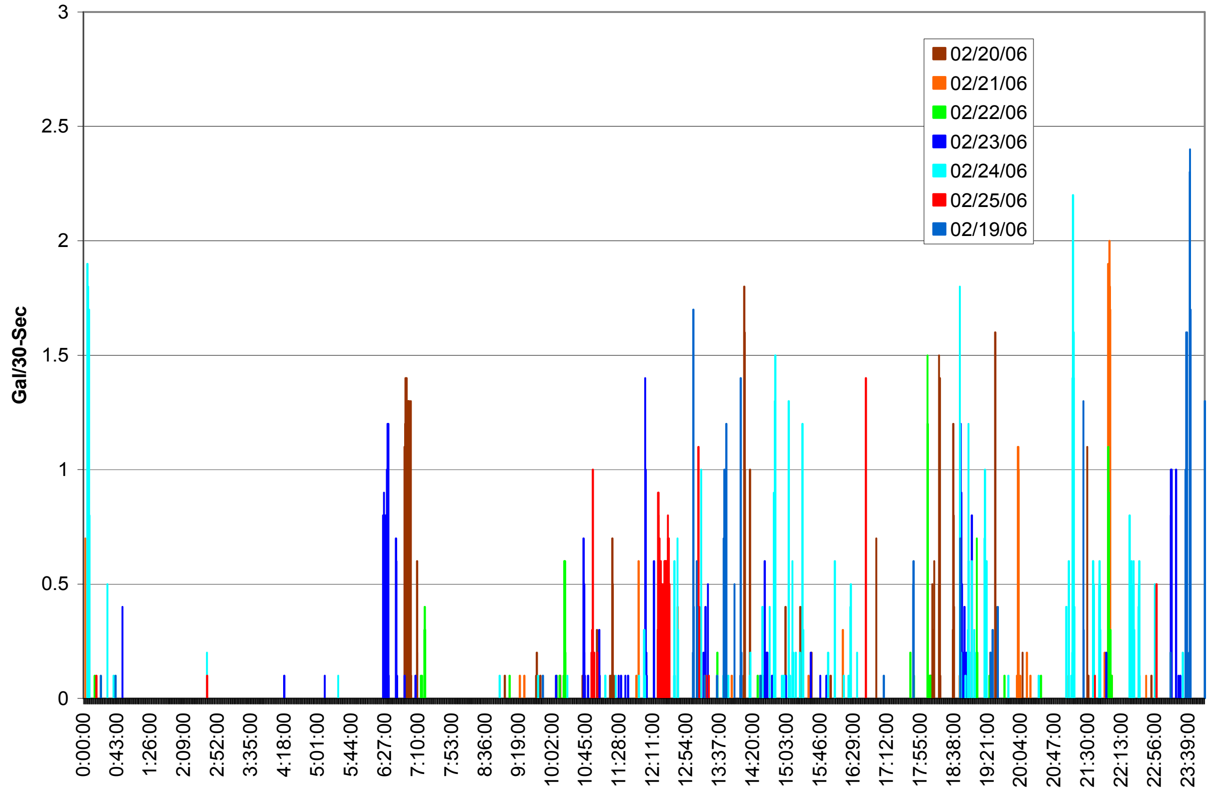

Figure 11: Low Hot Water Usage Profile Used in Performance Testing

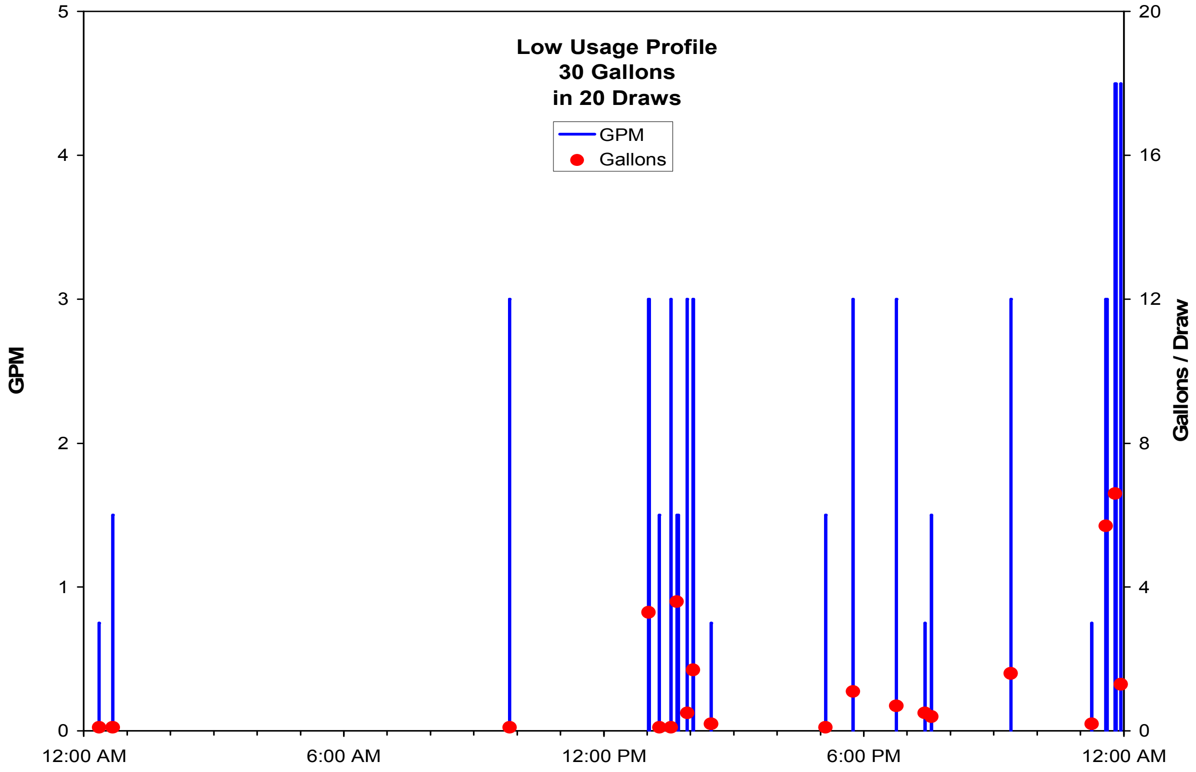

Figure 12: ASHRAE 90.2 Daily Domestic Hot Water Load Profile

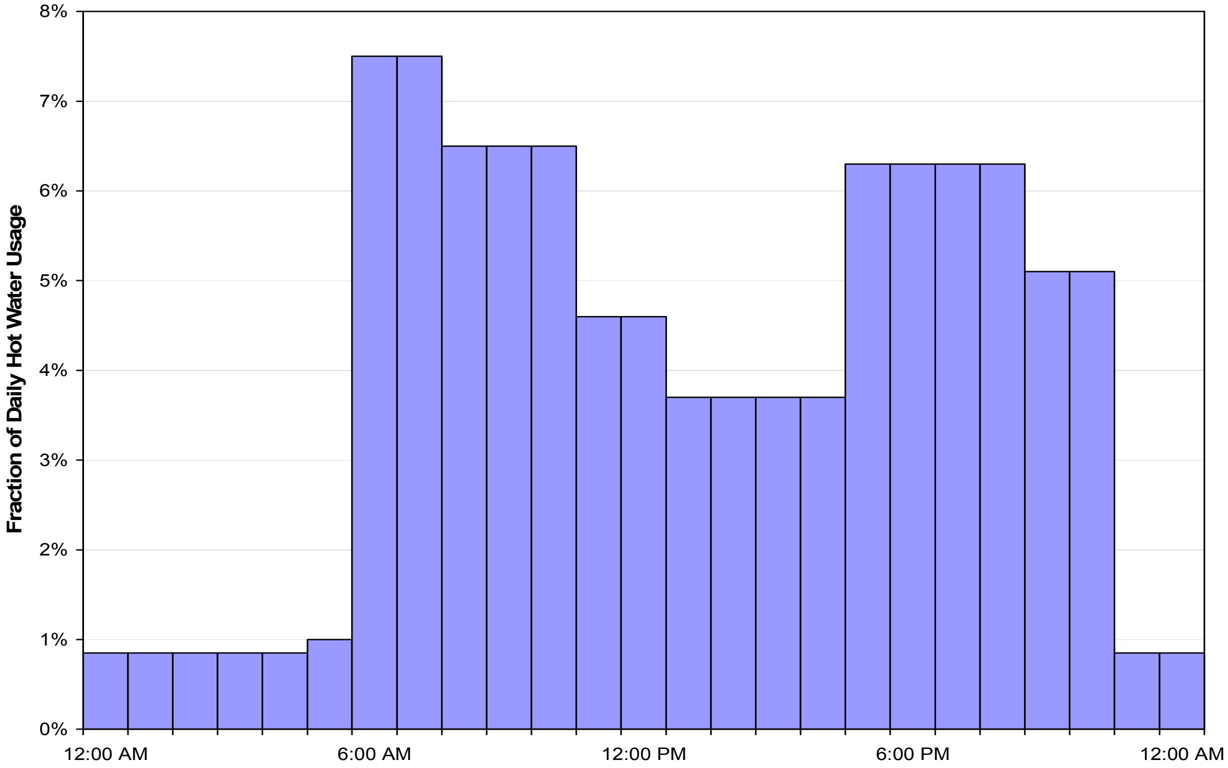

Figure 13: Derived ASHRAE 90.2 Draw Profile

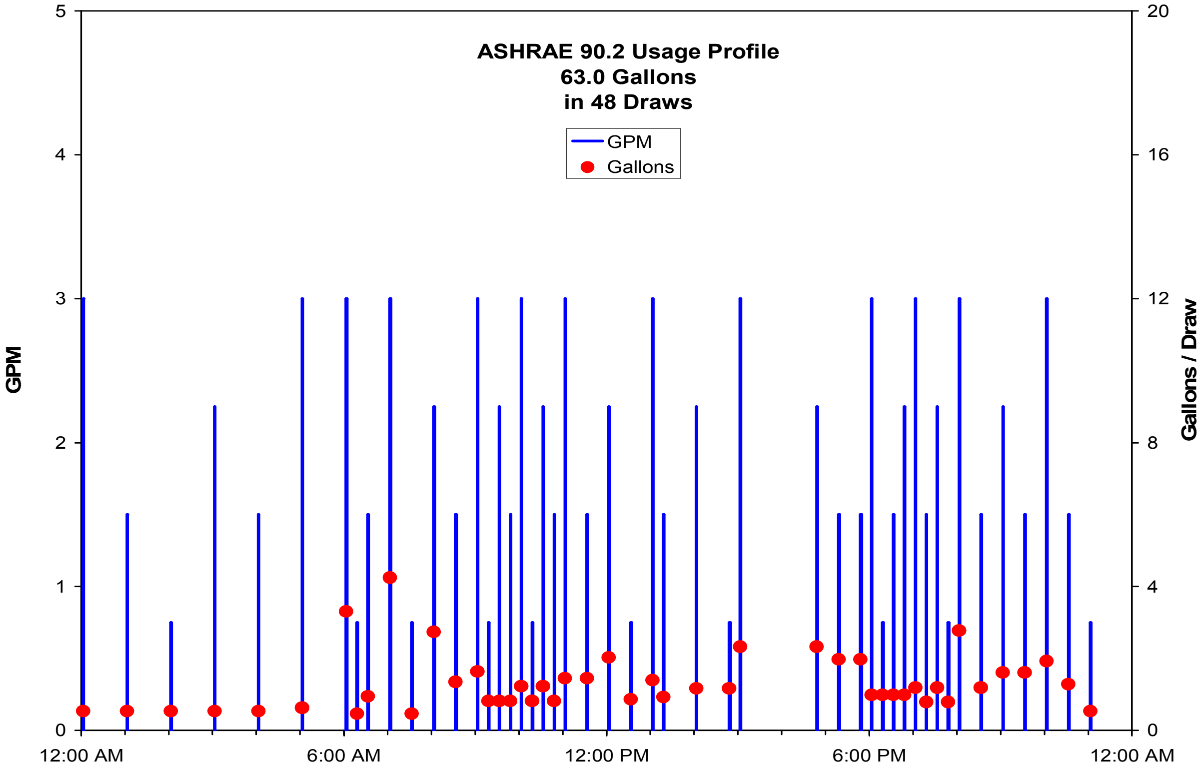

Figure 14: Draw Distribution Statistics

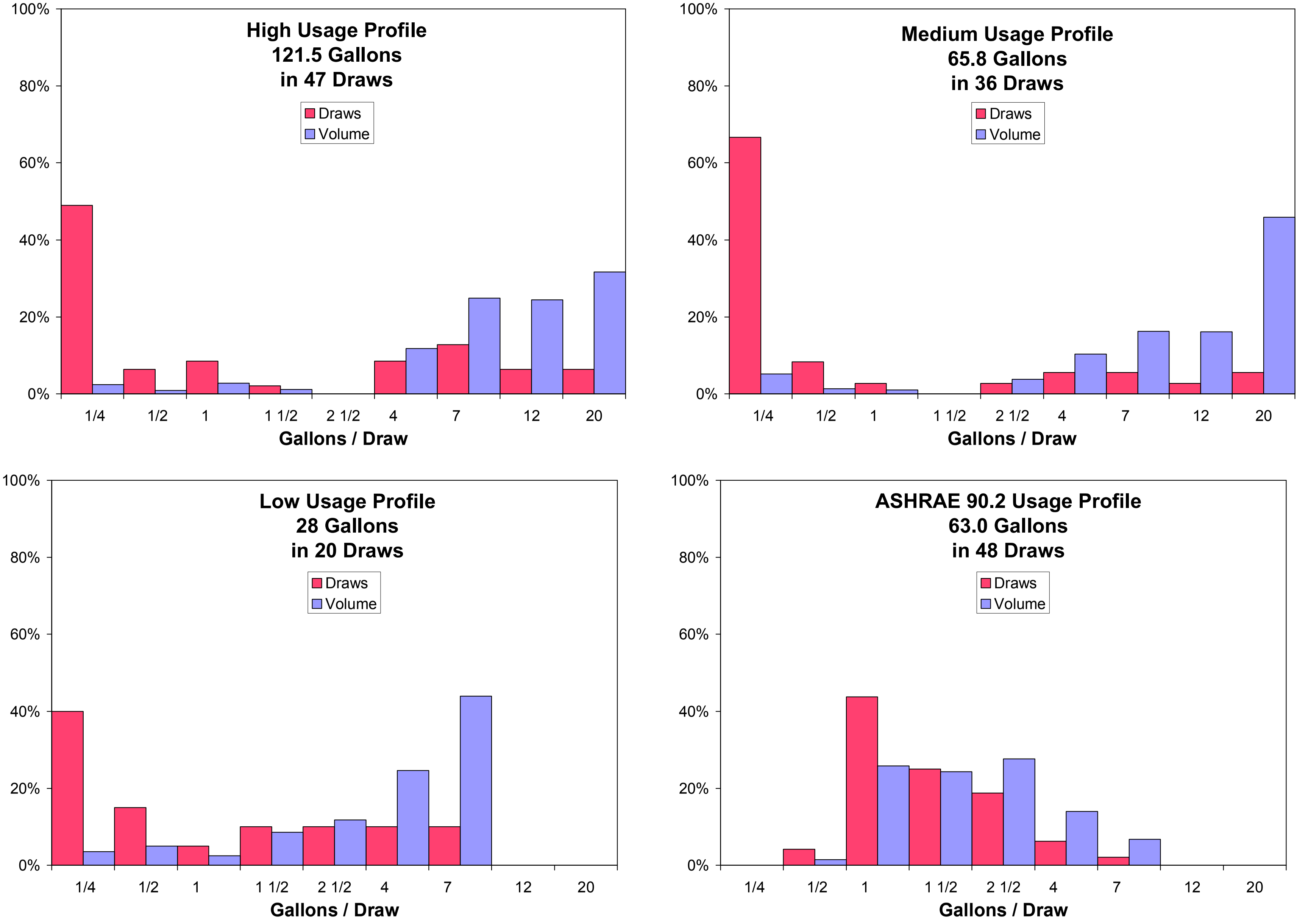

Figure 15: Daily Draw Quantities

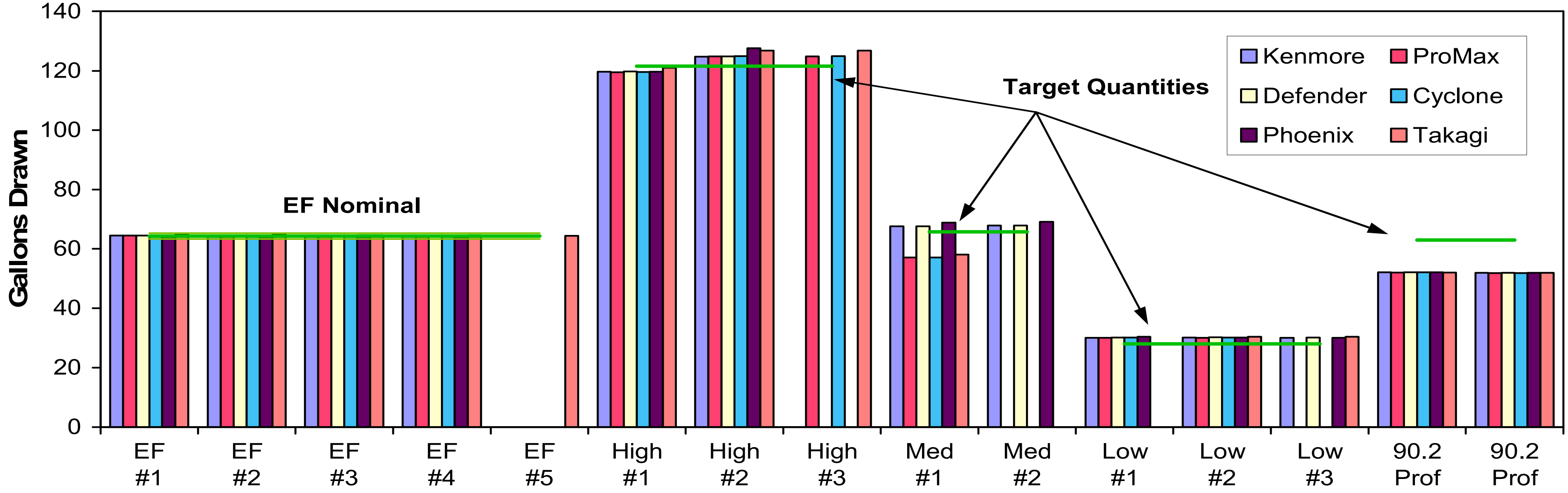

Figure 16: Total Daily Energy Drawn

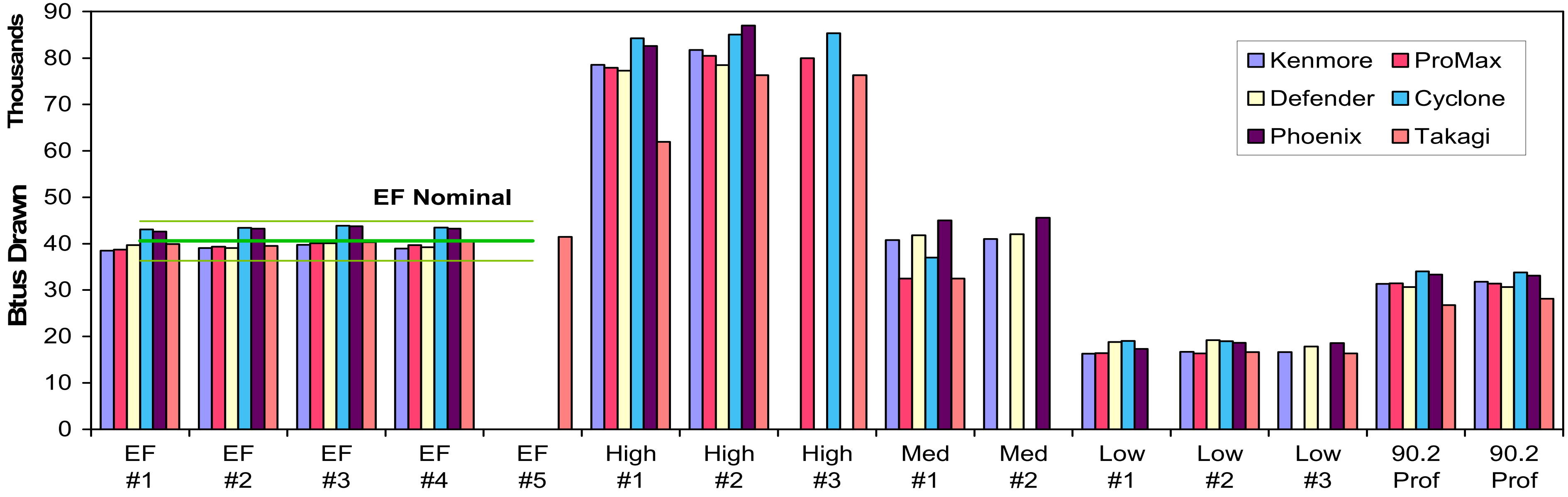

Table 10: Average Annual Energy Use

		Manufacturer Ratings			Annual Energy Use														
					EF* (64.3 gal.)			High Use (123 gal.)			Med Use (65 gal.)			Low Use (30 gal.)			ASHRAE 90.2 Profile (52 gal)		
Manufacturer	Product Line	Thermal Efficiency	Energy Factor	Energy Guide (therms/yr)	Gas (therms/yr)	Electric (kWh/yr)	Equiv. Gas (therms/yr)	Gas (therms/yr)	Electric (kWh/yr)	Equiv. Gas (therms/yr)	Gas (therms/yr)	Electric (kWh/yr)	Equiv. Gas (therms/yr)	Gas (therms/yr)	Electric (kWh/yr)	Equiv. Gas (therms/yr)	Gas (therms/yr)	Electric (kWh/yr)	Equiv. Gas (therms/yr)
Kenmore	Power Miser 6	-	0.59	254	249.6	-	249.6	449.0	-	449.0	259.0	-	259.0	136.1	-	136.1	213.0	-	213.0
A. O. Smith	ProMax+	-	0.62	242	248.5	-	248.5	438.8	-	438.8	209.9	-	209.9	126.4	-	126.4	203.6	-	203.6
Bradford-White	Defender	-	0.66	227	233.2	74.5	235.7	417.2	125.1	421.5	250.3	81.4	253.0	137.3	48.7	139.0	200.3	66.5	202.6
A. O. Smith	Cyclone	90%	-	-	218.3	45.7	219.8	394.4	83.5	397.2	201.1	42.4	202.6	112.9	24.4	113.7	180.1	39.3	181.5
Heat Transfer Products	Phoenix	94.8%	-	-	184.4	146.4	189.4	337.4	155.2	342.7	186.0	149.5	191.1	80.6	138.3	85.3	144.4	143.5	149.3
Takagi	Flash T-H1	92%	0.91	164	173.0	62.5	175.1	307.1	72.8	309.6	145.9	62.6	148.0	77.2	54.5	79.0	135.0	60.8	137.1

*Based on Energy Factor calculated using DOE Standard; average of four tests

Table 11: Average Annual Cost

		Manufacturer Ratings			Annual Cost*														
					EF** (64.3 gal.)			High Use (123 gal.)			Med Use (65 gal.)			Low Use (30 gal.)			ASHRAE 90.2 Profile (52 gal)		
Manufacturer	Product Line	Thermal Efficiency	Energy Factor	Energy Guide (therms/yr)	Gas ($/yr)	Electric ($/yr)	Total ($/yr)	Gas ($/yr)	Electric ($/yr)	Total ($/yr)	Gas ($/yr)	Electric ($/yr)	Total ($/yr)	Gas ($/yr)	Electric ($/yr)	Total ($/yr)	Gas ($/yr)	Electric ($/yr)	Total ($/yr)
Kenmore	Power Miser 6	-	0.59	254	$374.34	-	$374.34	$673.56	-	$673.56	$388.52	-	$388.52	$204.13	-	$204.13	$319.55	-	$319.55
A.O.Smith	ProMax+	-	0.62	242	$372.69	-	$372.69	$658.14	-	$658.14	$314.87	-	$314.87	$189.57	-	$189.57	$305.45	-	$305.45
Bradford-White	Defender	-	0.66	227	$349.80	$12.30	$362.10	$625.84	$20.64	$646.49	$375.39	$13.42	$388.81	$205.99	$8.03	$214.02	$300.47	$10.98	$311.45
A.O.Smith	Cyclone	90%	-	-	$327.40	$7.53	$334.94	$591.54	$13.78	$605.32	$301.66	$7.00	$308.66	$169.36	$4.03	$173.39	$270.19	$6.49	$276.67
Heat Transfer Products	Phoenix	94.8%	-	-	$276.63	$24.16	$300.79	$506.04	$25.61	$531.65	$278.95	$24.68	$303.63	$120.87	$22.82	$143.69	$216.63	$23.68	$240.32
Takagi	Flash T-H1	92%	0.91	164	$259.47	$10.31	$269.78	$460.63	$12.01	$472.64	$218.81	$10.32	$229.13	$115.75	$8.99	$124.74	$202.48	$10.03	$212.51

* At $1.50/therm and $0.165/kWh
** Based on Energy Factor calculated using DOE Standard; average of four tests

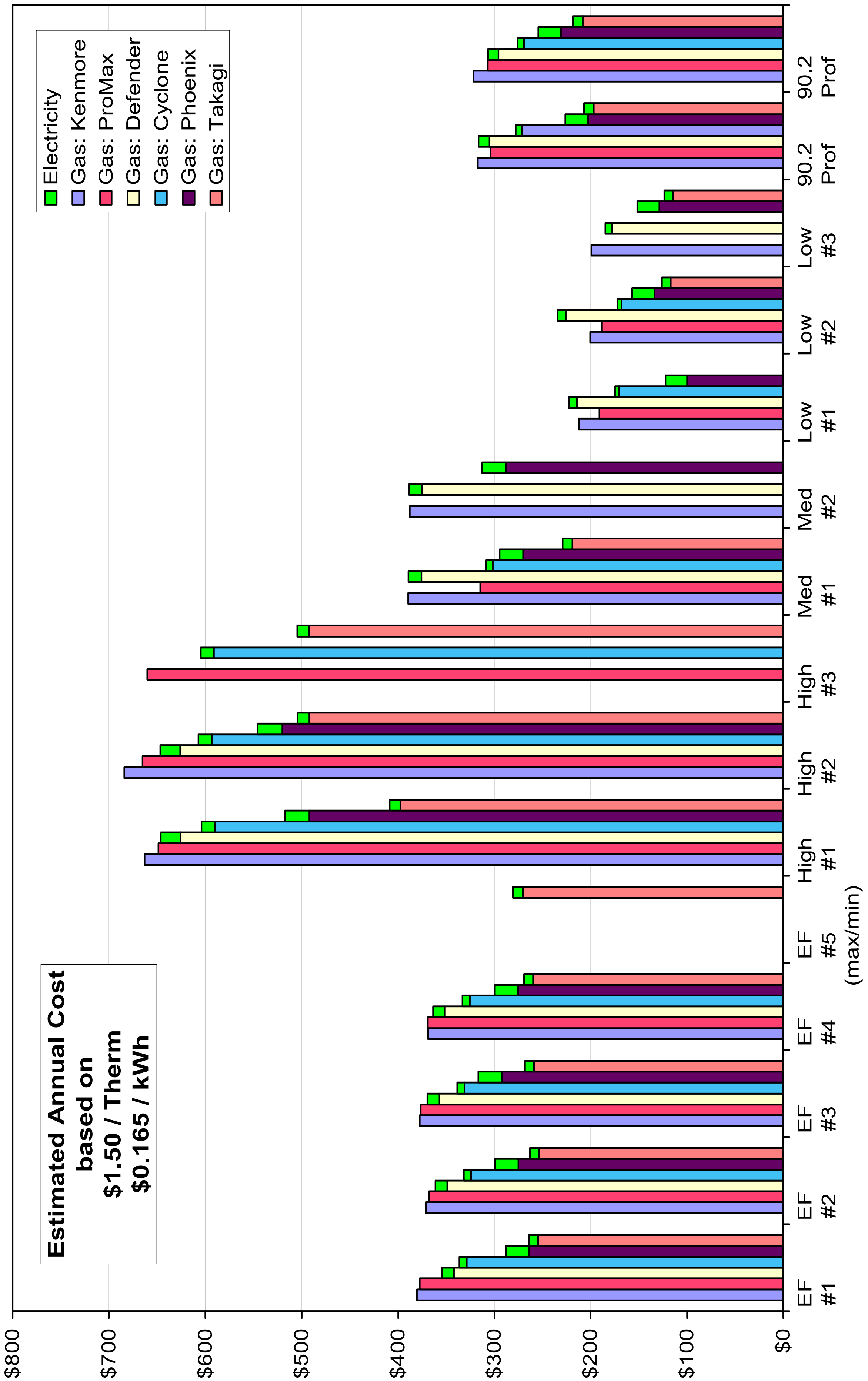

Figure 17: Annual Cost of Operation

Figure 18: Energy Factor Results for Kenmore PowerMiser 6

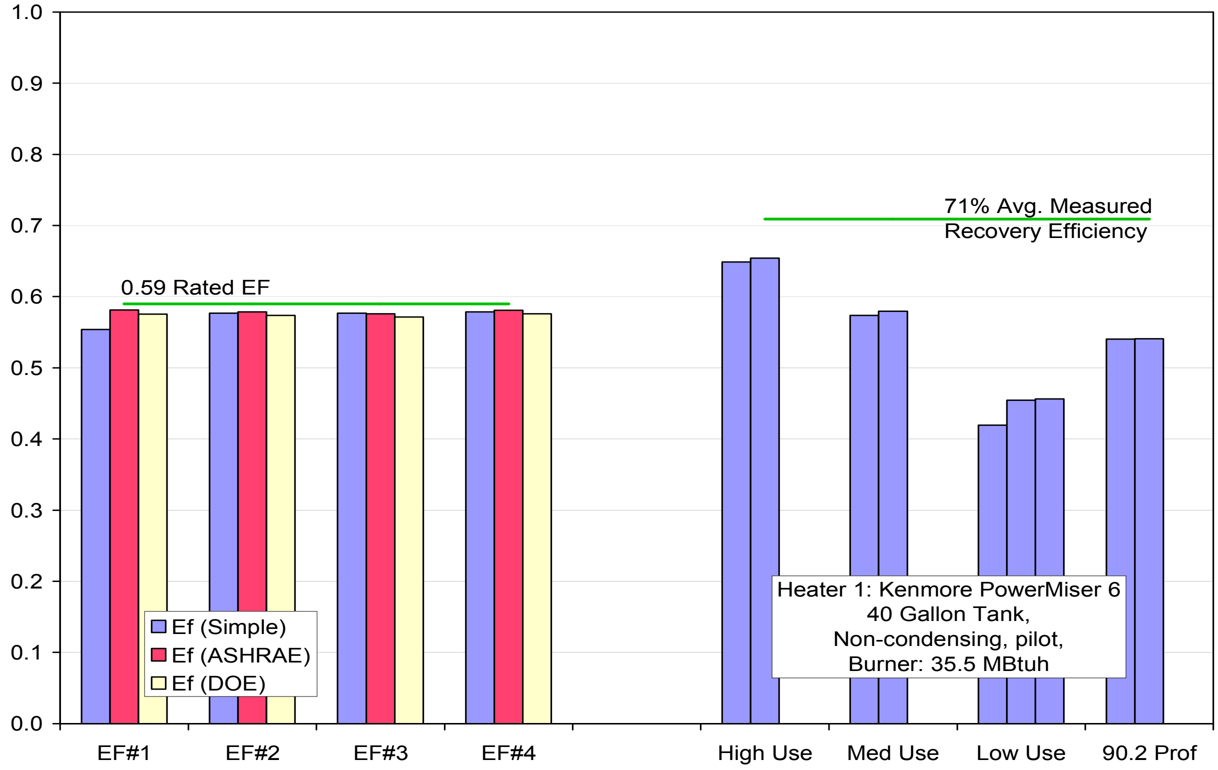

Figure 19: Energy Factor Results for A. O. Smith ProMax+

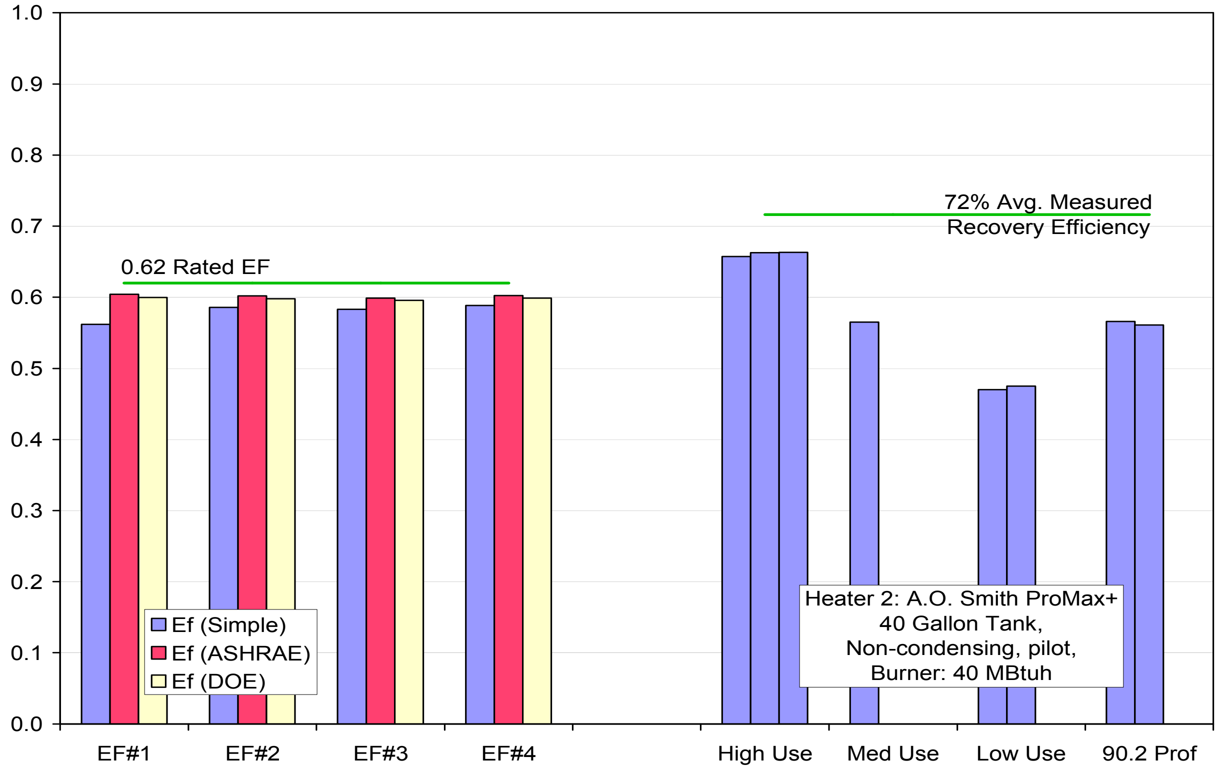

Figure 20: Energy Factor Results for Bradford-White Defender

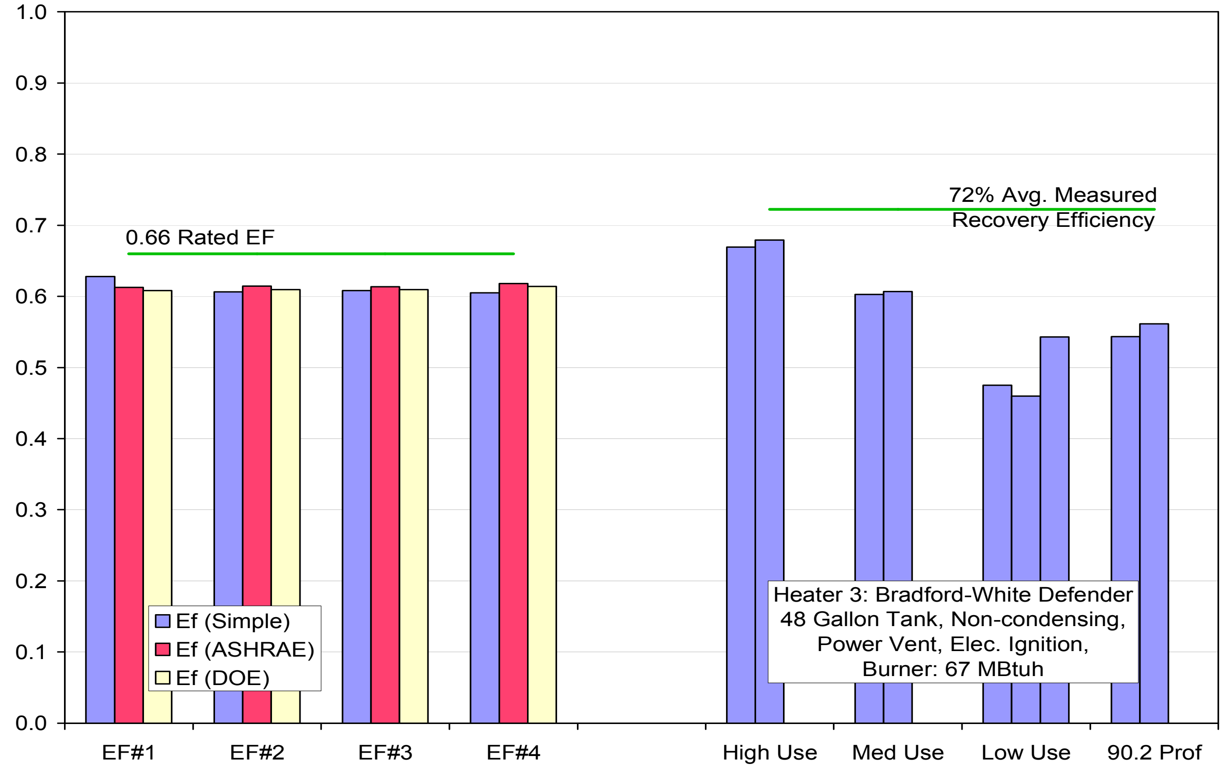

Figure 21: Energy Factor Results for A. O. Smith Cyclone

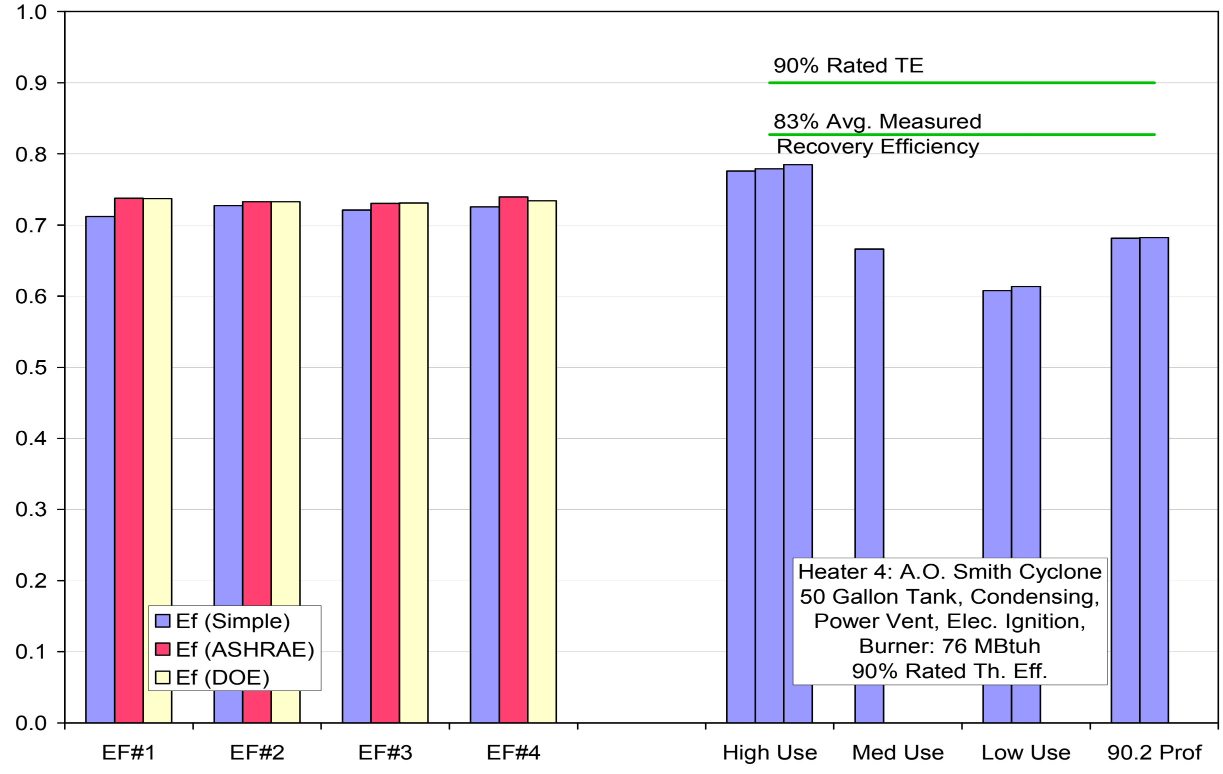

Figure 22: Energy Factor Results for Heat Transfer Products Phoenix

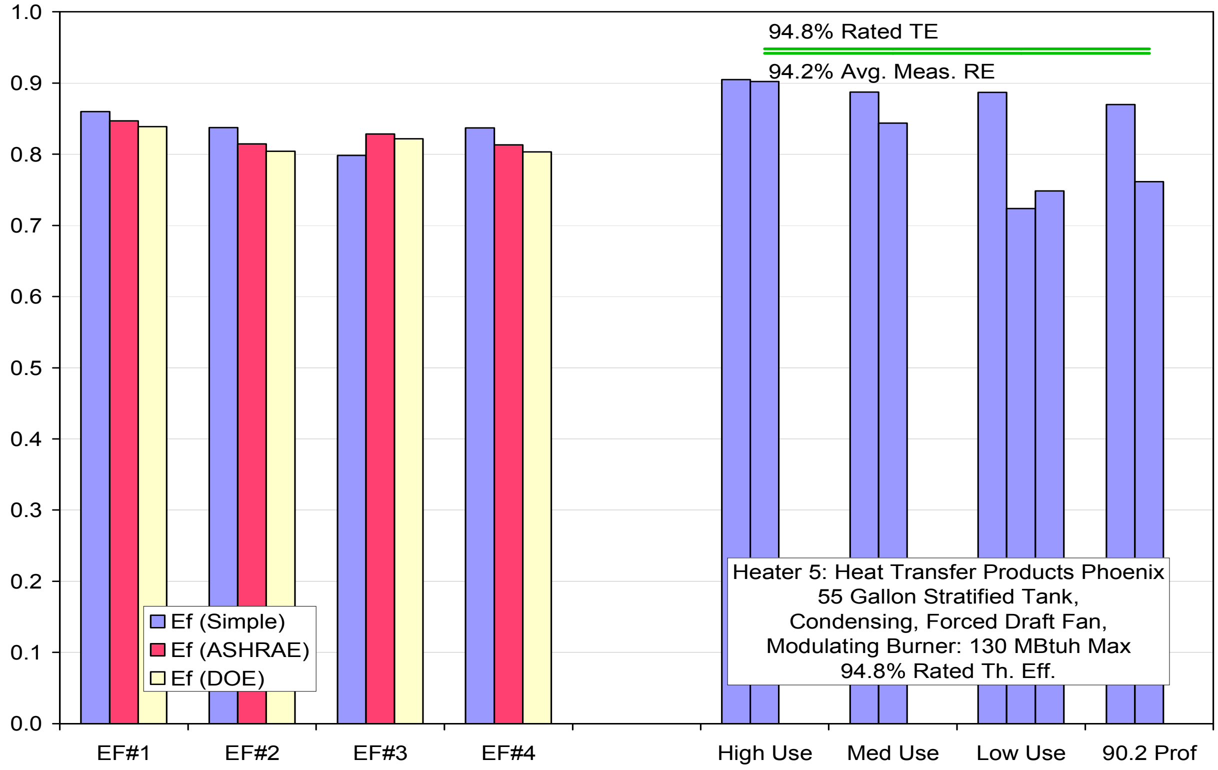

Figure 23: Energy Factor Results for Takagi Flash T-H1

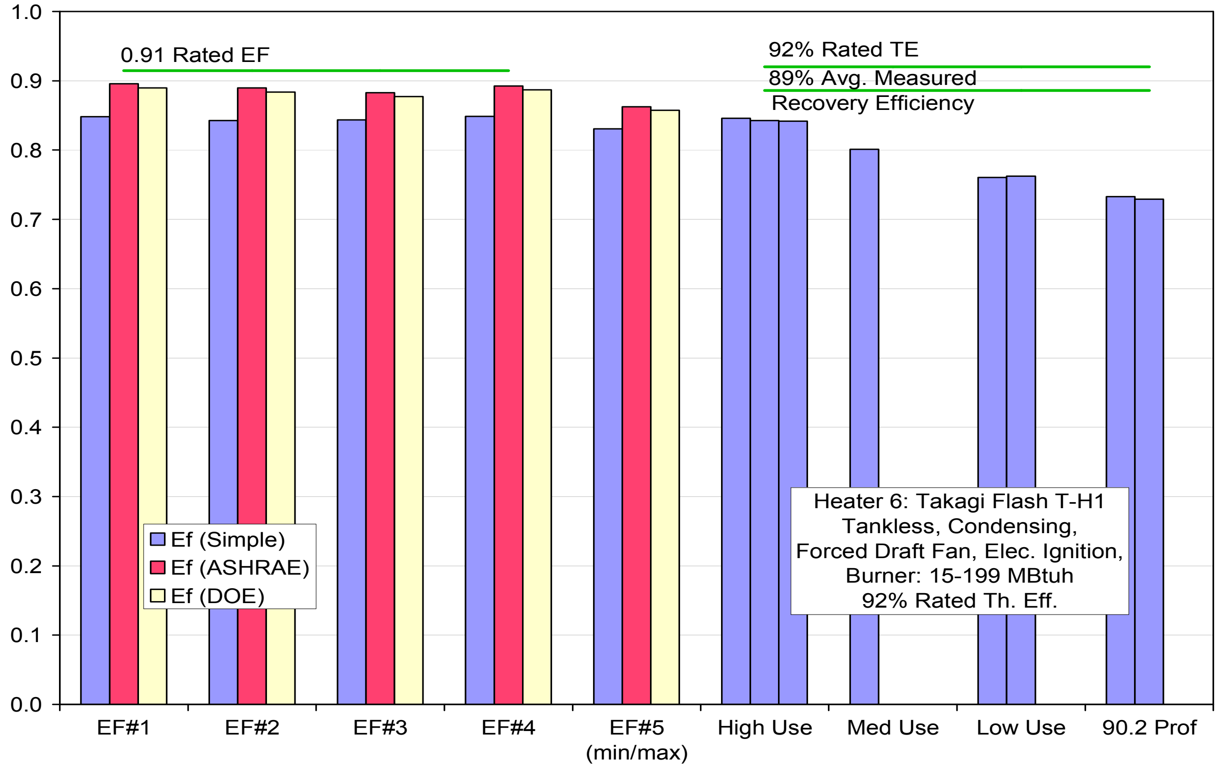

Figure 24: Simple Energy Factor as a Function of Daily Draw Quantity

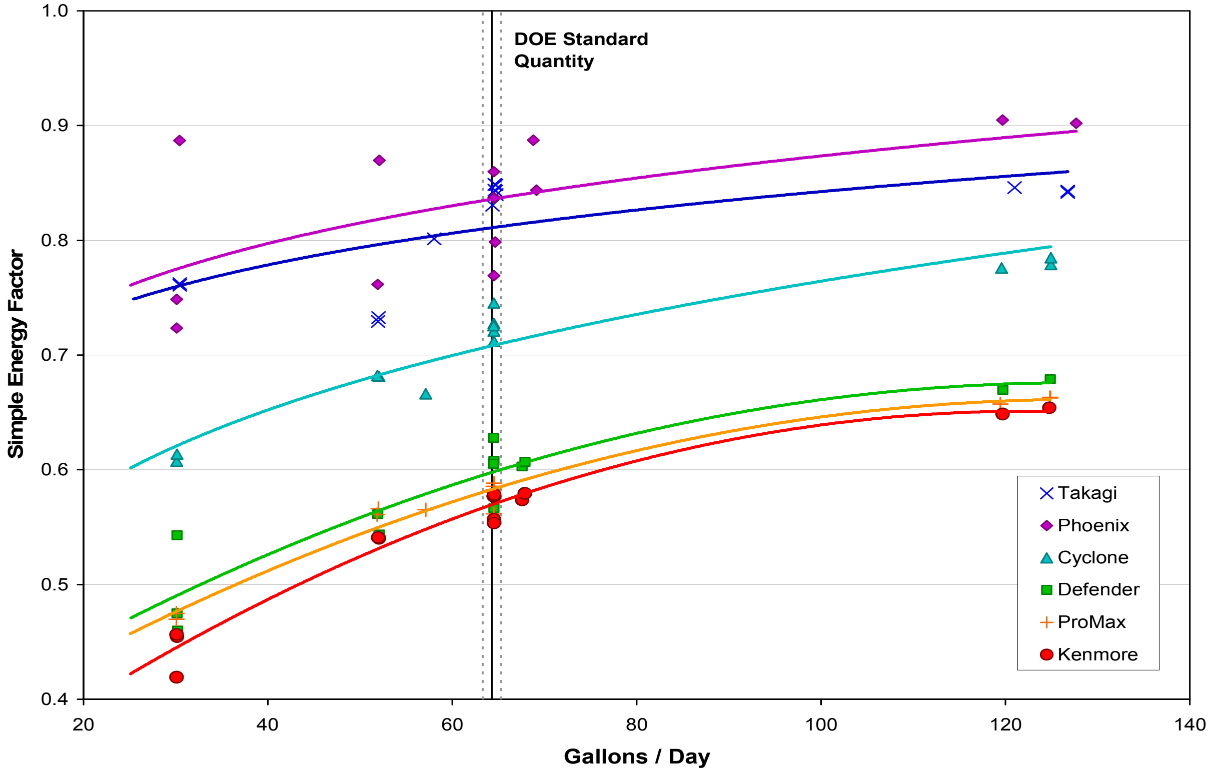

Figure 25: Simple Energy Factor as a Function of Daily Energy Drawn