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Side-by-Side Testing of Water Heating Systems: Results from the 2013–2014 Evaluation

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Building America Partnership for Improved Residential Construction

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Side-by-Side Testing of Water Heating Systems: Results from the 2013–2014 Evaluation

Prepared for:

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Office of Energy Efficiency and Renewable Energy

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The work presented in this report does not represent performance of any product relative to regulated minimum efficiency requirements.

The laboratory and/or field sites used for this work are not certified rating test facilities. The conditions and methods under which products were characterized for this work differ from standard rating conditions, as described.

Because the methods and conditions differ, the reported results are not comparable to rated product performance and should only be used to estimate performance under the measured conditions.

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Unless otherwise noted, all figures were created by BA-PIRC.

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Definitions

BA	Building America
BA-PIRC	Building America Partnership for Improved Residential Construction
COP	coefficient of performance
DOE	U.S. Department of Energy
EF	energy factor
FSEC	Florida Solar Energy Center
gpd	gallons per day
HPWH	heat pump water heater
HWS	hot water system(s)
UEF	uniform energy factor

Executive Summary

The Florida Solar Energy Center (FSEC) has completed a fourth year-long evaluation on residential hot water heating systems in a laboratory environment (east central Florida, hot-humid climate). The work is sponsored under the U.S. Department of Energy's (DOE) Building America Program and executed by the Building America Partnership for Improved Residential Construction (BA-PIRC) team at FSEC.

The evaluation studied the performance of five hot water systems (HWS) plus a reference baseline system for each fuel, (i.e., electric and natural gas). Electric HWS consisted of two residential electric heat pump water heaters (HPWHs, 60 and 80 gallons), a solar thermal system using a polymer absorber (glazed) collector with 80-gallon storage and a duplicate 50-gallon standard electric water heater with added cap and wrap insulation. Baseline performance data were collected from a standard 50-gallon electric water heater of minimum code efficiency to compare energy savings. Similarly, a standard 40-gallon upright vented natural gas water heater served as baseline for the natural gas fuel category. The latter, having a larger jacket diameter [18 in., with an energy factor (EF) of 0.62] with increased insulation, replaced a former baseline (17 in. diameter, EF = 0.59) that served during three previous testing rotations (2009–2013). A high-efficiency, condensing natural gas hybrid water heater with 27-gallon buffered tank was also tested and compared against the gas baseline. All systems underwent testing simultaneously side-by-side under the criteria specified elsewhere in this report (i.e., 120°F set point, 1.5 gallons per minute flow rate) using two alternating hot water draw schedules: ASHRAE 90.2 and an NREL/Building America (BA) draw schedule. The NREL/BA schedule differs from the ASHRAE profile, being dynamic by month, better representing that of a typical family load profile.

Figure ES-1 illustrates the average system efficiency results on-site as obtained for the period of August 2013 to July 2014. Results shown are based on combined (unweighted) draw schedules.

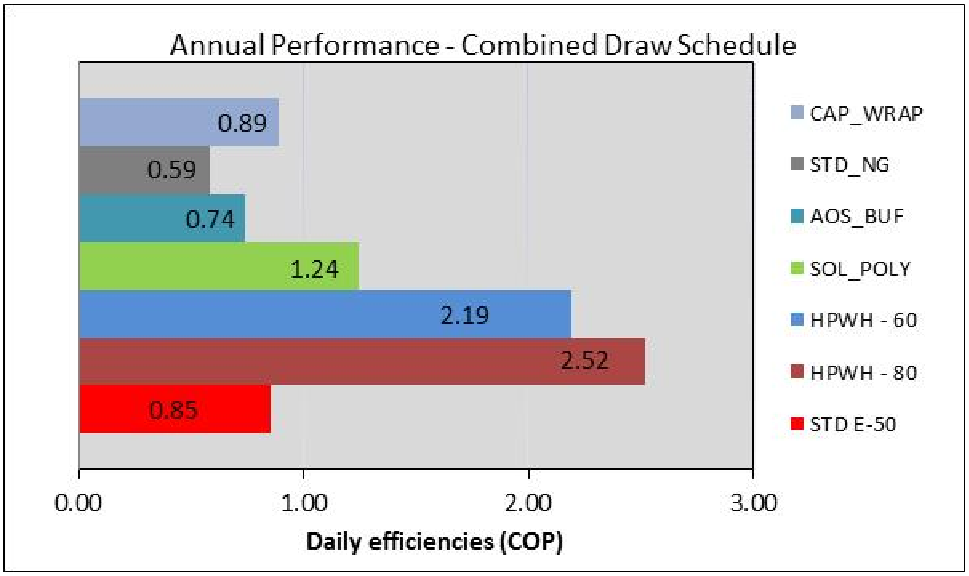

Figure ES-1. Average annual efficiency performance for combined hot water schedules

Overall monthly efficiencies for combined draws for five electric systems can be compared in Figure ES-2. Performance demonstrated by the 60 and 80 gallon HPWHs are shown at the top of the chart. These HPWHs led in efficiency [coefficient of performance (COP) >1.98] and measured very favorably against the baseline electric. The 80-gallon HPWH operates at higher efficiencies, possibly helped by the larger than expected deadband (20°F) that comes set as factory default.

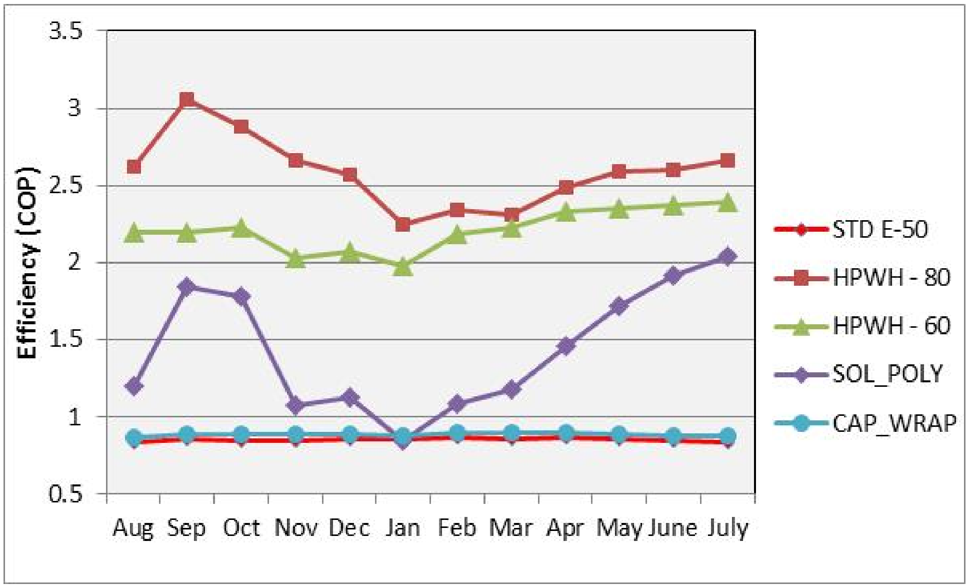

Figure ES-2. Average monthly efficiencies for electric systems (2013–2014)

Table ES-1 presents a summary of hot water temperatures delivered by each system and average-weighted by volume. The second column lists the averages for combined hot water schedule draws. Averages measured from the ASHRAE 90.2 draw schedule, being smaller in magnitude during events, help bring the average closer to the thermostat setting (120°F). This is evident from the lower temperatures shown in the third column recorded exclusively under the NREL/BA draw schedule. Hot water averages measure lower under this draw schedule due to the dynamic seasonal adjustment imposed and the closer sequence of draw repetitions better representing typical family demand. The right-most columns also provide the average daily minimum and maximum hot water temperatures delivered during the typical draw events of the NREL/BA schedule. The minimum temperature values provide an indication of adequate thermal comfort, which for residential consumption should be considered at 110°F or above.

Table ES-1. Summary of Average Weighted Delivered Hot Water Temperatures

Hot Water Heating System	All Draws (°F)	NREL/BA (°F)	Min. Delivered (°F)	Max. Delivery (°F)
Electric Standard	118.5	117.8	116.1	118.9
80-Gallon HPWH	114.3	112.7	108.0	115.7
60-Gallon HPWH	117.8	117.2	116.0	118.6
Solar Polymer w/80-Gallon Storage	118.9	118.4	114.5	127.0
Hybrid Tankless Condensing w/27-Gallon Buffer	119.9	118.3	108.7	124.2
Baseline Natural Gas 40-Gallon (2015 EF)	120.2	120.0	113.6	131.0
Electric 50-Gallon with CapWrap Insulation	119.6	119.2	117.4	120.2

Under load profiles tested, baseline water heaters demonstrated better temperature regulation due to their fast recovery of 40 kBtu/hr and 15 kBtu/hr (4.4 kW) for natural gas burner and electric resistance heating elements, respectively. Delivered temperatures for the 80-gallon HPWH demonstrated higher deviation than expected (108°F minimum) due to its wide factory default (deadband), which energizes the compressor or heating element. Furthermore, the solar thermal heating system manages to maintain consistency of hot water temperatures delivered, although the mixing valve deviated on the surplus side with hotter temperatures shown by the maximum daily average of 127°F. The standard electric 50-gallon water heater with cap insulation and wrap achieves a tight delivery temperature regulation being closest to the 120°F set point due to its higher level of insulation and rapid recovery from the 4.4 kW heating element.

Variations in seasonal hot water delivered by the HPWHs can be observed in Figure ES-3. The plot compares temperatures delivered by the electric baseline (STD E-50) and from two heat pumps of different volume capacity (60 and 80 gallons). Daily average-weighted inlet water temperatures recorded during draw events are shown on the secondary Y-axis (right) for reference. The two patterns imposed are clearly identifiable on the chart, where the higher temperature values are typical of ASHRAE 90.2 and the lower temperatures are caused by the higher demand of the NREL/BA. Even though the 60-gallon HPWH is 20 gallons smaller in volume, it was able to maintain tighter temperature control. The 80-gallon HPWH, on the other hand, demonstrated average-weighted daily temperatures deviating more than 10°F, specifically during winter and early spring seasons.

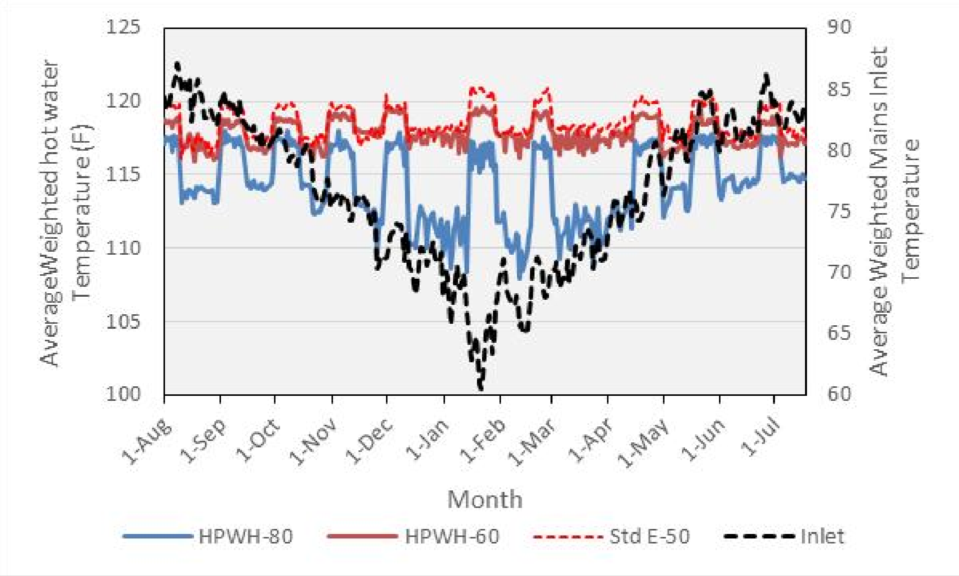

Figure ES-3. Seasonal hot water temperatures (°F) delivered (flow weighted) by standard 50-gallon electric baseline, 60- and 80-gallon HPWHs and mains inlet water temperatures

The average daily electric consumption plotted by month for each system under a typical (NREL/BA) load draw schedule is shown in Figure ES-4. The plot shows a small seasonal variation in electric consumption for HPWHs when compared to the baseline electric, as they capture heat from the relative seasonal warm air present at the laboratory site (50°–89°F daily average).

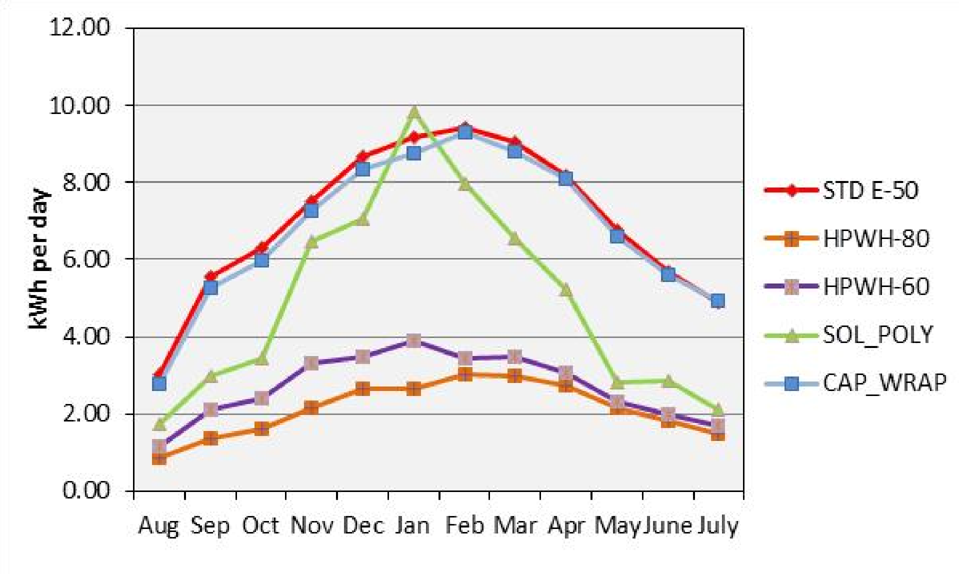

Figure ES-4. Average daily electric consumption for electric based systems

In the natural gas category, efficiency improvements in the range of 5% are evident by comparing results of the newest baseline natural gas water heater against those measured in previous rotations (COP of 0.59 vs. 0.56). Slightly higher operating efficiencies demonstrated by the baseline natural gas water heater are due to the extra inch of insulation (18 in. outside diameter) compared to the previous baseline unit used during 2009–2013. Average monthly performance under combined hot water draw schedules for the baseline (NG_Base) and hybrid (NG_Hyb) natural gas systems can be observed in Figure ES-5.

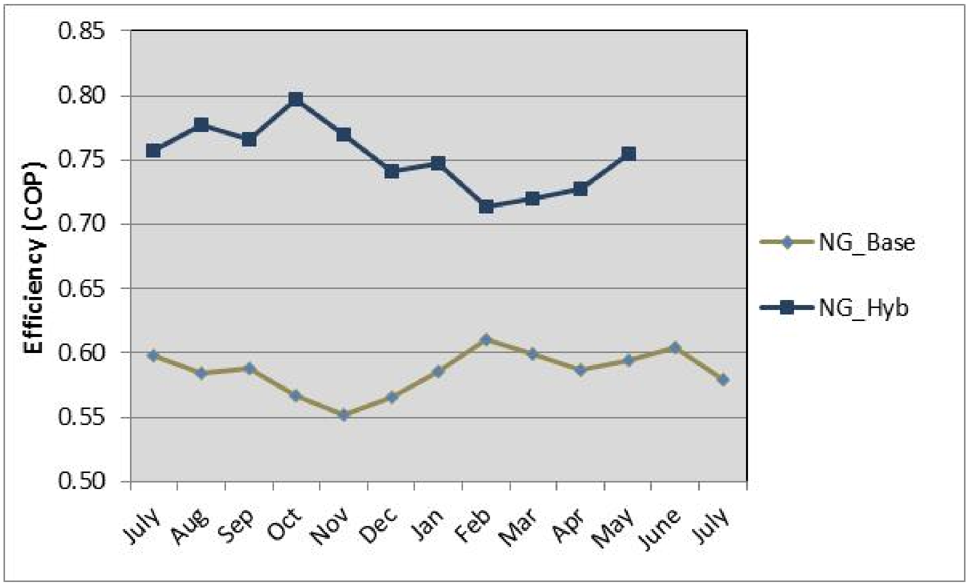

Figure ES-5. Average monthly site efficiencies (COP) for natural gas-fueled water heating systems

Compared to the baseline, the natural gas hybrid with storage operated at 25% higher efficiency, on average. However, the hybrid unit experienced a series of control malfunctions after 11 months in operation. It is now known that AOSmith has discontinued manufacturing the hybrid unit (HYB-90N). Despite its high parasitic power (576 Whrs/day), in part due to its 1/8 hp recirculation pump (~90 W), the unit is capable of instant hot water delivery due to its 27-gallon buffer storage. This feature improves on the ramp-up heating delay and cold sandwich intermittent temperatures associated with conventional tankless units.

As covered in previous BA-PIRC hot water heating laboratory reports, time-of-day energy demand was also investigated (site and source). Figure ES-6 presents the time-of-day source energy demand for all systems where the NREL/BA hot water draw schedule was imposed. Both HPHW units of medium capacity appear to shift and flatten electric demand compared to the electric resistance baseline. The 60-gallon HPWH also demonstrated a similar peak demand (~8 kBtu/hr) when compared to the 40-gallon natural gas unit. However, it also demonstrated 20% less source energy demand when integrated for the average day (32.3 kBtu/day).

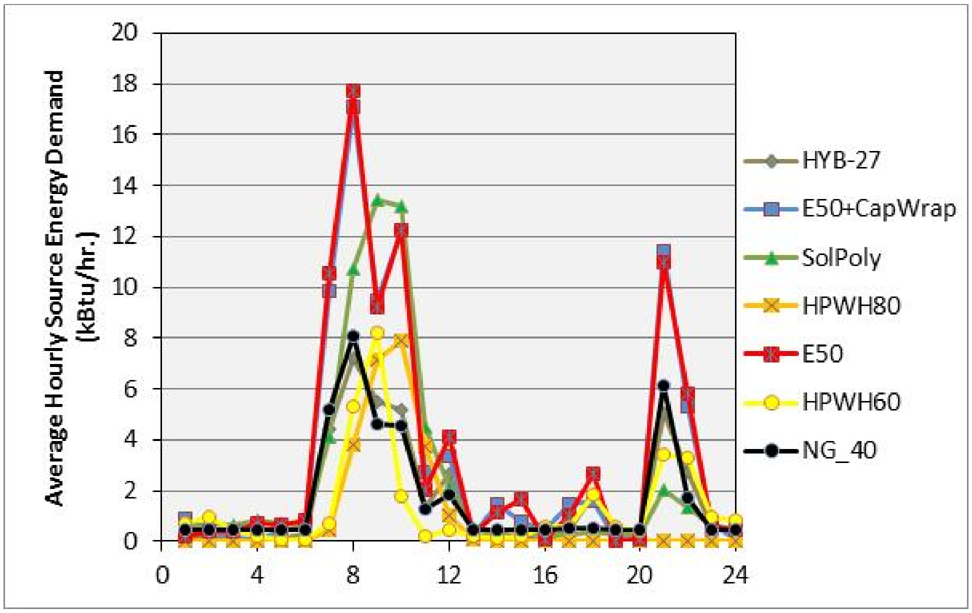

Figure ES-6. Comparison of time-of-day source energy of electric and natural gas water heaters averaged over the 12-month period, ending in July 2014

In conclusion, laboratory research measured the efficiency performance of larger capacity 60 and 80 gallons HPWHs, respectively COP of 2.2 and 2.5, under both standard and realistic family draw schedules. The 60-gallon HPWH managed to provide hot water under the typical load at an average electric consumption of 2.7 kWh/day. This represents a 61.5% efficiency increase over the standard electric baseline. It also indicates a favorable simple payback of 7.6 years (at $1,600 retail price paid) with an energy savings of 1,737 kWh per year at $0.12 per kWh. Unlike the previously tested 50-gallon HPWH, the 60-gallon HPWH managed to deliver hot water with minimal deviation from its temperature 120°F setting. Delivered temperatures were comparable to the standard electric water heater under heavy winter load. The 80-gallon HPWH, although it did not manage as well in providing temperature regulation due to its factory-set 20°F deadband, should be more than capable with the proper programmed turn-on setting 8°F or less. The 80-gallon HPWH, having a centrifugal fan type, operated with less noise—a welcome feature if installed indoors.

The solar water heater polymer-glazed collector with 80-gallon storage reduced the single element electric consumption by 30%. Furthermore, this type of polymer collector (27 lbs each) has a lower installed cost potential over traditional copper-based solar thermal systems. It is important to note that plumbing arrangements at the HWS laboratory present a larger than typical solar circulation loop length (>70 ft one-way), although insulated, may incur higher circulation losses.

Regarding the electric water heater, wrap and cap insulation retrofit system, the argon-filled wrap proved better performance compared to a triple bubble-wrap strategy. Data indicate superior benefits of the argon insulation properties preventing heat losses at lower tank (120°F) to ambient temperature differences. Warm year-average ambient temperatures (e.g., 72.4°F and 77.2°F measured outdoors and indoors, respectively, at the HWS laboratory facility) are typical of Florida's hot-humid climate. Improved insulation would be beneficial under this scenario, and would provide faster payback. For example, a hypothetical argon blanket and insulated water heater cap at a cost of $40 with argon or $30 air bubble wrap would have a simple payback of three and four years, respectively, for year-average ambient temperatures of 75°F assuming a $0.12/kWh cost.

This fourth round of HWS evaluation completes a final rotation of data collection under the methodology explained including a thermostat setting of 120°F. Follow-up evaluation efforts on HWS have already begun, but concentrating only on the typical load draw schedule. Field data from a previous residential hot water research study on 125 homes in central Florida support that the average residential thermostat is set to deliver 127°F. This level of temperatures also indicates that the actual thermostat setting is higher than the average temperature measured. Currently, the BA-PIRC HWS laboratory has increased thermostat settings on all water heating systems to 125°F to better represent field conditions. Coincidentally, the new testing procedure to determine the uniform energy factor for water heaters starting in 2015 utilizes a thermostat set point of 125°F.

1 Introduction

The Florida Solar Energy Center (FSEC), under the Building America program, has completed a year-long evaluation of residential hot water heating systems (HWS) in a laboratory testing environment of east Central Florida (hot-humid climate). The work is sponsored by the U.S. Department of Energy's (DOE) Building America Program and executed under the Building America Partnership for Improved Residential Construction (BA-PIRC) team at the FSEC under subtask 2.2.1.

This report contains a summary of research activities regarding the evaluation of two residential electric heat pump water heaters (HPWHs), a solar thermal system utilizing a polymer glazed absorber, and a high efficiency natural gas system. Electric baseline data were collected from a standard 50-gallon electric water heater to compare performance and energy savings achieved by other systems that undergo testing simultaneously side-by-side. A standard residential 40-gallon gas water heater with atmospheric-vented flue served as baseline for the natural gas fuel category. This newest water heater with a 0.62 energy factor (EF), having 1 in. of extra jacket insulation (18 in. outside diameter), replaced a former baseline (EF = 0.59) utilized in three previous evaluation rotations (2009–2012). A high-efficiency, natural gas hybrid integrated water heating system was measured and its performance compared. Systems were evaluated for a year under the criteria specified elsewhere in this report (i.e., 120°F set point, 1.5 gallons per minute) using two alternating hot water draw schedules: ASHRAE 90.2 and an NREL/Building America load schedule, where the latter represents that of a typical family load profile. The year-long evaluation began in August 2013, alternating draw schedules every month through July 2014.

1.1 Testing Facility and Hot Water Systems

The HWS laboratory (Figure 1) is an unconditioned 10 ft x 16 ft structure, with uninsulated vinyl siding walls and a white metal roof. It is located on the west end grounds of FSEC's premises in Cocoa, Florida.

Figure 1. The HWS laboratory is a 160 ft^2 building with metal roof, housing seven systems and one externally-mounted tankless water heater.

The laboratory, which has been operating at FSEC since 2009, has undergone four year-long testing rotations. The fourth and latest testing rotation (Phase IV, 2013–2014), detailed in this report, evaluated five unique water heating systems with capacities or technology types differing from those previously evaluated. These systems are compared against their respective fuel (electric or natural gas) baseline system. The small 160 ft^2 building serves as housing for seven hot water tanks or systems with a tight side-by side layout configuration (see Figure 2).

Figure 2. HWS laboratory layout and systems for 2013–2014

Hot water draws are measured with positive displacement flow meters, which are also used as feedback control mechanisms. Individual hot water solenoid valves for each system follow programmed time-schedule draws.

The HWS laboratory had previously evaluated a 50-gallon HPWH. The latest two HPWHs having 60 and 80 gallons of hot water storage, provide additional data and performance measurement of this technology, also operating in its highest efficiency (refrigerant-compressor) mode (Colon and Parker 2013). Testing performed in Florida also enhances operational HPWH efficiency results such as those published by NREL which has evaluated this technology (Sparn, Hudon, Christensen 2014).

Under the natural gas category, a high efficiency hybrid tankless condensing with integrated storage (27-gallon buffer tank) system was evaluated. The integrated storage tank features a centered-top (entry) and side (exit) flue passage where the combustion exhaust of the tankless heater is forced via internal fan. The flue then bends upwards through a 90 degree elbow where it exits at the top of the unit to be vented outdoors. As with most condensing-type tankless units operating to deliver in the 120°F hot water range, polymer (PVC, CPVC, or ABS) flue piping connections can be used instead of stainless steel, which save on installation costs. Because of the hot water storage buffer, the system is able to deliver instant hot water compared to a tankless system that needs a ramp-up heating period if the heat exchanger is cold.

A natural gas water heater with 40-gallon capacity and improved insulation thickness serves as baseline. This water heater may be capable of complying with 2015 minimum code standards, having an EF of 0.62. However, the latest revision of final ruling on water heater rating methodology released in June 2014 indicates that the former EF rating does not necessarily directly carry over to the new efficiency rating, referred to as the uniform energy factor (UEF).

A brief description of the seven water heating systems evaluated follows:

- Standard 50-gallon electric water heater: Electric baseline reference heater

- Standard (upright vent) 40-gallon: Natural gas baseline reference heater
- This latest generation of standard natural gas water heaters with thicker jacket insulation (18-in. tank OD) feature a new thermostat design with intelligent diagnostics. The constant burning pilot flame provides enough energy to drive a thermopile providing power to the microcontroller for monitoring, burner control, and LED diagnostics. This feature, however, does not appear to provide any benefits of increased efficiency.
- Standard 50-gallon electric water heater with insulated cap (0.5 in. of airspace + radiant barrier + 2.0 in. of polyisocyanurate) and insulation blanket wrap (a or b)

  a) Blanket wrap + insulated cap: Argon-filled (advanced type honeycomb chambered) double-sided aluminum metallized film

  b) Blanket wrap + insulated cap: triple-layered, double bubble insulation foil wrap with double layer of aluminum metallized film.

High-efficiency electric systems (Figure 3) were tested using the factory default hybrid efficiency mode:

- Electric 80-gallon HPWH: AirGenerate (ATI 80)
- Electric 60-gallon HPWH: AOSmith Voltex (PHPT-80)

Figure 3. Two heat pump water heaters of large and medium storage capacity (80 and 60 gallons)

High-efficiency natural gas: AOSmith HYB 90N

- Hybrid natural gas tankless (Figure 4) condensing with storage buffer: A packaged integrated unit consisting of a tankless heat exchanger unit and condensing water heater forcing the exhaust flue gases through a 27-gallon storage tank.

Figure 4. Hybrid natural gas tankless condensing with storage water heater

Solar Thermal (Polymer): UMA EcoSpark

- Electric-assisted solar thermal with a polymer-glazed collector: Two flat-plate polymer-glazed solar thermal system (58.5 ft^2 total collector area) – direct open loop with 80-gallon solar storage tank (single-element, Huch Brand) and active pump (Grundfos 120 VAC, 68 watt at medium-speed setting) controlled by a differential controller (8°F turn-on, 4°F turn-off differential).

The imported (Magen, Israel) solar system is designed to compete in the marketplace priced at lower cost compared to traditional copper based collector systems. The collectors being of polymer material are freeze tolerant, lightweight (27 lbs each), provide an aesthetic low profile and are easy to install, reducing labor costs (Figure 5).

Figure 5. Solar polymer collector (glazed) at FSEC's HWS laboratory (Cocoa, Florida) mounted on roof test stand

The solar collector system is comprised of two 3.9 ft x 7.5 ft absorbers with connecting manifolds that allow multiple collectors to be attached. The molded manifold connector system utilizes a flat gasket with secured clip mechanism—a clever design for mounting the collector to the roof substrate, which takes into consideration expansion of the absorber. On shingle-based roofs, a molded polymer mounting base is attached to the roof with lag-bolts, penetrating the roof plywood substrate into the top chord of a truss. The mounting base system allows lateral and vertical movement of the collector as it expands and contracts. A sliding polymer T-shape rail is molded and protruding as part of the collector header. The T-shaped rail is attached to a sliding attachment that allows horizontal and vertical movement along the roof, sliding on its bolted base footer (Figure 6). The collector is also designed to be freeze tolerant, having the capability of expanding in case of water freeze.

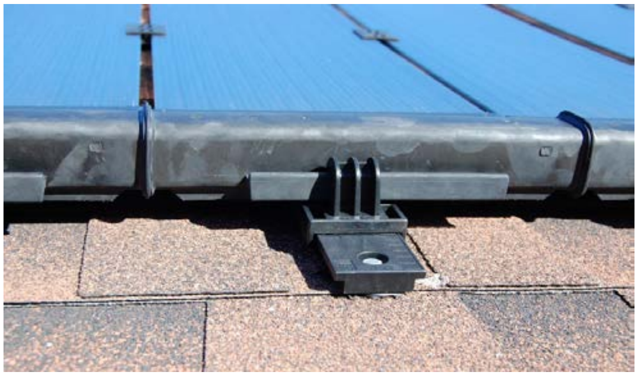

Figure 6. Solar thermal polymer collector slide-rail type roof mount

1.2 Methodology

As in previous rotations performed between 2009 and 2013 at the HWS laboratory, the strategy implemented for hot water heating system evaluations utilized alternating draw schedules every month. The ASHRAE 90.2 and NREL/BA hot water draw schedules were used as hot water load patterns to evaluate all systems. The ASHRAE schedule imposes a uniform load schedule throughout the year, while the NREL/BA schedule changes dynamically in volume magnitude each month (Figure 7). Residential field data collected in Florida, indicate larger volumes of hot water use in the winter season compared to summer months, as indicated in Florida reports to the Florida Public Service Commission (Merrigan 1983) and Florida Power Corporation (Masiello and Parker 2000). This latter usage pattern plays an important role in the operational evaluation of HWS because it represents a typical varying seasonal hot water load. The NREL/BA draw schedule is adjusted monthly to draw as much as 67 gallons per day (gpd) in the winter months, with a low approaching 42 gpd in summer months.

Regarding hot water draw events, draws were initiated at any minute within the hour when using the NREL/BA schedule, while draws using the ASHRAE were initiated at the beginning of every hour.

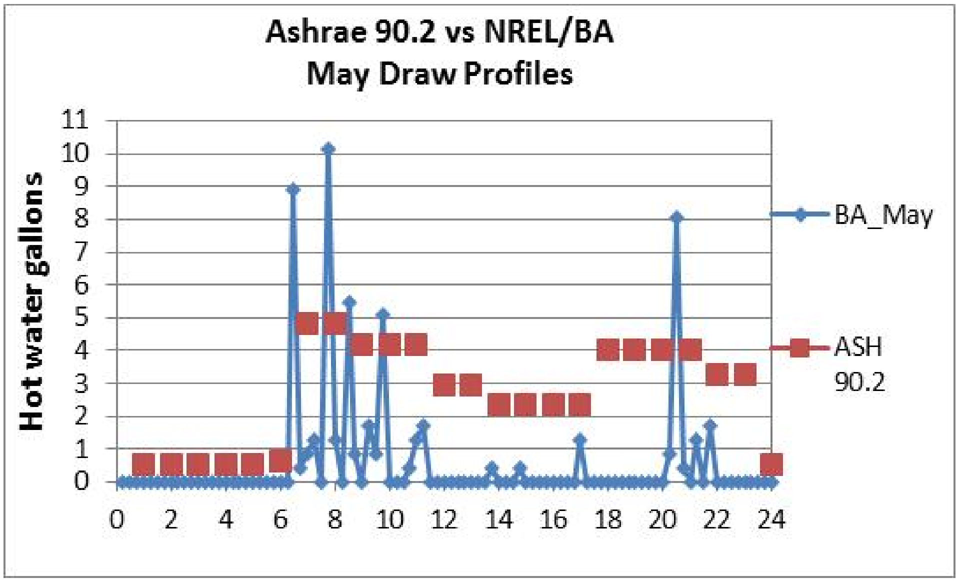

Figure 7. Comparison of ASHRAE 90.2 and NREL/BA (month of May) draw schedule

1.3 Instrumentation and Data Acquisition

The HWS laboratory automated instrumentation and controls are programmed into a Campbell Scientific CR10X which executes measurements every 12 seconds. Data are then averaged (e.g., temperature) or totaled (e.g., watt-hour pulses) into 15-minute intervals, stored, and time-stamped into final memory. A custom program takes into consideration the hot water draw events that occur during the day. Inlet water temperatures were physically measured using ungrounded immersion well (stainless steel) type T thermocouples of special limit error (SLE +/-0.5°C) positioned upstream of the flow meter at floor level to avoid convective temperature migration from the tank. Hot water outlet temperatures were also measured with immersion thermocouples at the system positioned less than 6 inches from the outlet port. The immersed thermocouple sensors were positioned to measure in a counter-flow direction. Additional processing routines were written to handle inlet and outlet temperatures to be averaged only during hot water draw events. The data are automatically uploaded twice per day via facilities network and archived under FSEC's GET database capabilities. The accessible database is linked to a custom online web page that reports a daily summary with statistics at www.infomonitors.com/HWS/. Power measurements were performed using Continental Controls WNB-2D-240P watt-hour transducers (+/-0.5%) and flow measurements were acquired from Elster positive displacement meters (+/-1.5%) equipped with pulse initiating output. Daily energies, efficiency COP, and inlet and outlet temperatures are calculated and displayed on the default summary page. Inlet and outlet water temperatures for the day are calculated and reported as weighted averages. This weighting process takes into consideration the magnitude of hot water volume in the average process. The database enables researchers to perform basic analysis and compare archived data such as the seasonal inlet city water temperature shown in Figure 8 for 2009 through 2013.

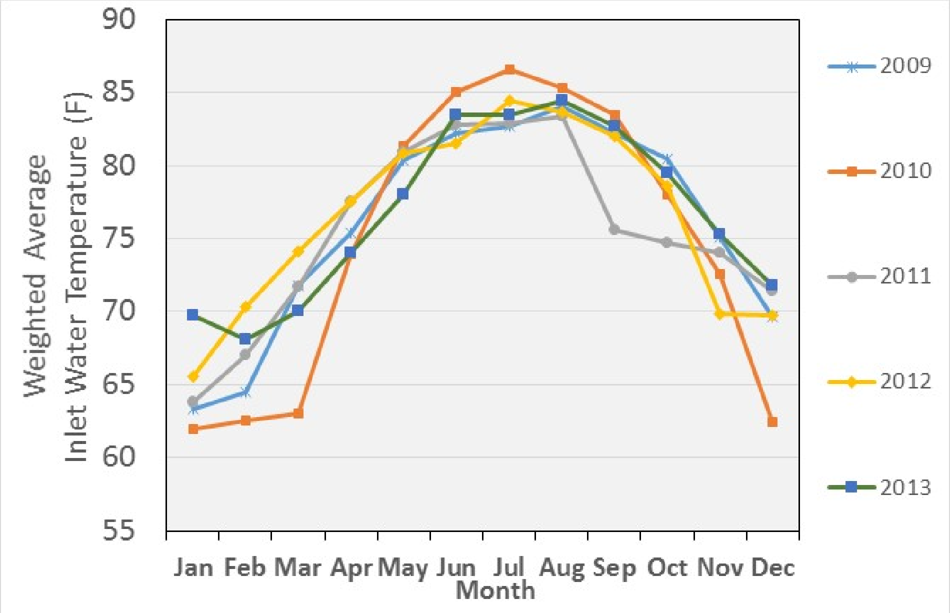

Figure 8. Five-year (2009–2013) compilation of inlet water temperatures (°F) at the HWS laboratory in Cocoa, FL

Inlet water to the HWS laboratory is supplied by a 1-1/4 in. PVC water line that is over 100 ft long and buried 18 inches below grade.

2 Results

2.1 Thermostat Setting and Hot Water Delivered

Thermostat setting on the electric and natural gas baseline water heaters was accomplished by trial adjustments until hot water outlet temperatures reached daily weighted averages as close as possible to the intended 120°F level. On units featuring electronic thermostat with visual display, such as HPWHs and hybrid natural gas units, the 120°F level was simply dialed on the controller pad. Accuracy of setting via manual adjustment on analog thermostats is difficult to accomplish compared to digital electronic types because most manufacturer scales only provide a visual calibrated reference. The thermostat setting on the baseline reference, 40-gallon natural gas water heater, was also set carefully by adjusting the dial until the desired 120°F temperature was achieved. However, as experienced in earlier evaluations, setting the thermostat to 120°F can be a hard task since movements of less than 1 mm on the rotating dial may or may not provide the adjustment desired. The natural gas water heater thermostat was reset at least two times throughout the year. On one occasion, the temperature setting changed dramatically by itself, upwards (~130°F) deviating unexpectedly from the initial setting (120°F), as shown in the circled data points in Figure 9. Higher temperature peaks (135°F) flowed when the thermostat was counter rotated and adjusted to the previous mark noted before the dial was rotated. The exercise required another careful adjustment to bring the level back down, as shown in February and thereafter.

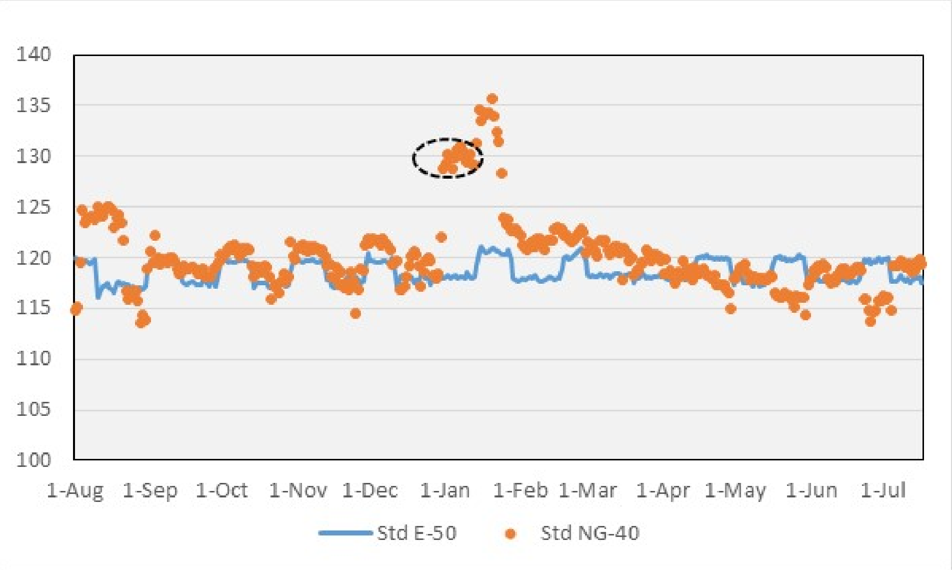

Figure 9. Behavior of thermostat settings for natural gas and electric baseline water heaters compared (120°F thermostat setting)

Table 1 shows a summary of hot water temperatures delivered that are average weighted (by volume) for each system. The second column lists the averages for combined hot water schedule draws. As seen in previous HWS evaluations performed at FSEC, daily hot water averages measured from the ASHRAE 90.2 draw schedule are typically closer to the thermostat setting (120°F). As reported in the first contract report (2009–2010), the average weighted temperatures delivered under ASHRAE 90.2 load measure higher compared to NREL/BA load schedule because magnitude of volume is the same year-round (Colon and Parker 2010). The right-most columns present the average hot water delivered for the family (NREL/BA) hot water schedule, exclusively. Hot water averages measure lower under this draw schedule due to the dynamic seasonal adjustment imposed and the sequence of draw repetitions representing typical family demand. Temperatures delivered by the 80-gallon HPWH clearly demonstrate higher deviation than expected due to the system's large thermostat "turn-on" deadband (i.e., a 20°F factory default). A 50-gallon HPWH previously evaluated (Phase II, 2010) while operating in its highest efficiency compressor mode demonstrated that hot water temperatures delivered during the winter season may be insufficient, approaching the low 105°F mark. The minimum and maximum average-weighted daily temperatures are also shown for the NREL/BA draw in the right-most columns. The evaluated 60-gallon HPWH performed well under the higher demand peaks of the typical schedule (NREL/BA) considering that the minimum daily average-weighted temperature of 116°F was the lowest reached.

Table 1. Average-Weighted Daily Hot Water Temperatures Delivered During Evaluation August 2013–July 2014

Hot Water Heating System	All Draws (°F)	NREL/BA (°F)	Min. Delivered (°F)	Max Delivery (°F)
Electric Standard	118.5	117.8	116.1	118.9
80-Gallon HPWH	114.3	112.7	108.0	115.7
60-Gallon HPWH	117.8	117.2	116.0	118.6
Solar Polymer w/80-Gallon Storage	118.9	118.4	114.5	127.0
Hybrid Tankless Condensing w/27-Gallon Buffer	119.9	118.3	108.7	124.2
Baseline Natural Gas 40-Gallon (2015 EF)	120.2	120.0	113.6	131.0
Electric 50-Gallon with CapWrap Insulation	119.6	119.2	117.4	120.2

Although the solar thermal with polymer water heating system maintained the consistency of hot water temperatures delivered, the mixing valve deviated with hotter temperatures shown by the maximum daily average of 127°F. The standard electric 50-gallon water heater with cap insulation and wrap achieves the closest temperature regulation to the 120°F set point due to its rapid recovery from the 4.4 kW heating element.

2.2 Performance Results

Averaged efficiency results for the combined hot water schedules over the one-year period ending in July 2014 are shown in Figure 10. The bar chart compares the daily average efficiency (COP) of five electric and two natural gas systems.

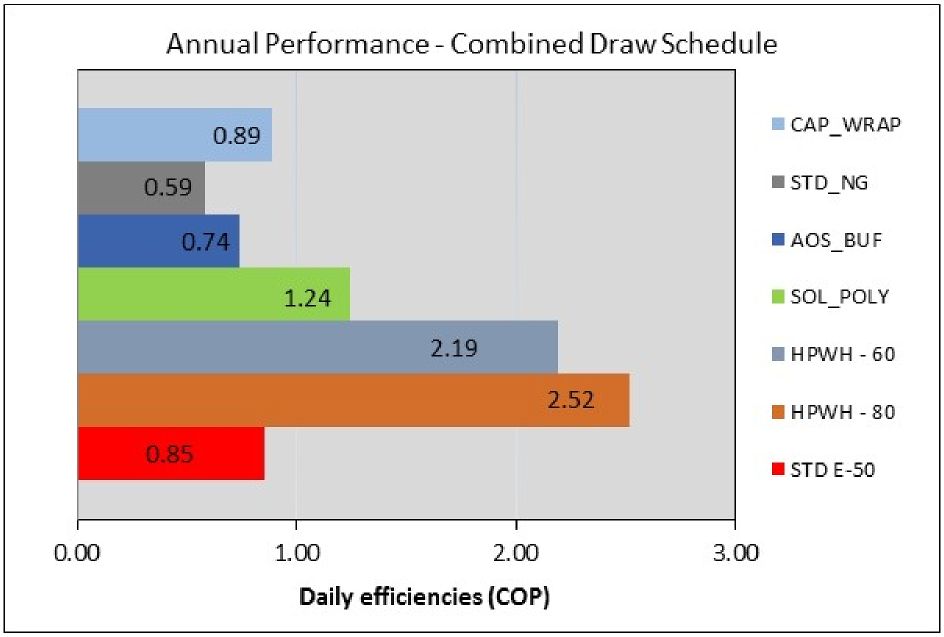

Figure 10. Average daily efficiency performance for electric and natural gas water heating systems for the one-year period ending in July 2014

The plot indicates that the 80-gallon HPWH leads in efficiency performance. As discussed in Section 2.1, the 80-gallon HPWH (HPWH-80) thermostat deadband was not on par with that observed by the 60-gallon HPWH (HPWH-60). The longer standby period behavior contributes to the higher COP shown, since storage losses are less compared to a system that recovers sooner. The 60-gallon HPWH demonstrated efficiencies of 2.19 COP, a 157% efficiency increase over the baseline of 0.85 COP.

The polymer solar thermal system managed to increase efficiency substantially (46%) over the baseline, but it did not match the performance of previously tested copper absorber flat plate systems. The standard 50-gallon electric heater fitted with insulated cap and blanket wrap as demonstrated in a previous rotation, improved performance by 4.7%. Two types of blankets were evaluated with the goal of improving on what had been measured before at a reasonable cost.

In the natural gas category, the hybrid-condensing system demonstrated efficiencies typical of tankless water heaters (25% over baseline), but parasitic energy used for the circulation pump and controls subtracted from achieving a higher performance.

Performance demonstrated by these systems under the typical NREL/BA hot water load schedule reveals a slightly lower overall performance (Figure 11).

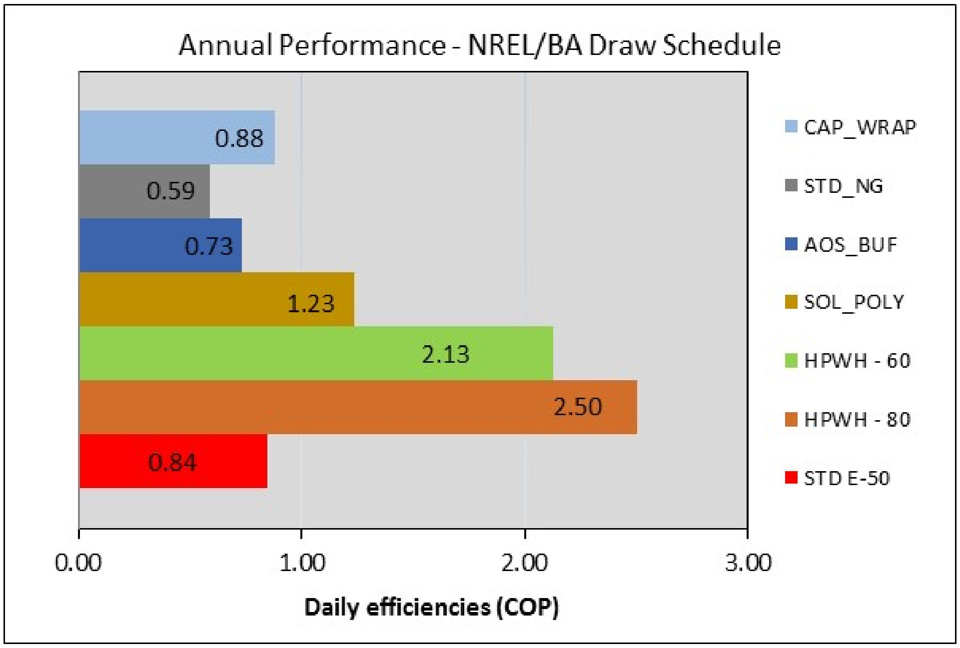

Figure 11. Average daily efficiency for NREL/BA draw schedule

The operating efficiency (COP) of the water heaters is completely independent of the EF because testing conditions are not the same.

3 Analysis

3.1 Monthly Efficiencies

Figure 12 presents the combined draw schedule average monthly performance for electric systems. HPWHs clearly demonstrated COP above 2.0, except for the month of January where the 60-gallon HPWH average efficiency (COP) measured at 1.9. Data indicate that there was electric auxiliary heating element activity for a short period during two days in January. Note that the 80-gallon HPWH benefited from the large deadband of its thermostat, which results in higher performance due to the reduced standby losses incurred.

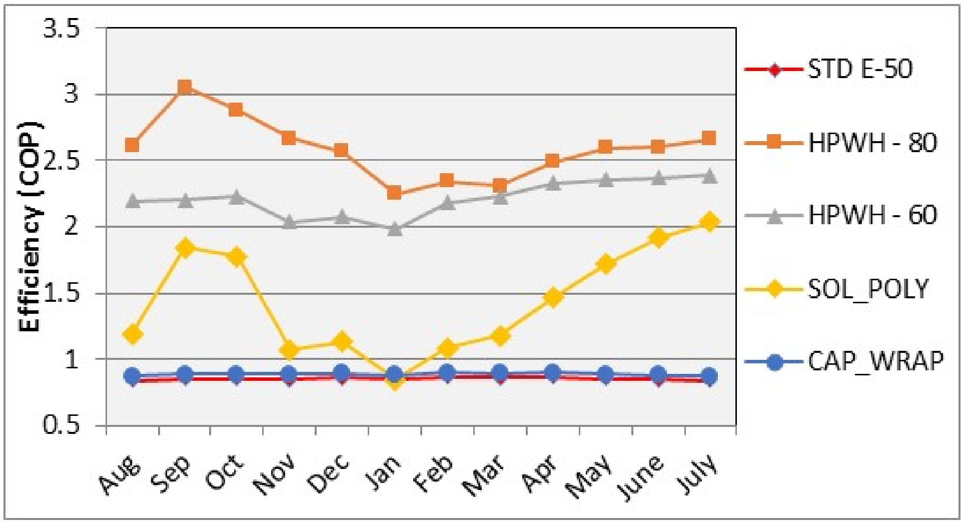

Figure 12. Average monthly efficiency performance for electric water heating systems from combined draws

Performance demonstrated by these systems for days where the NREL/BA hot water draw schedule was implemented reveals a slightly lower performance on all systems.

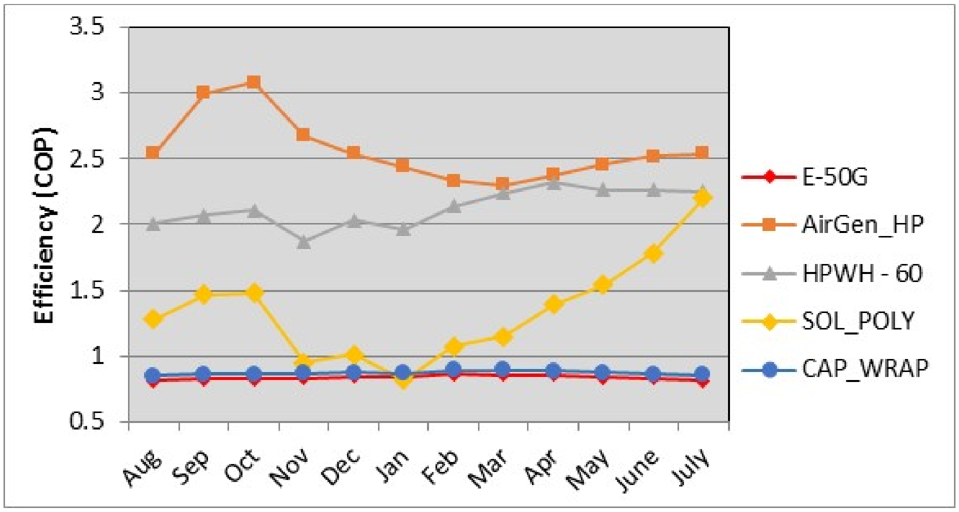

Figure 13. Average monthly efficiency performance for electric water heating systems based on typical NREL/BA hot water draws

The average monthly performance of the two HPWHs can be observed in Figure 14 against the laboratory ambient temperatures (averaged monthly).

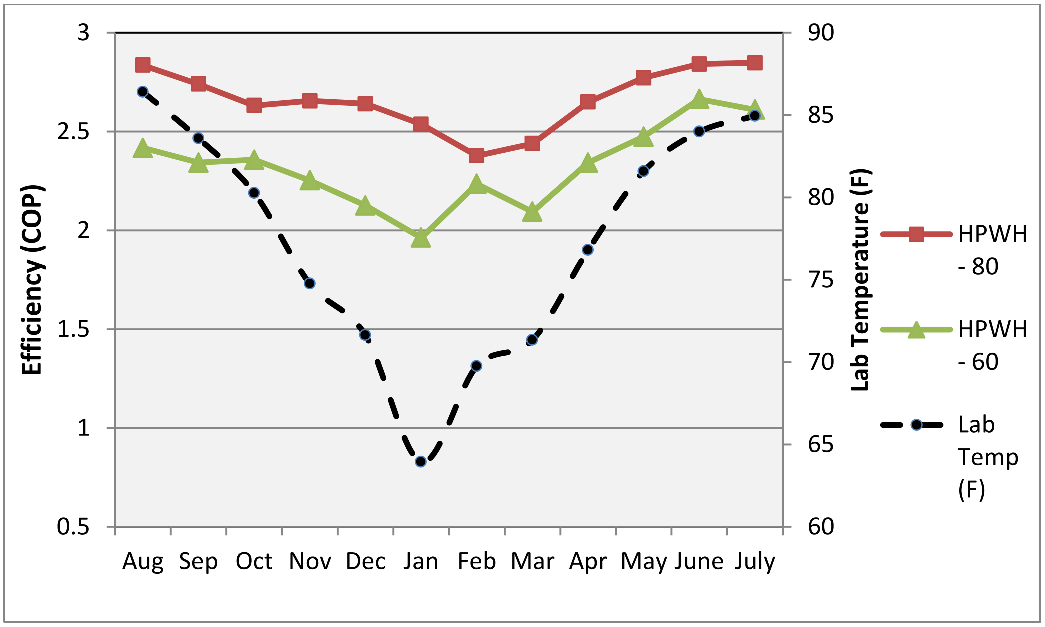

Figure 14. Efficiency of two heat pump water heaters compared showing seasonal average ambient temperatures (°F)

3.2 Solar Thermal Polymer Performance

The solar thermal polymer system utilizes an imported storage tank vessel (Huch brand). This tank relies on a soft-shell polymer and insulation material as opposed to urethane insulation steel shell used by most water heater manufacturers in the United States. Prior to installing the collectors on the roof stand, the 80-gallon storage tank was plumbed, pressurized with city water, and connected to its dedicated 240 VAC electric line. Draws were imposed during the last days of June through early August. The single-element 80-gallon water heater had good operation efficiency, perhaps due to the element position, which only heats the upper two-thirds of the tank. Efficiencies throughout the two-month summer period are shown in Table 2.

Table 2. Efficiencies Measured for Solar Storage Tank in Auxiliary Electric-Only Mode

	ASHRAE 90.2 (COP)	NREL/BA (COP)
June 2014	0.90	n/a
July 2014	0.91	n/a
August 2014	0.93	0.89

Beginning in mid-August, the solar thermal polymer collector loop was put into operation. The differential controller (Goldline) and 68-watt pump parasitic energy was included in the efficiency (COP) calculation. Monthly-daily efficiencies recorded during the one-year evaluation are plotted against the averaged kilowatt-hours used per day, as shown in Figure 15.

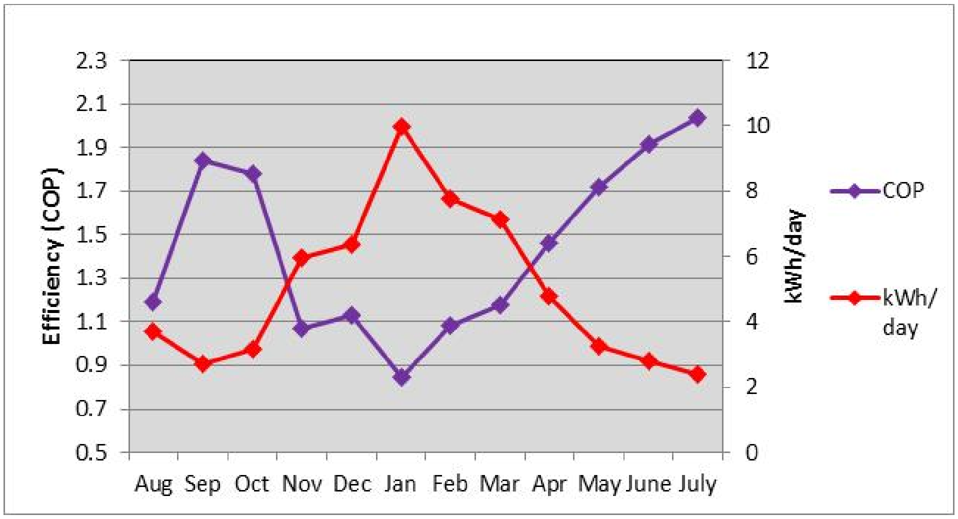

Figure 15. Solar thermal system efficiency and electric consumption throughout the year

Efficiency of the solar thermal polymer collector system experienced a similar solar winter performance which is sensitive to climate, loads, and sizing. Performance degradation has also been observed in other solar thermal systems previously evaluated.

3.3 Argon-Filled Thermal Blanket Insulation

The Fi-Foil gas-filled panel insulation is constructed of aluminum foil and polymer laminates that can be expanded to form chambers filled with argon gas. It was utilized as an advanced insulation wrap over a standard 50-gallon electric water heater (Figure 16, left). When filled and expanded with argon (a noble gas), it conforms to 1.5 in. thickness providing an R-6.4 level of insulation. The same product filled with air would provide an R-value of 5.0, as indicated in the Fi-Foil literature. Multiple vertical indented areas that make up the individual adjacent honeycomb chambers reduce the thickness, which may compromise the full potential effectiveness of the insulation. However, results generated by the argon gas-filled insulation system demonstrated improved benefits over the triple layers of double bubble (air) wrap insulation (Figure 16, right). The latter proved no better results than a two-layer wrap, tested earlier, and cost does not justify the added layer. As a result, the double-layer bubble wrap and insulated fitted cap, evaluated the previous testing rotation (2012–2013), remain a favorite low-cost (~$32) electric water heater tank insulation strategy. Insulation blankets made of polymer laminated aluminum foil are the preferred tank insulation method for indoor installation when compared to fiberglass blankets, because there is no possibility of airborne particulates which can impact indoor air quality.

Figure 16. Argon gas-filled wrap (left), triple-layer bubble wrap (right)

The average monthly electric use per day can be compared in Figure 17 between the baseline electric 50-gallon tank and the same with added blanket and cap insulation.

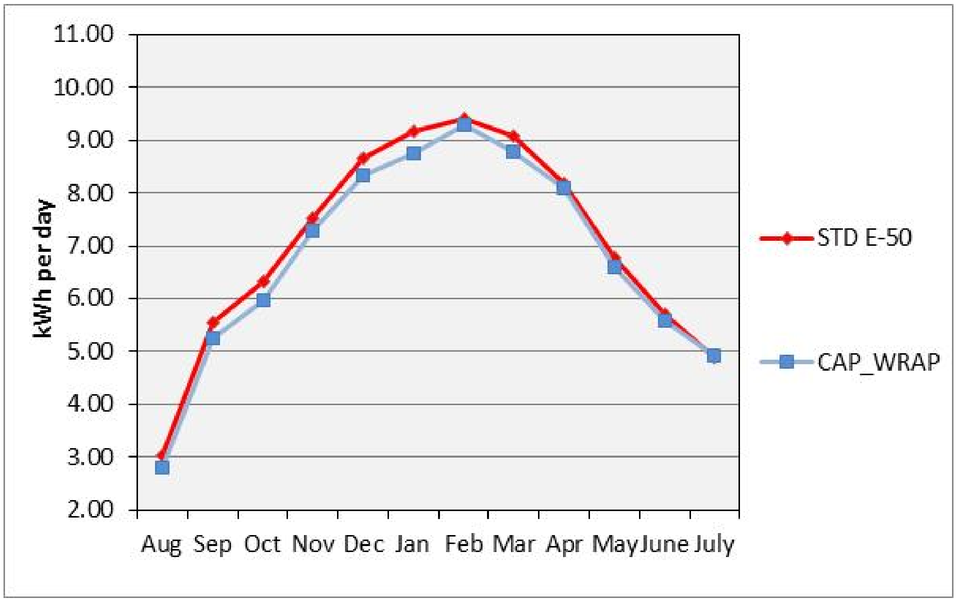

Figure 17. Average monthly daily electric consumption of two 50-gallon electric water heaters compared

During the period of September 13, 2013, through January 13, 2014, the argon-filled wrap was used as a blanket on the 50-gallon electric water heater. Figure 18 shows the daily energy savings as a function of the laboratory ambient conditions. Savings were calculated by subtracting the daily electric energy consumption of the insulated heater from the baseline heater, and plotted against average daily ambient temperature. As expected, higher savings are achieved with lower ambient temperatures. Note that some data points are shown as negative savings due to the random heater recovery controlled by the tanks' thermostats. If water heating recovery by thermostat activation were to happen before or after midnight, it would have a larger impact on the overall balance for that day.

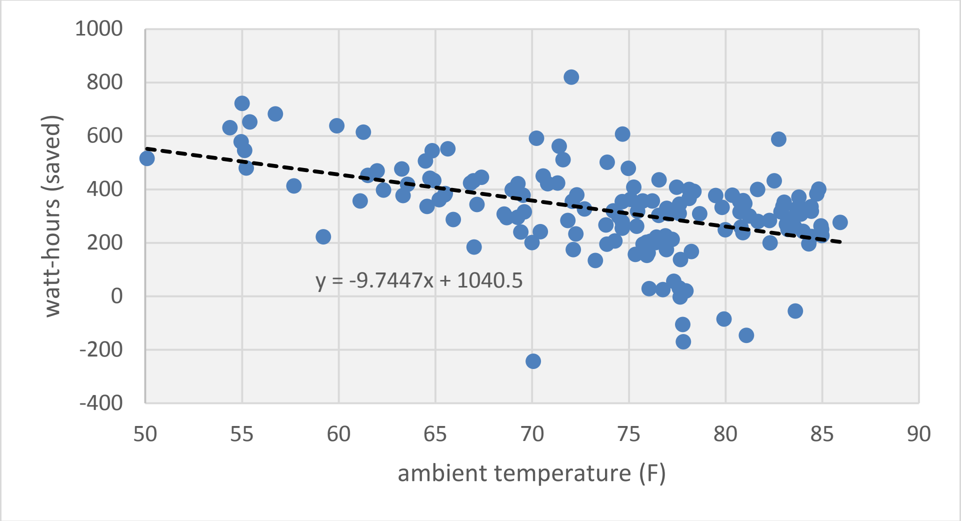

Figure 18. Daily electric savings as a function of ambient temperature (°F) comparing baseline electric 50-gallon tank against tank wrapped with argon-filled wrap and insulation cap

For the period of January 14, 2014, through July 20, 2014, results in Figure 19 were observed for the tank wrapped in a triple layer of bubble insulation. A higher negative slope was calculated, implying that less savings were attained at higher temperatures.

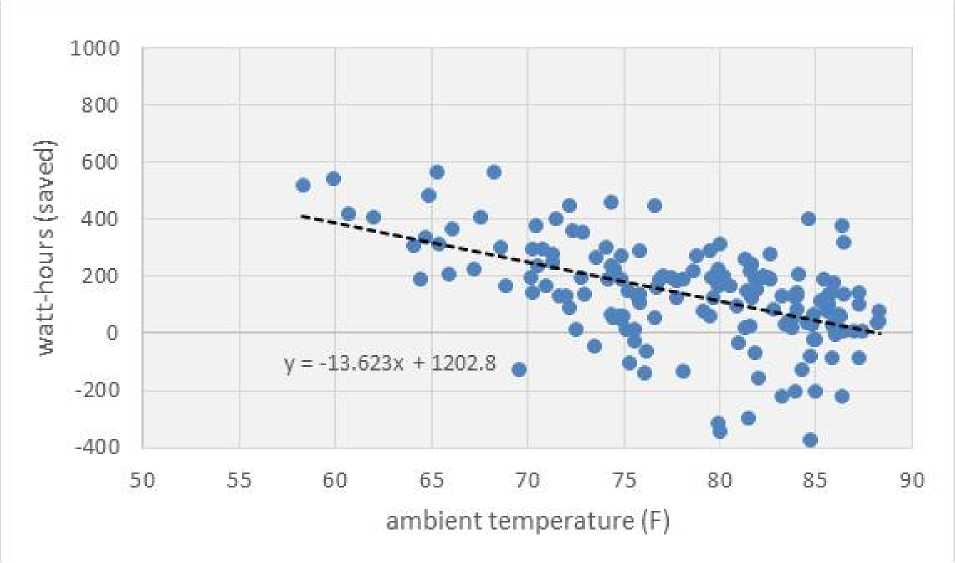

Figure 19. Electric savings as a function of ambient temperature (°F) comparing baseline electric 50-gallon tank against tank wrapped with aluminized triple bubble wrap and insulation cap

Figure 20 illustrates projected energy savings from the two wrap insulation blankets on a 50-gallon electric water heater operated with a 120°F thermostat setting. Linear regressions shown in Figures 18 and 19 were plotted and extrapolated until they intercepted the x-axis. The argon gas blanket wrap is capable of higher energy savings under warmer ambient temperatures, which are typical of hot-humid climates.

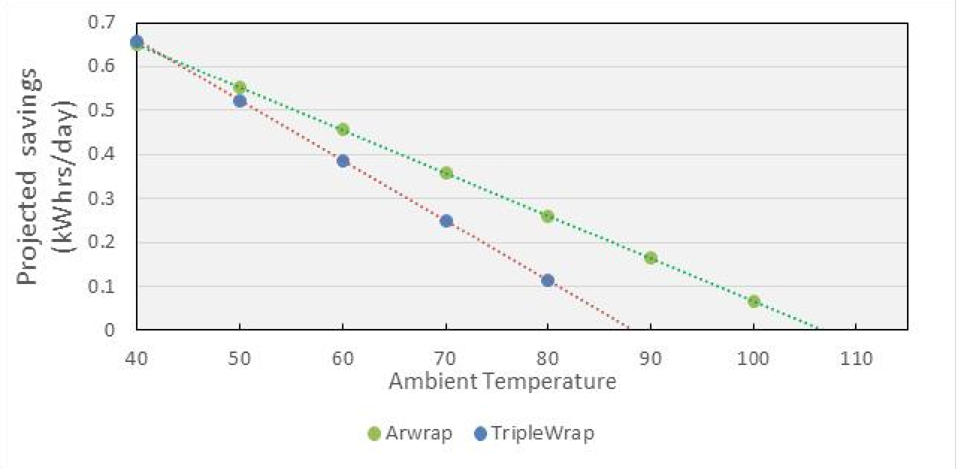

Figure 20. Water heater tank insulation strategies compared as linear function of ambient temperatures

Given the cost of electricity at $0.12 per kWh, the energy savings in Table 3 were generated as a function of ambient temperatures.

Table 3. Daily and Annual Electric Energy Savings for Two Tank Insulation Strategies with Projected Simple Payback

Amb. Temp. (°F)	Argon Wrap + Cap kWh/day	TripleBubble wrap filled + Cap kWh/day	ArgonWrap + Cap Energy Savings kWh/yr	Triple Bubble Wrap Energy Savings kWh/yr	Argon filled ($40) Simple payback at $0.12/kWh (Years)	Triple bubble ($30) Simple payback at $0.12/kWh (Years)
55	0.504	0.453	184.1	165.5	1.81	1.51
65	0.407	0.317	148.6	115.8	2.24	2.16
75	0.310	0.181	113.9	66.1	2.95	3.78
85	0.212	0.045	77.4	16.4	4.30	15.27

3.4 Natural Gas Systems

Compared to the baseline natural gas used in previous evaluations, slightly higher operating efficiencies demonstrated by the newer baseline natural gas water heater are evident from the data collected. The small efficiency increase is due to the thicker factory jacket insulation (18-in. outside diameter) compared to the previous baseline used during 2009–2013 (17-in. diameter).

The natural gas, integrated-hybrid tankless condensing unit with small storage operated at 25% higher efficiency on average compared to the baseline. However, the hybrid unit experienced operational failure disrupting the heating operation. Error codes were indicated by its display panel after 11 months in operation. It is now known that the manufacturer (AOSmith) has discontinued manufacturing and retracted this model. In contrast to its high parasitic power (576 Whrs/day), the unit is capable of instant hot water delivery due to its small buffer hot water storage (27 gallons), which improves upon the ramp-up heating delay associated with single tankless units. Site efficiency of the hybrid heater is compared against the baseline NG in Figure 21.

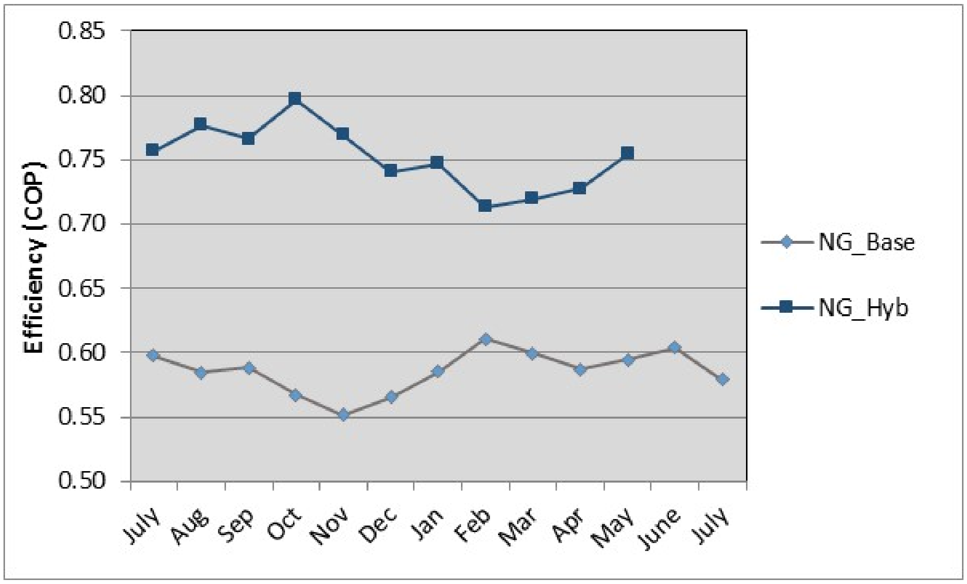

Figure 21. Site efficiency performance of baseline natural gas water heater compared to hybrid tankless condensing heater with buffered storage

The hybrid tankless condensing system with small buffer storage solves the instantaneous temperature delivery delay associated with tankless gas water heaters. However, the additional parasitic energy used by the internal circulation pump was found to increase dramatically, as a function of inlet water temperatures approaching winter season as shown in Figure 22. Davis Energy Group also noted a high parasitic energy use on this particular hybrid model in a field study on advanced residential water heating technologies in California (Hoeschele et al. 2011).

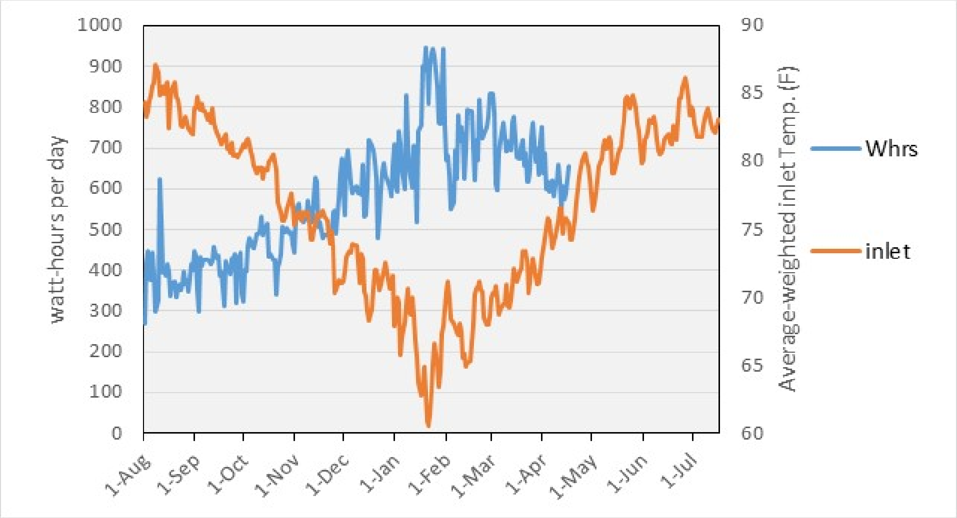

Figure 22. Parasitic energy consumption of hybrid tankless condensing unit with small storage for the period of August 2013 through April 2014

3.5 Average Daily Electric Use

Average daily electric use by month was plotted for the ASHRAE 90.2 (Figure 23) and NREL/BA (Figure 24) hot water draw profiles. Electric use can be compared between the two load schedules. Winter season consumption does not represent a drastic impact on HPWHs.

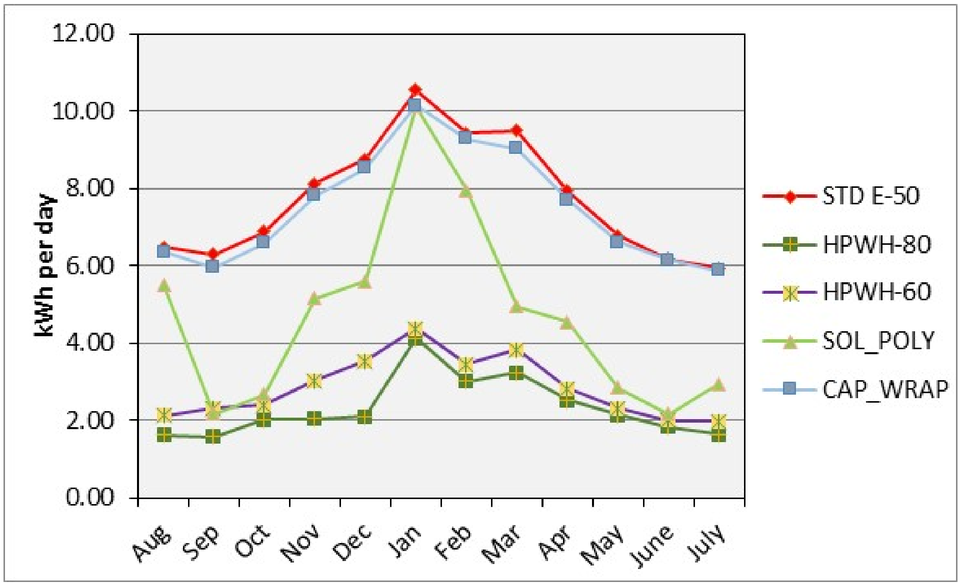

Figure 23. Average HWS daily electricity use for ASHRAE 90.2

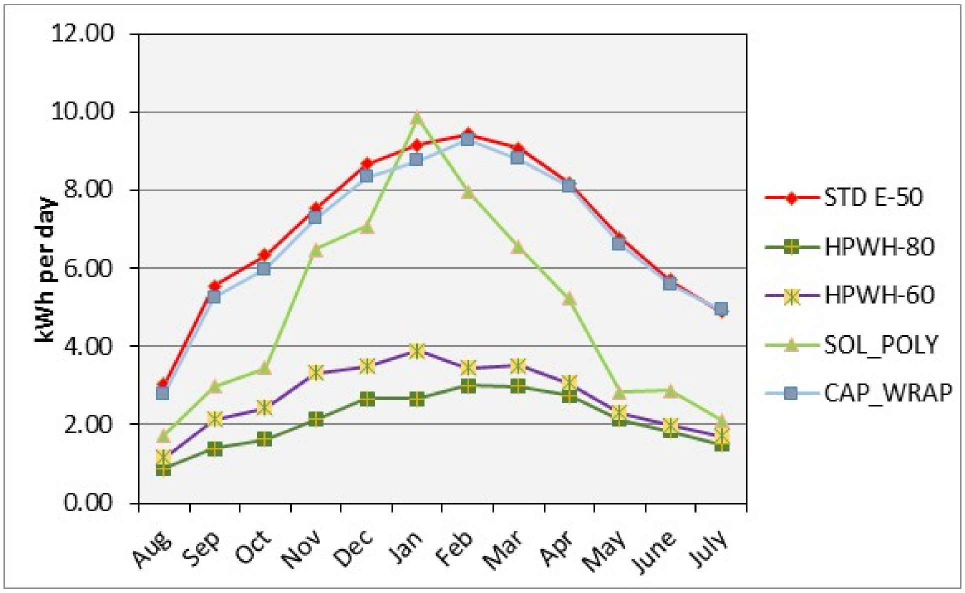

Figure 24. Average HWS daily electricity use for NREL/BA

The average daily electricity used for combined hot water draw schedules is shown in Figure 25.

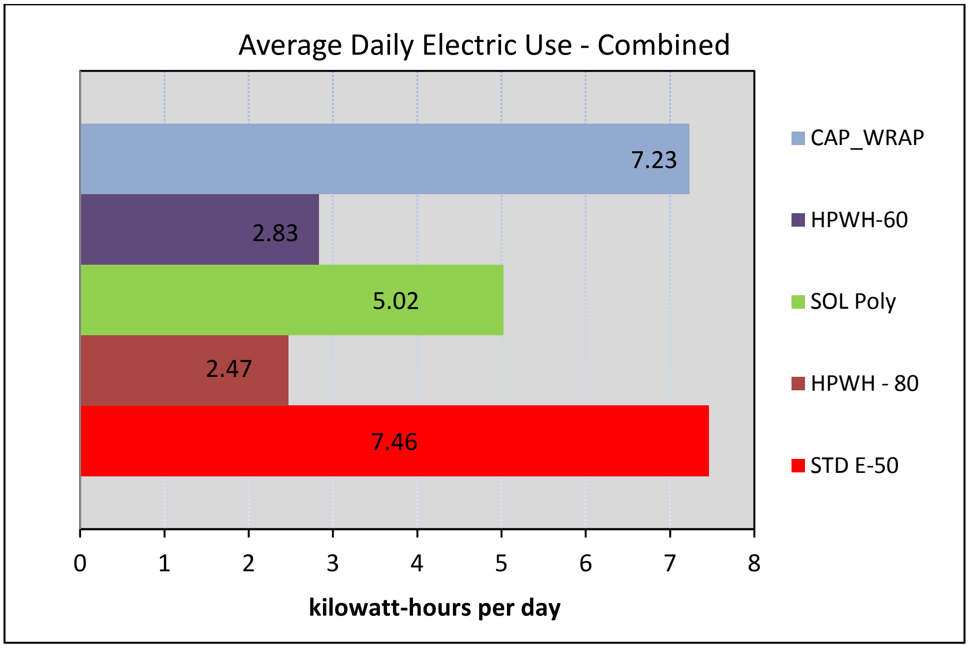

Figure 25. Annual average daily energy consumption for electric systems for combined draw schedules

3.6 Time-of-Day Demand

Electric demand comparison is reported as the systems operate in a simultaneous side-by-side configuration. Figure 26 reveals the overall electric system demand obtained from combined hot water draw schedules.

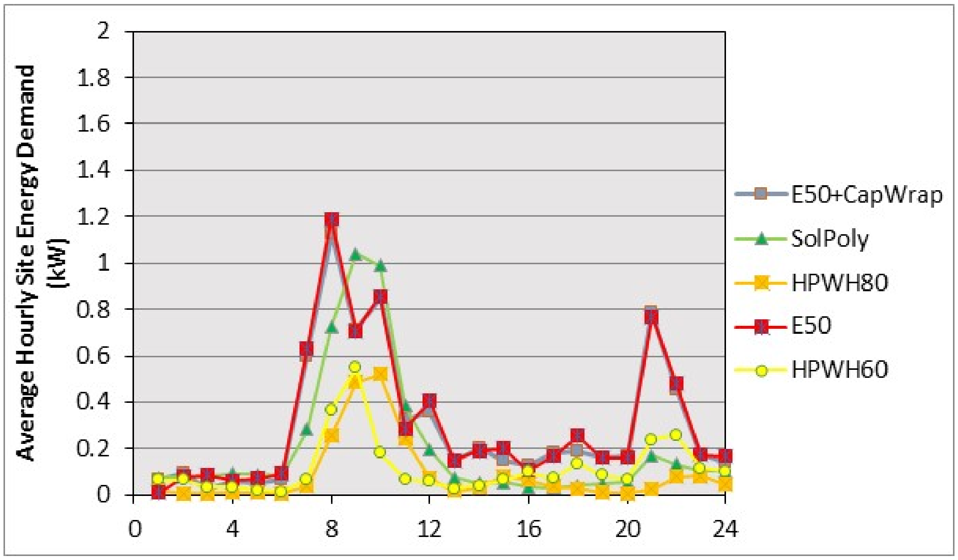

Figure 26. Time-of-day site energy demand for electric water heating systems; results are shown for combined hot water draw schedules

Site energy demand for electric systems under the NREL/BA hot water load schedule shows larger peak loads, as displayed in Figure 27. Larger capacity heat pumps (60 and 80 gallons) appear to have a slight shift in demand between 6:00 a.m. and 10:00 a.m., achieved from using an 800-watt compressor versus the 4.4 kW typical of heating elements used in this region. However, it is the 54% peak demand (1.54 kW vs. 0.71 kW) that makes these systems stand out. The solar polymer system also manages to reduce peak demand by 24% (1.5 kW vs. 1.1 kW).

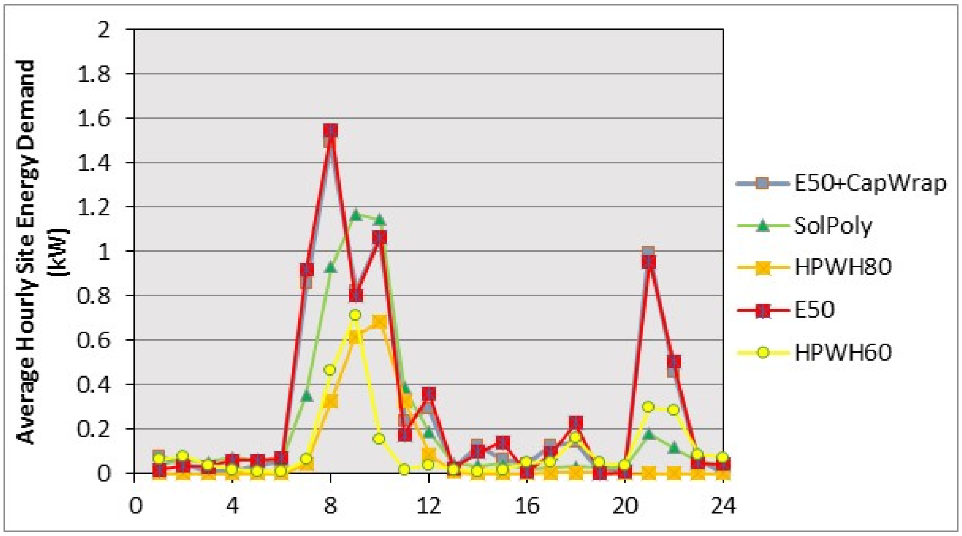

Figure 27. Time-of-day site energy demand for electric water heating systems; results shown are generated from a typical hot water draw schedule

Winter site demand under NREL/BA draw load schedule is shown in Figure 28. The peak demand reductions are shown beginning at 8:00 a.m. (2.0 kW vs. 0.75 kW and 0.6 kW) for the 60- and 80-gallon water heaters, respectively.

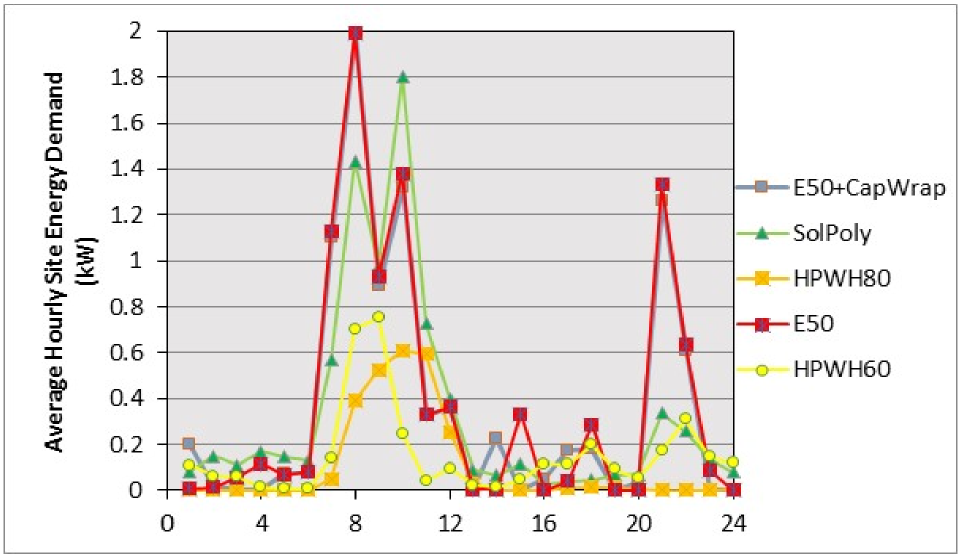

Figure 28. Time-of-day site energy demand for electric water heating systems; results are shown for a three-month winter season (Dec.–Feb.) generated from the typical NREL/BA hot water draw schedule

Time-of-day source energy demand calculated for all systems was analyzed by applying DOE source energy conversions for electric and natural gas (Me = 3.365 and Mg = 1.02). A conversion of energy demand using the same metric (kBtu/hr) allows the comparison between natural gas systems and electric systems (Figure 29). The plot reveals that the highest demand of HPWHs is comparable in magnitude (~8 kBtu/hr) to the natural gas heating systems on a source-level basis.

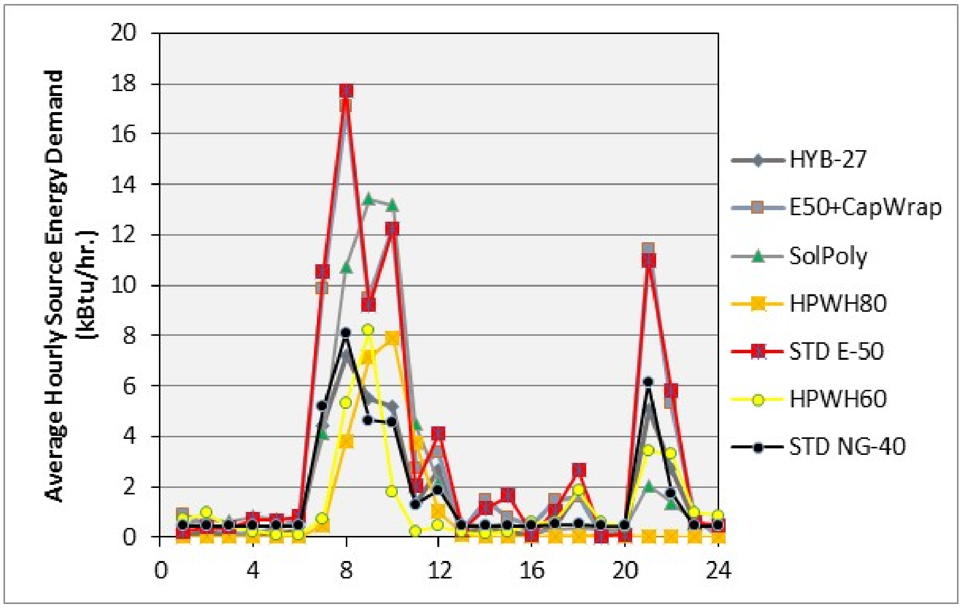

Figure 29. Time-of-day source energy demand for all water heating systems; results shown are generated from typical NREL/BA hot water draw schedules

4 Conclusions

The fourth year-long round of residential hot water heating evaluations completes performance measurements on a variety of systems operating under a hot-humid climate (central Florida). Data collected at the HWS laboratory during 2014 are the last gathered with a 120°F thermostat setting. Measured performance obtained from two HPWHs of medium and large capacity (60 and 80 gallons) enhances the range of electric consumption that has been established over the last five years of testing (2009–2014)[1]. The bar chart generated, as shown in Figure 30, places the latest high efficiency HPWH systems in a tally arrangement comparing a broad range of electric energy used on water heating equipment. The chart also establishes a general comparison of energy savings against a baseline electric 50-gallon water heater (labeled E-50). Although the inlet water conditions vary differently for each particular year period, the average daily energy use provides a realistic projection of Florida energy savings potential from various water heating technologies available in the residential market.

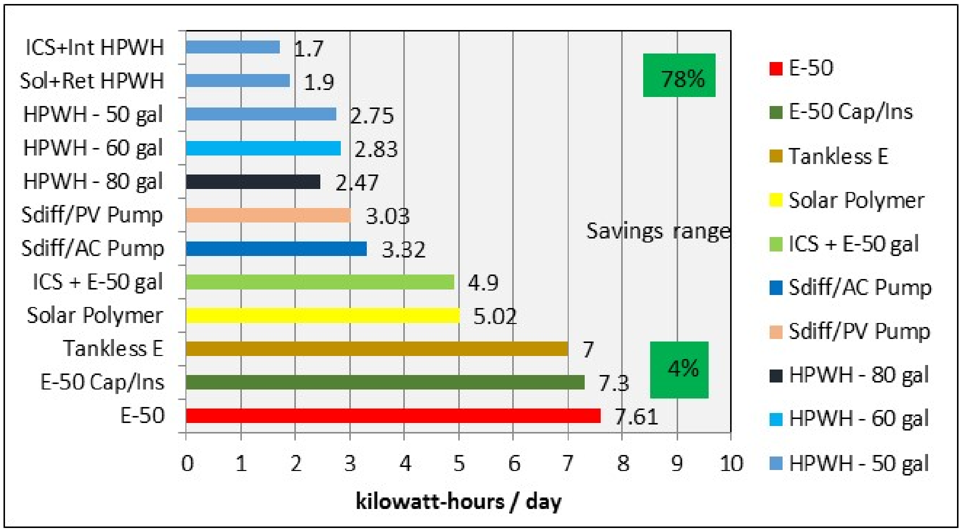

Figure 30. Overall comparison of daily use electric on a range of hot water heating systems gathered from 2009 and 2014, based on combined hot water draws ASHREE 90.2 and NREL/BA

The chart also provides a graphical view of efficiency achievements for water heating and may serve to promote and challenge the industry to develop systems that operate at an average of 1.5-2.0 kWh/day using solar energy. At the top of the chart, solar thermal collector based systems combined with auxiliary HPWH lead with energy savings in the 78% range. HPWHs are well positioned in the electric consumption scale, providing energy savings in the 65% range. Laboratory data suggest that under family hot water loads examined in this evaluation (~60 gpd), a 60-gallon heat pump provided enough hot water temperature levels comparable to the standard 50-gallon electric heater. These levels of hot water temperatures delivered by the 60-gallon HPWH are a positive outcome considering that a 50-gallon HPWH previously evaluated showed questionable hot water capacity during winter operation under most efficient compressor-only mode. The 80-gallon HPWH, as discussed in the body of the report, could not provide the same level of hot water temperatures delivered due to its high deadband setting of 20°F. However, due

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[1] NREL had evaluated similar HPWH from AirGenerate and AOSmith but different gallon capacities in 2011.

to its large capacity, there is no doubt that the 80-gallon unit can provide the same level of hot water with the proper setting (e.g., 8°F or less). The centrifugal fan featured on the 80-gallon HPWH reduces operational noise and is a welcomed asset for those units installed indoors.

In the natural gas category, residential-type system performance has been examined including the latest baseline heater with improved efficiency (averaged COP of 0.59). Similar operating efficiencies are to be expected from improved natural gas water heaters that comply with the upcoming 2015 UEF minimum efficiency standards.

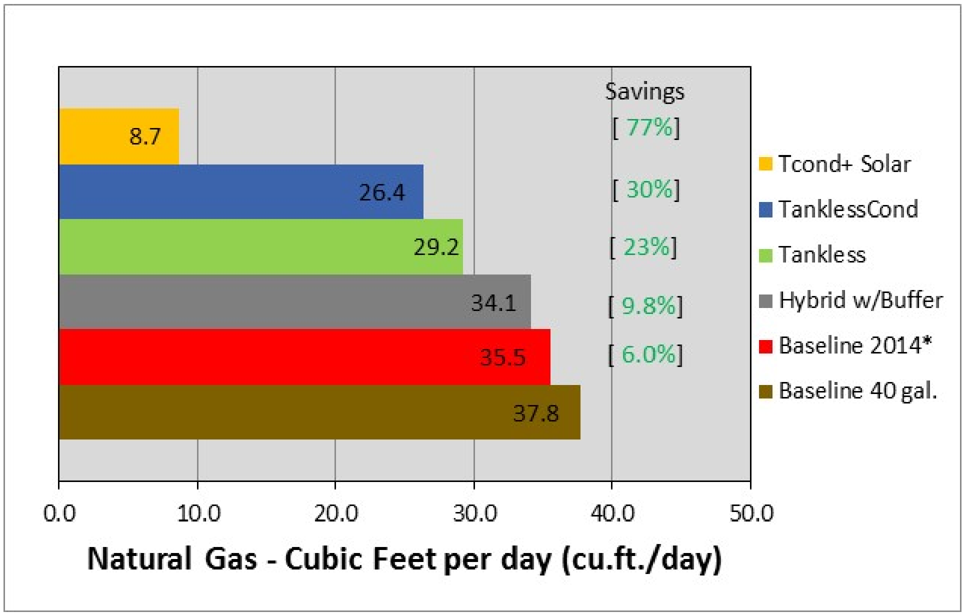

Figure 31. Overall comparison of average daily natural gas usage (cubic ft/day) by system, based on combined hot water draws ASHREE 90.2 and NREL/BA

A compilation of most common natural gas water heater performance obtained at the HWS laboratory from 2009 through 2013 is shown in Figure 31. The latest two systems present an improvement in fuel consumption of 6.0% and 9.8%, respectively, for the newest “baseline 2014” and the hybrid unit (no longer in production). The hybrid unit gas savings are significantly lower than the tankless units. Savings will vary with load and climate.

Results observed from these charts point out the level of energy consumption with the minimum thermostat setting recommended by code. Similar evaluation efforts have already begun at the HWS laboratory with the thermostat setting of 125°F. However, only three months of data have been completed, which would be too early to determine the average annual energy increase.

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