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Lab Testing of Advanced Gas Storage and Tankless Water Heaters

Building America Expert Meeting
September 28th, 2012

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Motivation for Testing

- Goal is to provide detailed understanding of general field performance and investigate operational issues of interest for gas-fired residential water heaters.
- Lab tests performed by:
  - Gas Technology Institute (GTI)
    - Focus on short-term performance of Tankless WHs with simulated use tests and a battery of short term tests.
  - PG&E Applied Technology Services (ATS)
    - Performed 24 Hour Simulated Use tests of Storage WHs, focusing on performance differentiation amongst higher EF SWHs, including parasitic electricity consumption.

NOTE: Neither PG&E ATS nor GTI are certified laboratories for the rating of residential water heaters, results reported are only relevant in relative comparison to data from this project.

Storage Water Heater Tests

> "15 Year Old" Water Heaters
  – 2 recovered from field test sites for EF degradation test
> 0.67 EF Energy Star Water Heaters (0.62 - 0.70 EF)
  – Performance comparison including electric parasitic for atmospheric (vent damper) vs. power vent vs. direct vent
  – Different hot water draw pattern 24 tests and derated EFs
> EF for Non-EF Rated Condensing Water Heaters
  – Generate non-certified EF rating for TE rated units
  – Different hot water draw pattern 24 tests and derated EFs

Storage Water Heater Results

Efficiency Results

Description	DOE First Hour Rating		DOE Std Draw [1]		GTI Mid Draw	GTI Low Draw
	Mnfr.	Test	Mnfr.	Test	Test	Test
"15 Year Old" Water Heater	63	80	0.64	0.59	0.60	0.44
0.62 EF Atmos	71	70	0.62	0.60	0.60	0.48
0.67 EF Atmos/Vent Damper	67	70	0.67	0.66	0.66	0.57
0.67 EF Power Vent	70	89	0.67	0.64	0.64	0.53
0.67 EF Direct Vent	73	76	0.67	0.64	0.64	0.53
0.70 EF AtmosFan Boost	70	77	0.70	0.66	0.66	0.54
Hybrid	189	130 [2]	90% [3]	0.68	0.68	0.56
Condensing Storage	123	148	90% [3]	0.74	0.73	0.62

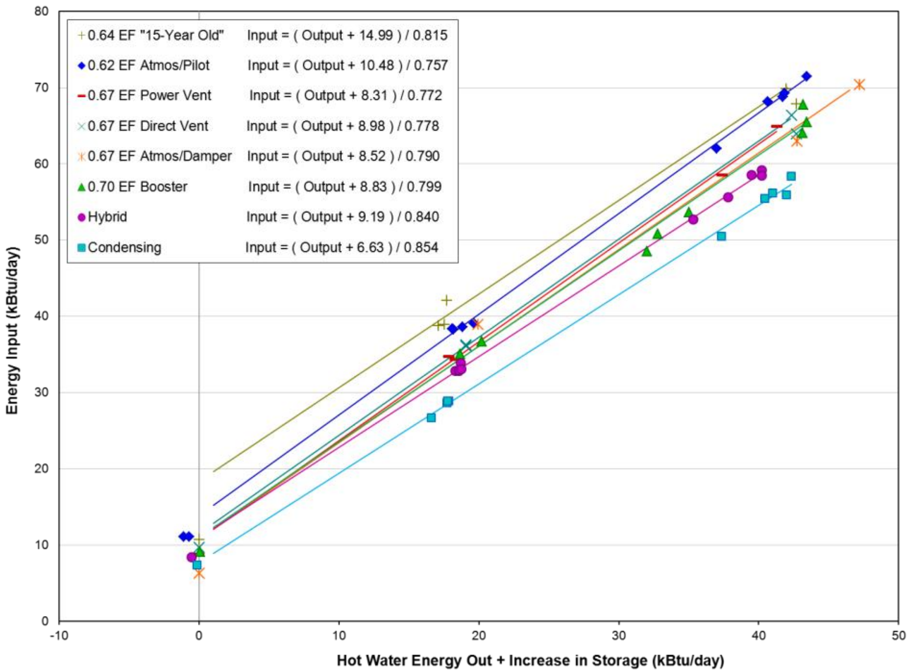
[1] EF results for the DOE standard draw have been adjusted according to the DOE standard procedures for operational offsets from the standard test conditions and the change in stored energy between the start and the end of the test. The GTI profile tests have only been adjusted for the change in stored energy.
[2] These results are under review, the manufacturer was consulted and it was suggested that an unwanted blockage existed in the recirculation loop, the results were not representative of a properly working product.
[3] Both the Hybrid (100,000 Btuh) and the Condensing (76,000 Btuh) are rated with burner inputs above 75,000 Btuh, and thus are classified as commercial units and have a thermal efficiency rating.

Key takeaways

- Efficiency is strong function of daily hot water draw. DOE and GTI-Mid (≈ 64 gal/day) have similar results.
    - Suggesting validity of I/O MOT, including stored energy adjustment (w/ TC tree).
- Lower daily volume has consistently lower efficiencies, greater portion of energy output lost as standby losses.

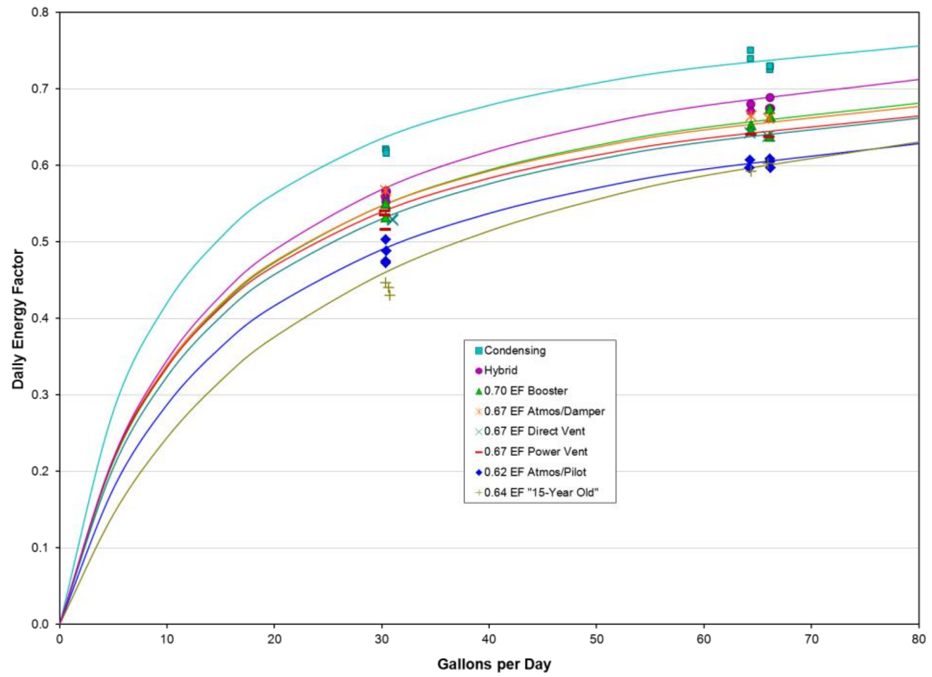
Storage Water Heater Results

Input vs. Output



$$\text{Input} = \frac{(\text{Output} + \text{Standby Loss})}{\text{Recovery Efficiency}}$$

Efficiency vs. Daily Volume



Curves are derived from I/O lines with a 77°F temperature rise

- I/O Chart (Left) shows linear relationship quantified on prior slide
- $EF_{estimate}$ vs. Daily draw (Right) trends are found with SWH field data and is typical for SWHs and TWHs alike

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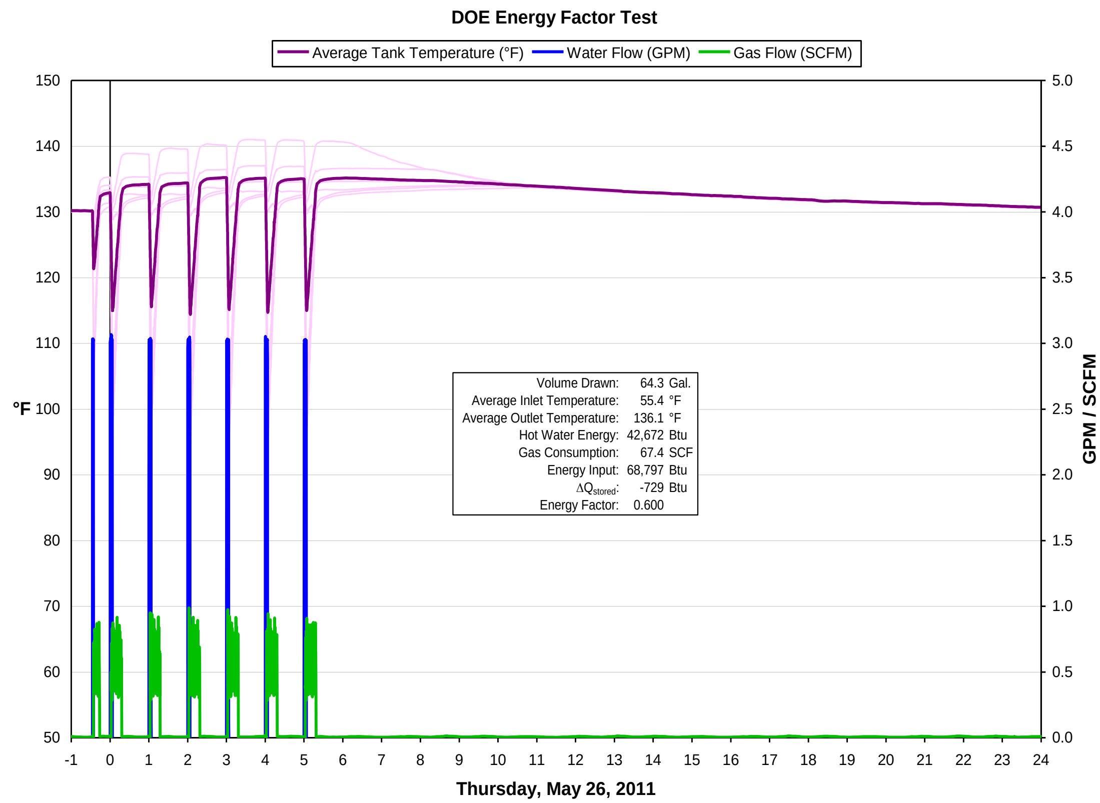
Storage Water Heater Results

Standby Heat Loss

Description	Number of Standby Fires	Non-firing Energy Input (Btu/hr)
15 Year Old Water Heater	0	458.0
0.62 EF Atmos	0	488.0
0.67 EF Atmos/Vent Damper	1	20.1
0.67 EF Power Vent	1	2.7
0.67 EF Direct Vent	1	2.0
0.70 EF Atmos/Fan Boost	1	25.9
Hybrid	3	27.0
Condensing Storage	1	2.4

- Units with pilot lights do not have standby fires during DOE 24 Hr Test.
- Units with electronic ignition (0.67 EF – 0.70 EF) have one standby recovery, impacting overall efficiency.

0.62 EF Atmospheric



Storage Water Heater Results

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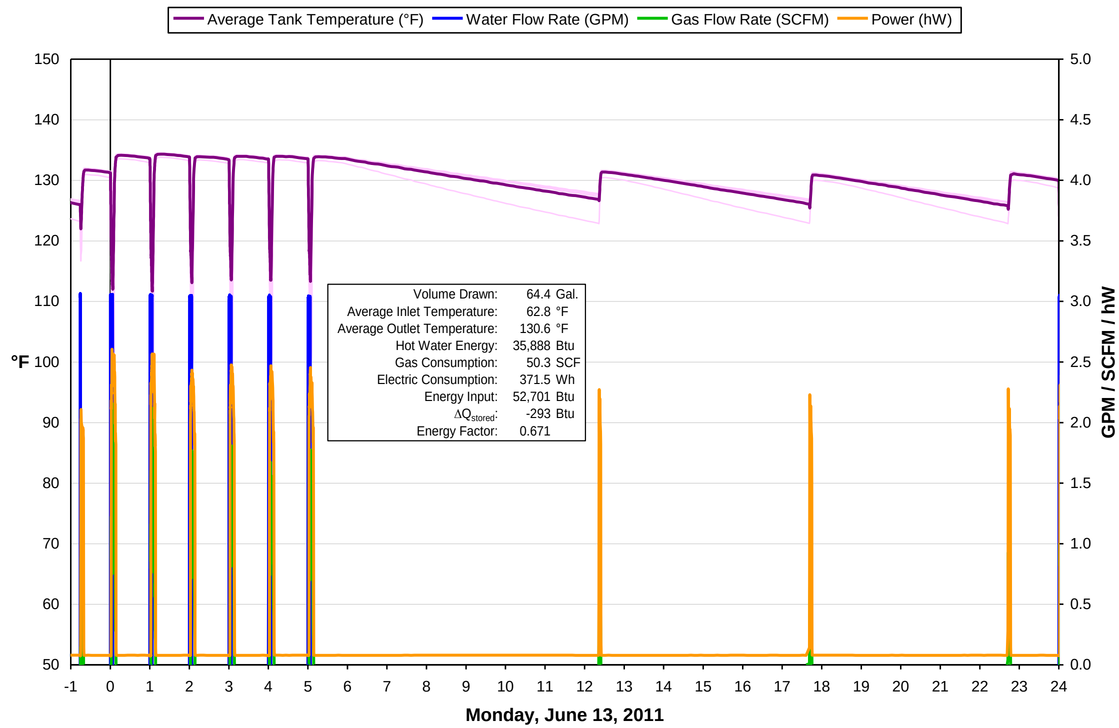
- Hybrid Water Heater has more standby fires with tighter dead band and higher standby heat loss (smaller tank, higher surface area/volume).

Hybrid Water Heater

DOE Energy Factor Test



Storage Water Heater Results

Operating Cost Savings

2010 Mid CA Electricity Price	0.1575	$/kWh
2010 Average CA Natural Gas Price	0.9688	$/therm

		15 year old water heater	0.62 EF Atmos	0.67 EF Atmos/Vent Damper	0.67 EF Power Vent	0.67 EF Direct Vent	0.70 EF Atmos/Fan Boost	Hybrid	Condensing Storage
Estimated Annual Operating Cost	DOE Standard EF	$239.74	$231.25	$229.17	$219.74	$236.53	$194.31	$208.69	$194.01
	GTI Mid Draw	$246.81	$246.10	$255.53	$244.03	$245.71	$242.43	$226.91	$206.41
	GTI Low Draw	$141.08	$136.13	$144.06	$129.85	$134.35	$136.18	$132.16	$103.31
Gas Consumed (therms)	DOE Standard EF	0.678	0.654	0.624	0.574	0.631	0.515	0.529	0.528
	GTI Mid Draw	0.698	0.696	0.699	0.637	0.655	0.650	0.573	0.562
	GTI Low Draw	0.399	0.385	0.384	0.338	0.357	0.352	0.319	0.280
Electricity Consumed (Whs)	DOE Standard EF	0	0	148.4	291.8	233.3	212.4	376.4	127.2
	GTI Mid Draw	0	0	145.5	326.9	245.3	219.0	422.7	133.7
	GTI Low Draw	0	0	144.0	179.8	141.2	203.8	336.8	74.8

Tankless Water Heater Tests

TWHs are not simple on/off appliances:

- Delay to deliver hot water depends impacted by on-board safety checks & other controls.
- Heat exchanger capacitance is important.
- Modulating combustion with 10:1/20:1 turndown.
- Outlet water temperature can be controlled with restrictor and bypass valves.

Units Tested

Description	Firing Rate (Btu/hr)		Certified Performance			Unit Weight (lbs)	Water side volume (gal, measured)
	Min	Max	EF	Max GPM	at ΔT (°F)		
Non-condensing	11,000	199,900	0.82	4.3	77	54	0.23
Condensing 1	9,500	199,000	0.93	4.4	77	70.5	0.45
Condensing 2	19,900	175,000	0.92	4.2	77	74	0.24
Condensing with small 2 L buffer tank (BT)	17,000	199,000	0.95	5.1	77	86	0.97

Tankless Water Heater Tests

Quantify:

- > Thermal/physical characteristics (UA, thermal capacitance, etc.)
- > Impact of on-board storage on performance
- > Gas and electricity use to better quantify operating economics

Delineate:

- > **Startup and shutdown operations**
- > **Response to changing hot water demands - Stability of delivered temperature**

Understand:

- > Impacts of more frequent hot water draws in 24 hour profiles on efficiency.

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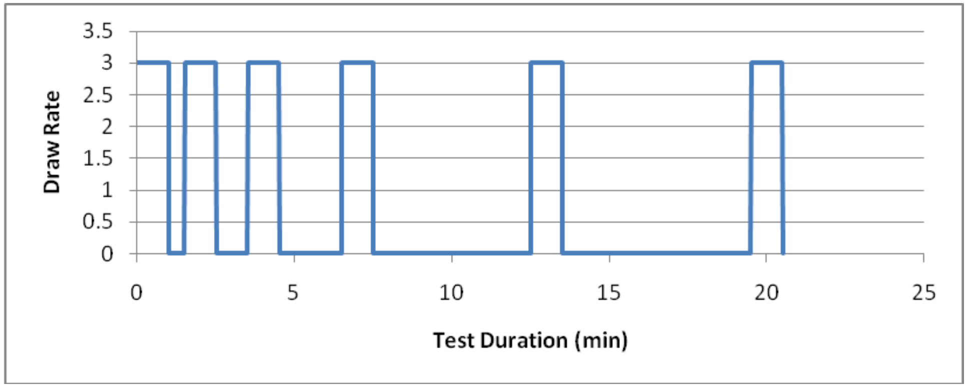
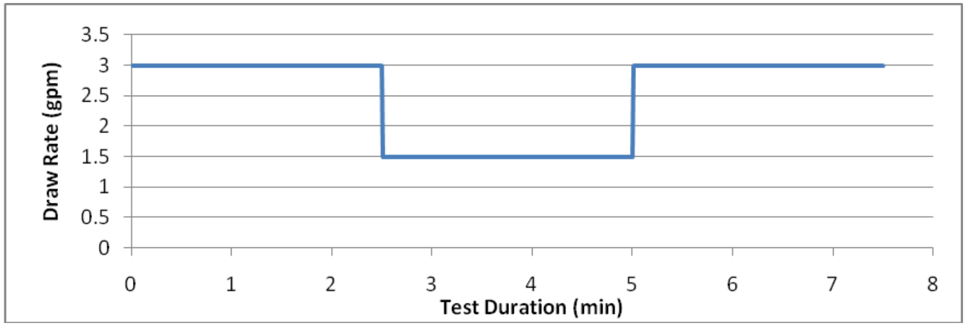
Tankless Water Heater - Short Term Tests



Short Term Intermittent Test (3 gpm example)



"Two Shower" Draw Pattern (1st example)

Short Term Intermittent Tests

> 6 - 8 tests varying target draw rate and setpoint temperature:

- 0.7, 1.5, 3.0, and 4.0 gpm
- 110 F and 130 F setpoint
- Focus on reaction time during 1st (cold), 2nd, and final draw.

"Two Shower" Test Matrix		
Set Point (F)	High/Low flows (gpm)	Incoming Water Temperature (F)
120	3/1.5	58 - Normal
120	4/2	58 - Normal
120	4/2	95 - Elevated
140	4/2	58 - Normal

Short Term Tests – Intermittent Draws

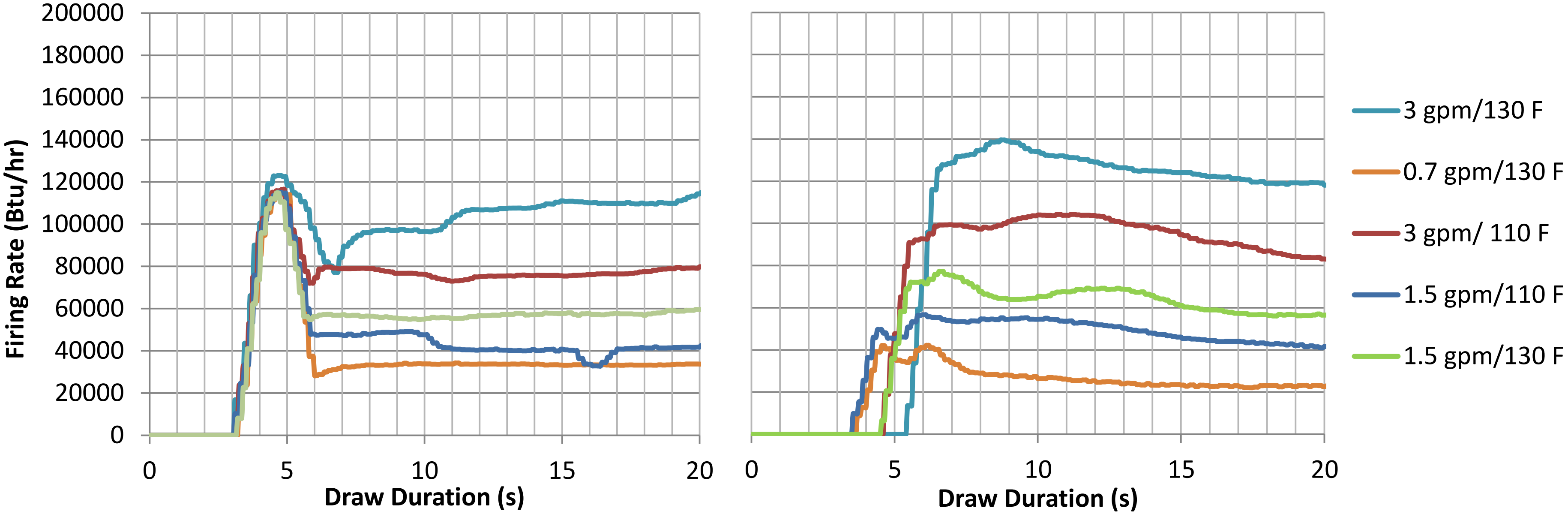
Method: Use a sequence of intermittent draws, with gaps of increasing duration, to characterize delays (a) to fire and (b) to deliver hot water.

- A mass-flow meter is used for fuel metering
- It is evident the NCTWH uses an “active standby mode” for draws less than 6 minutes apart.
- On average, all units have 5 s delay to fire

Delay to Open Gas Valve (s) - Average

Draw No.	Time Since Prior Draw (sec.)	Non-Condensing	Condensing
1	n/a	3.1	2.8
2	30	1.4	2.9
3	60	1.3	2.9
4	120	1.4	2.9
5	300	1.5	2.9
6	360	2.6	2.8

Short Term Tests – Intermittent Draws

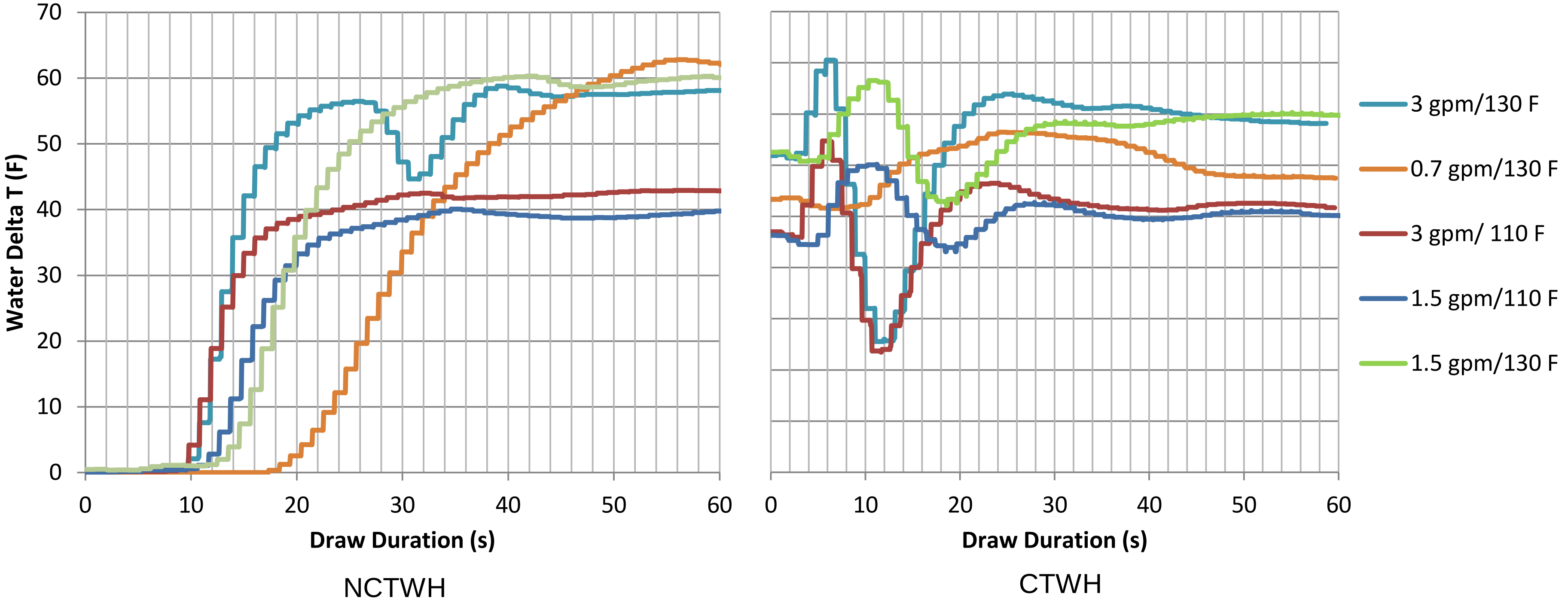


NCTWH CTWH

Comparing the modulating combustion strategy of the NCTWH (Left) and one of the CTWHs (Right), there are clear differences:

- The NCTWH "assumes" the load is appx. 120 kBtu/hr and adjusts from there.
- The CTWH uses finer control to land near the steady state load initially, with a delay.

Short Term Tests – Intermittent Draws



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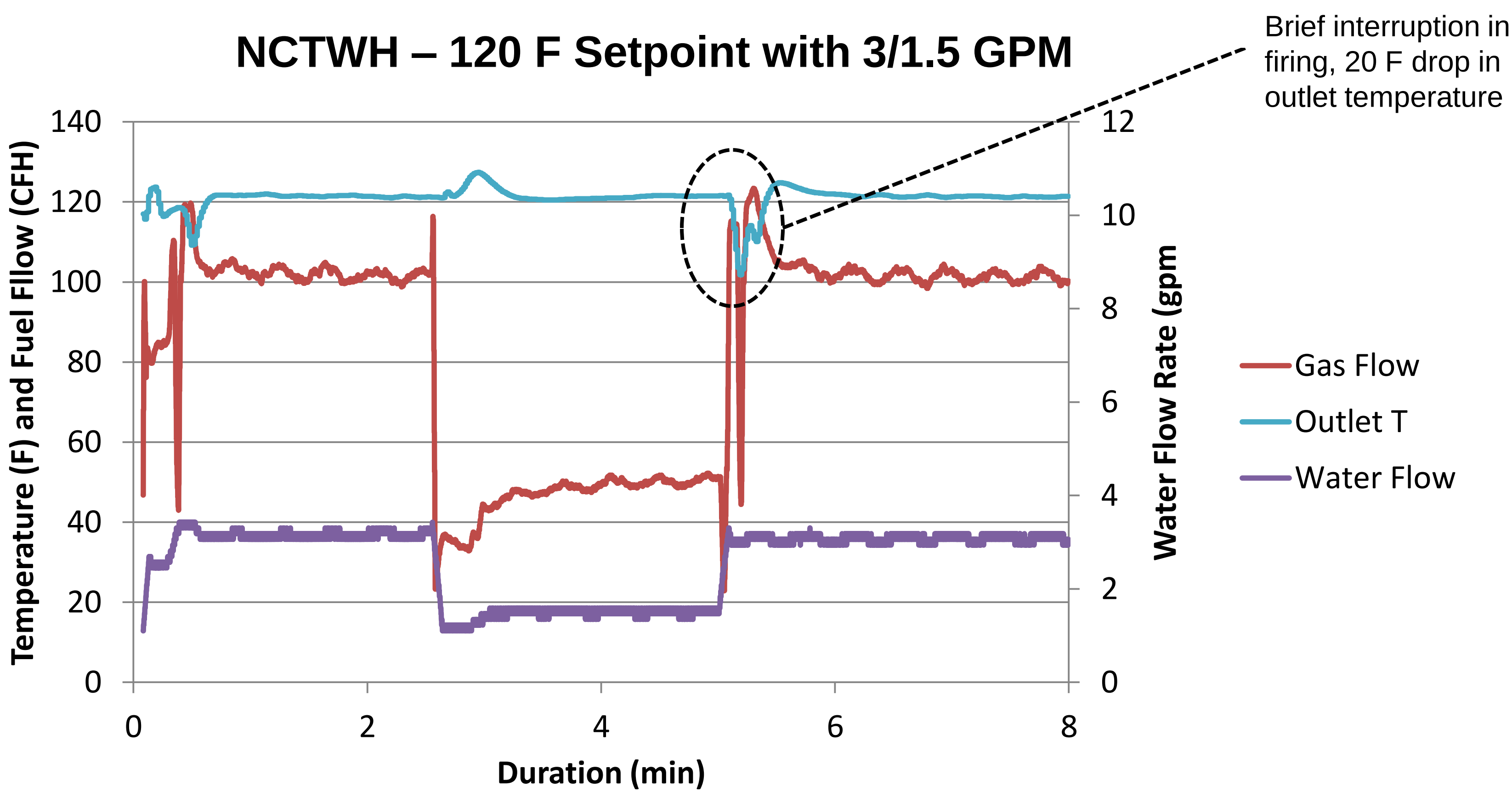
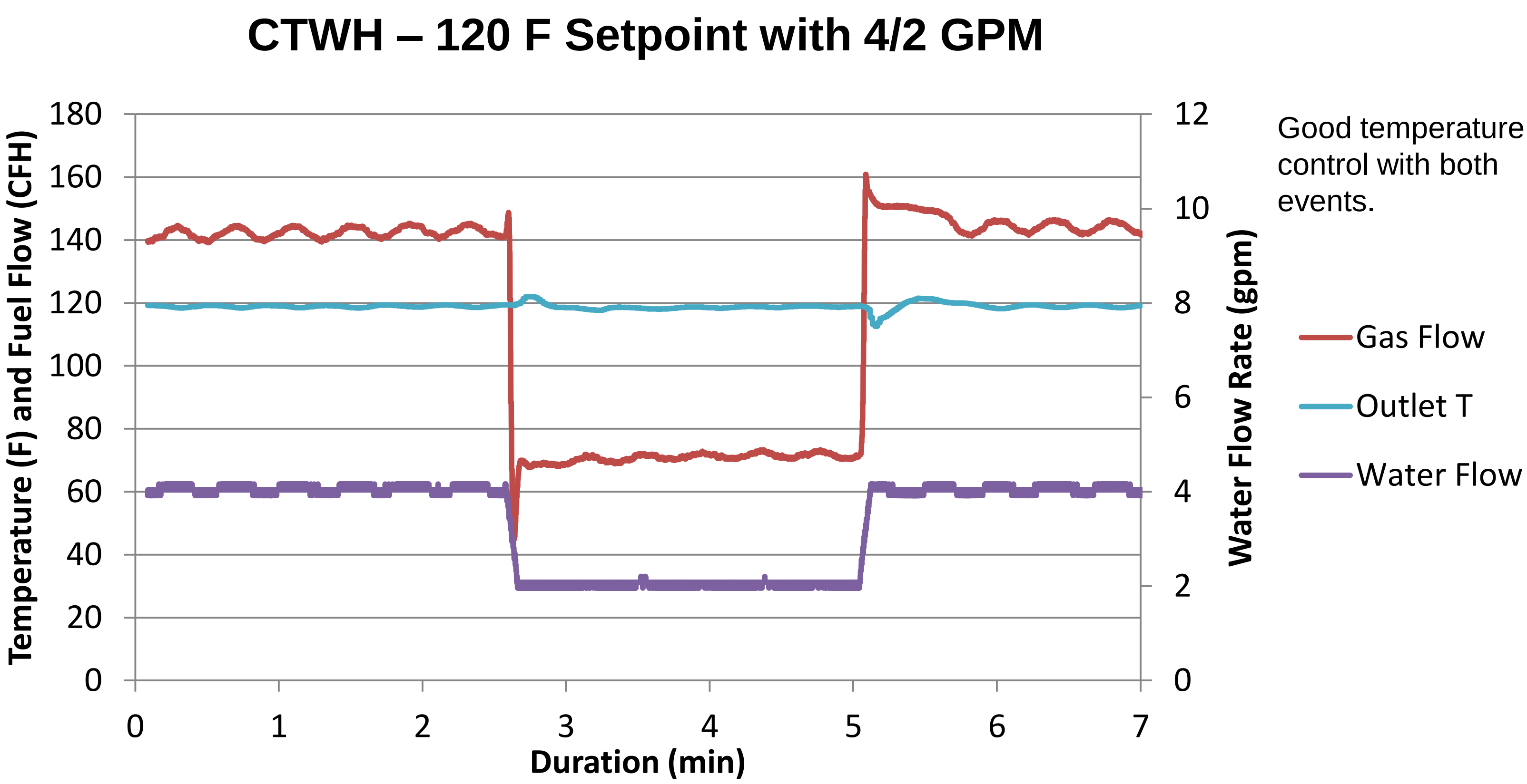
Short Term Tests – Two Shower Draws



Short Term Tests – Two Shower Draws



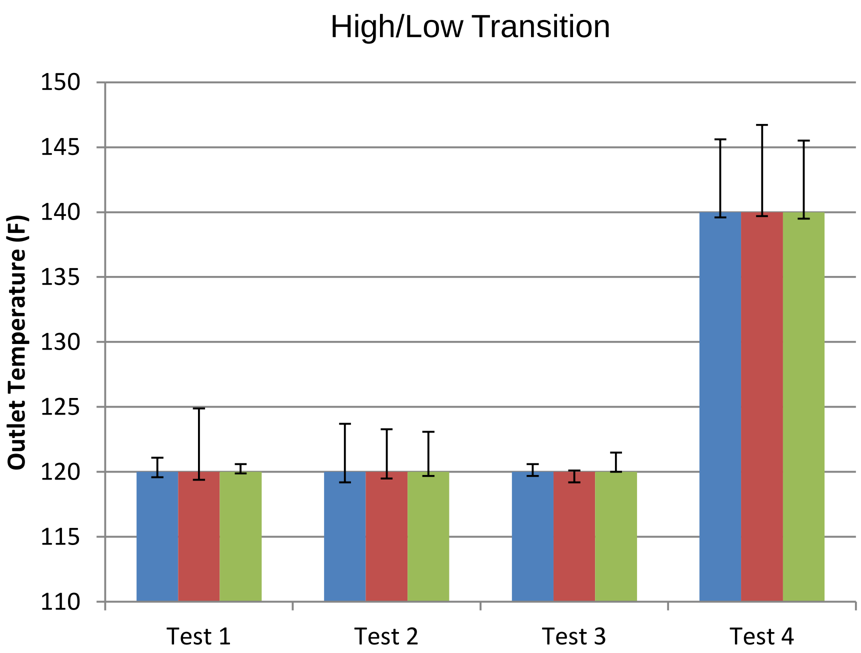
Good temperature control with both events.

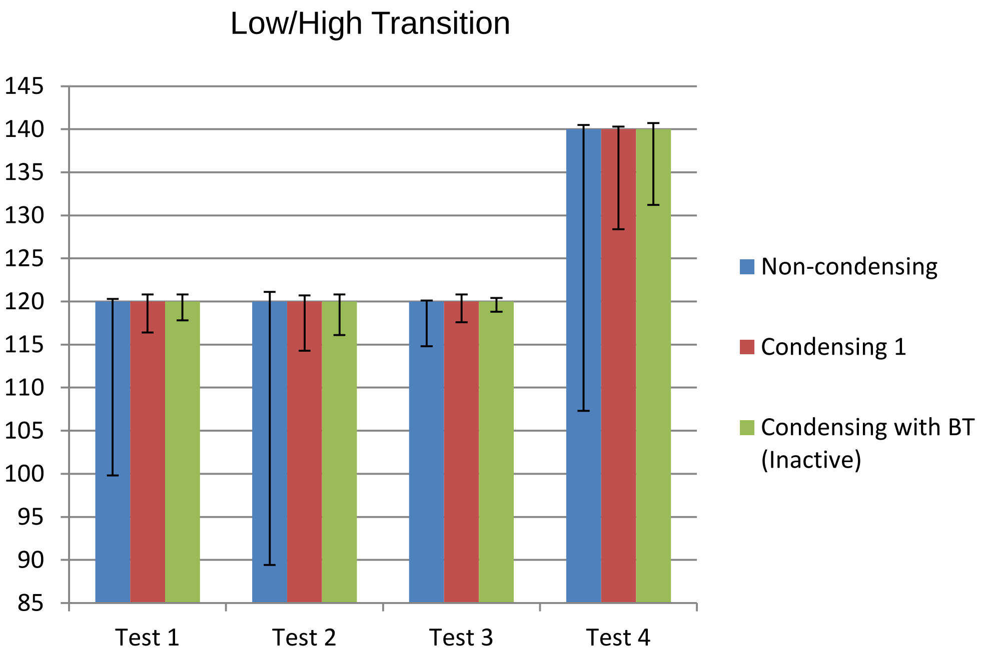
Short Term Tests – Two Shower Draws

Method: Observe impact of step changes in hot water draw at various draw rates/inlet T

- Following transitions (low/high & high/low), the critical metrics are: delay to reach steady outlet temperature and **observed temperature over/undershoot**, errs to undershoot.

Temperature Overshoot/Undershoot at Transition Point





Questions?

Reporting

Full dataset to be reported in Q4 in public document

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Additional Background Slides

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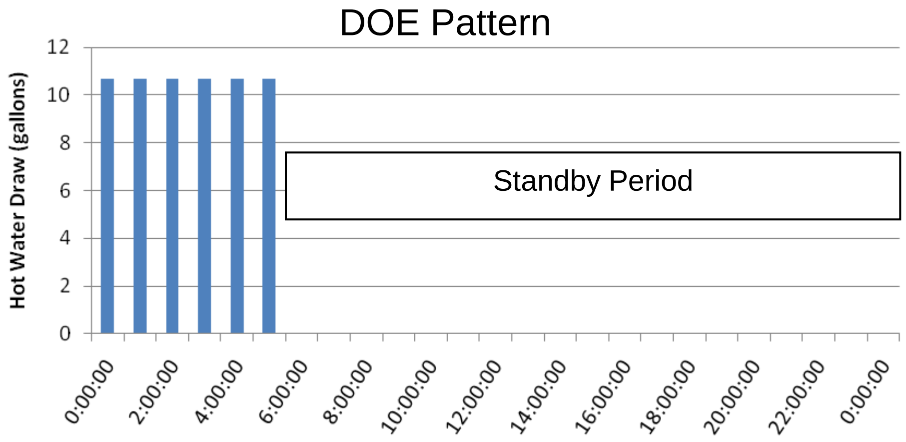
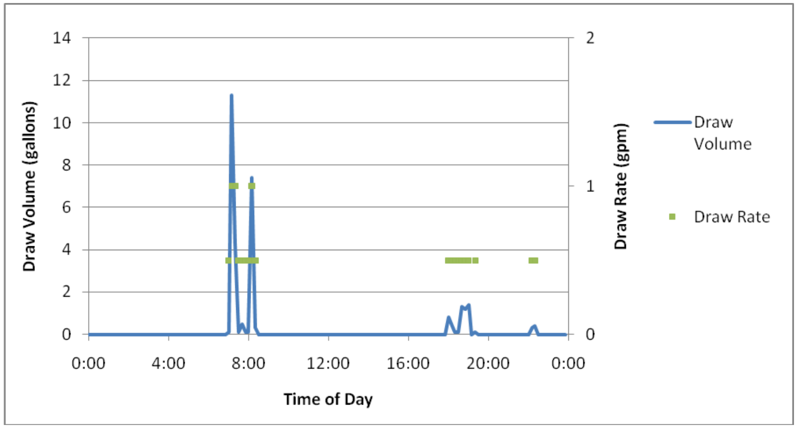
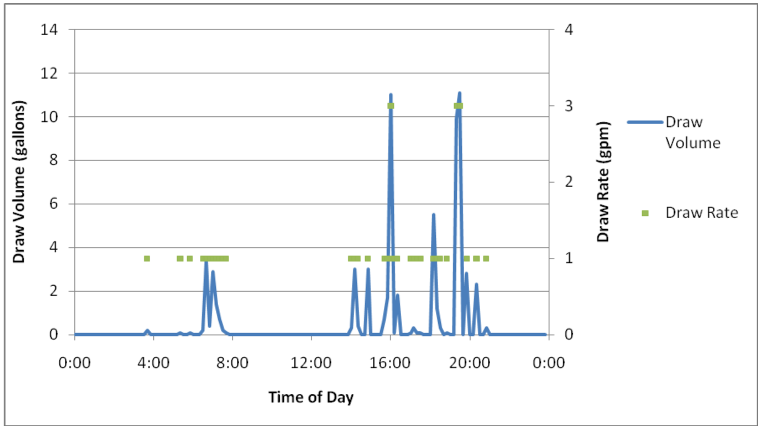
Draw Patterns Used

Daily Simulated Use Tests – TWH Testing





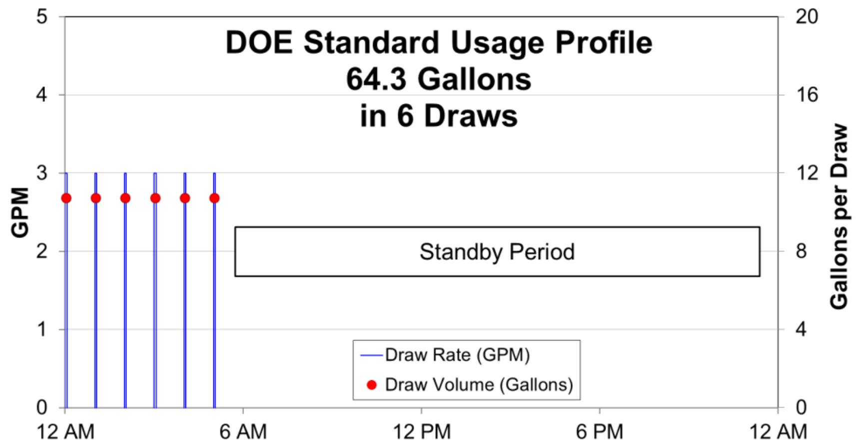
GTI Low Use Pattern (30 gal/day)

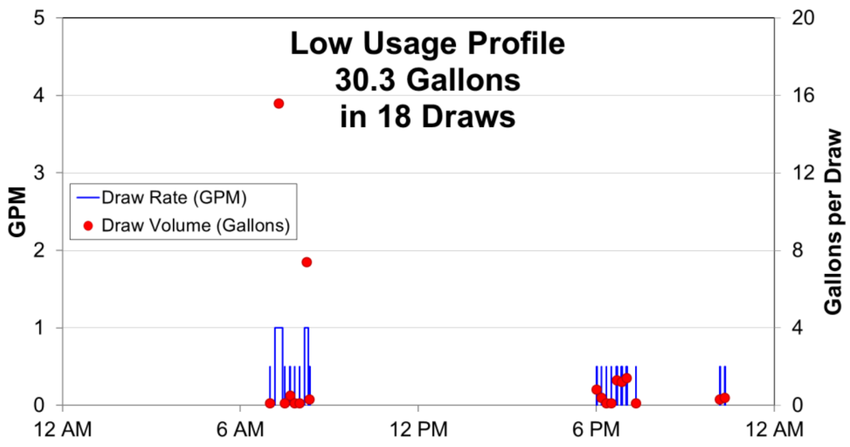


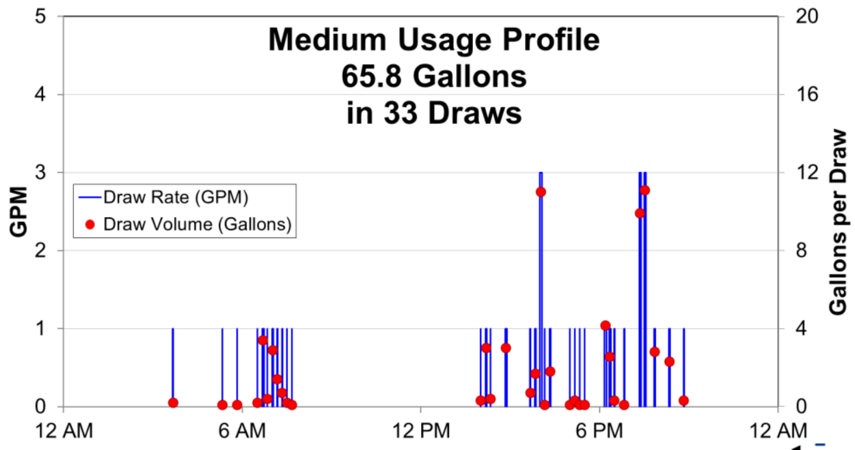
GTI Mid Use Pattern (64 gal/day)

Draw Patterns Used

Daily Simulated Use Tests – SWH Testing







TWHs - Thermophysical Parameters

Use published model of *Burch et al.* to estimate *UA* and thermal capacitance during focused short term tests:

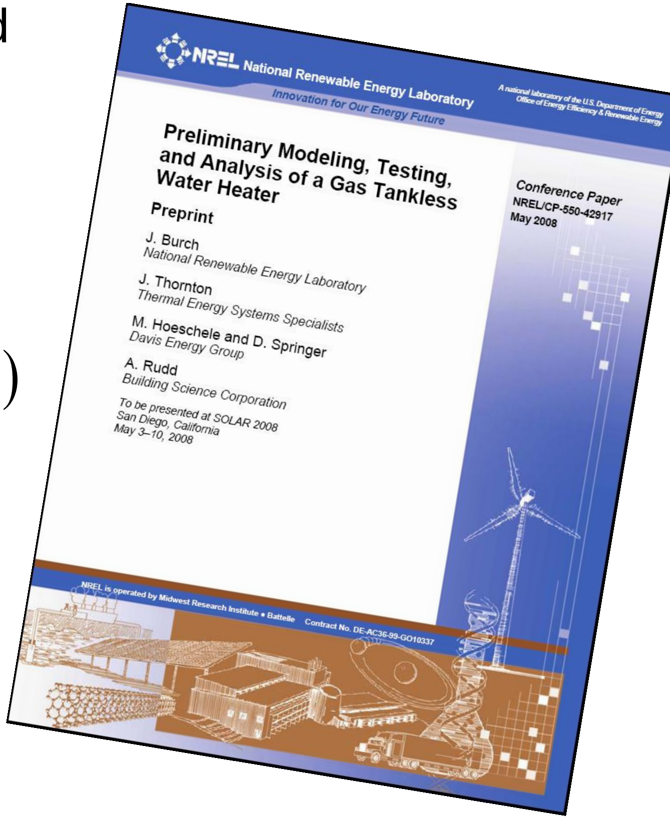
Steady State: $\eta_{Comb}\dot{Q}_{Gas} = \dot{m}C_P(T - T_{in}) + UA(T - T_{env})$

Ramp-up: $C\,{}^{dT}\!/_{dt} = \eta_{Comb}\dot{Q}_{Gas} - \dot{m}C_P(T - T_{in}) + UA(T - T_{env})$

Environmental Decay: $C\,{}^{dT}\!/_{dt} = -UA(T - T_{env})$

Draw Decay: $C\,{}^{dT}\!/_{dt} = \dot{m}C_P(T - T_{in}) - UA(T - T_{env})$

Efficiency Definitions: $\eta_{comb} = \dfrac{Q_{Gas} - Q_{FG}}{Q_{Gas}}$ $\eta_{Th} = \dfrac{Q_{Water}}{Q_{Gas}}$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A national laboratory of the U.S. Department of Energy Office of Energy Efficiency & Renewable Energy

Preliminary Modeling, Testing, and Analysis of a Gas Tankless Water Heater

Preprint

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To be presented at SOLAR 2008
San Diego, California
May 3–10, 2008

Conference Paper
NREL/CP-550-42917
May 2008

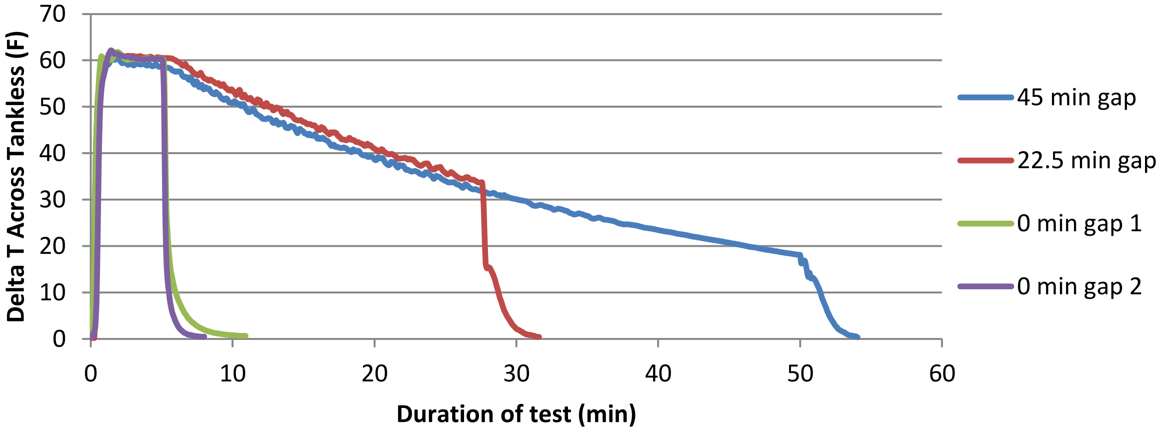
NREL is operated by Midwest Research Institute • Battelle Contract No. DE-AC36-99-GO10337

Burch, J., Thornton, J., Hoeschele, M., Springer, D., and Rudd, A. “Preliminary Modeling, Testing, and Analysis of a Gas Tankless Water Heater”. National Renewable Energy Laboratory paper NREL/CP=550-42917, presented at SOLAR Conference (2008).

TWHs - Thermophysical Parameters

Determine UA/C for Non-condensing TWH:

- Following 5 minute steady state firing, cut off fuel and continue with 0.5 gpm draw until inlet/outlet temp. is within 1°F.
- UA is estimated during 'env. decay' & steady state, with known comb. efficiency.
- Thermal capacitance (C) is estimated during 'draw down'.
- Note that with 0 gap time, the total energy stored within the HX is appx. 250 Btus.



	Gap Time (min)	**Avg C** Btu/°F	**Avg UA** (Btu/hr)/°F	**Heat Withdrawn During Draw Down** (Btus)	**Standby Heat Loss** (Btus)
Draw 1	0	6.5	41.6	256.6	0
Draw 2	0	6.7	38.8	248.4	0
Draw 3	22.5	6.9	41.5	170.0	82.5
Draw 4	45.0	6.3	25.8	133.1	119.3
Average		**6.6**	**36.9**		

TWHs - Thermophysical Parameters

Input	Non-Condensing	Condensing		
Capacitance	12.9	5.9	Btu/F	Max output @ 77F rise
	6.9	2.5	Btu/F	Min output @ 77F rise
UA	32	28.3	Btu/hr-F	Max output @ 77F rise
		5.3	Btu/hr-F	Min output @ 77F rise
		8.7	Btu/hr-F	Blower Off - 130 F Inlet
	8	7.3	Btu/hr-F	Blower Off - 150 F Inlet
Thermal Efficiency	86%	95.4%		Max output @ 77F rise
		98.2%		Min output @ 77F rise
On-time delay	5	5	sec	
Power Consumption	55	160	W	Active – Average
	5	7	W	Standby - Average
	N/A	59	W	Active - Rated
		2	W	Standby - Rated

TWHs – 24 Hour Sim. Use Tests

Energy Efficiency

DOE Draw Pattern Test Results

TWH	EF	Estimated EF	Recovery Eff (high)	Recovery Eff (low)	Average Delivered T (F)
Non-condensing	0.77	0.75	82.0%	74.9%	129.6
Condensing 1	0.92	0.92	94.8%	92.3%	127.5

Draw Pattern	TWH	Estimated EF	Average Delivered T (F)	Input		Output
				Gas (Btu)	Electricity (Wh)	DHW (Btu)
GTI Mid	Non-condensing	0.75	125.3	45,120	323	34,610
	Condensing 1	0.90	123.7	43,110	279	39,650
	Condensing with BT (Active)	0.67	126.4	54,430	889	38,350
	Condensing with BT (Inactive)	0.85	119.8	40,270	486	35,460
GTI Low	Non-condensing	0.73	129.9	23,600	301	17,960
	Condensing 1	0.87	123.8	19,780	245	17,870

TWHs – 24 Hour Sim. Use Tests

Operating Cost

2010 Mid CA Electricity Price	0.1575	$/kWh
2010 Average CA Natural Gas Price	0.9688	$/therm

		Non-condensing	**Condensing 1**	**Condensing with Buffer Tank (24 hr*)**	**Condensing with Buffer Tank (Inactive*)**
Estimated Annual Operating Cost	DOE Standard EF	$201.74	$157.49	Not tested	
	GTI Mid Draw	$178.11	$168.47	$243.59	$170.29
	GTI Low Draw	$100.72	$84.03	Not tested	
Gas Consumed (therms)	DOE Standard EF	0.500	0.394		
	GTI Mid Draw	0.451	0.431	0.544	0.403
	GTI Low Draw	0.236	0.198	Not tested	
Electricity Consumed (Whs)	DOE Standard EF	433.9	313.6		
	GTI Mid Draw	322.9	278.8	889.3	485.5
	GTI Low Draw	300.5	245.0	Not tested	

*Indicates scheduling of recirc. pump

TWHs – 24 Hour Sim. Use Tests

Recirculation Behavior of CTWH w/ Buffer Tank (GTI Mid Pattern)

	Average
Duration (s)	28.5
Electricity Consumed (Wh)	4.9
Gas Consumed (Btu)	232
Firing rate (Btu/hr)	29,470
Power Draw (W)	665.4
	Total
Duration (min)	23.8
Power Drawn (Wh)	247.0
Gas Burned (Btus)	11,630