Hot Water System Performance Testing at PG&E's Applied Technology Services: Mimicking a Full-Service Restaurant in the Laboratory

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CALIFORNIA ENERGY COMMISSION

Pacific Gas and Electric Company®

FISHER NICKEL
A division of Frontier Energy, Inc.

ATS Water Heater Test Lab Since 2007

- Capable of sequencing up to six WHs with identical draw profiles and consistent inlet water and air temperatures
- Designed following DOE (10CFR430) and ASHRAE (Std 118.2) test methods

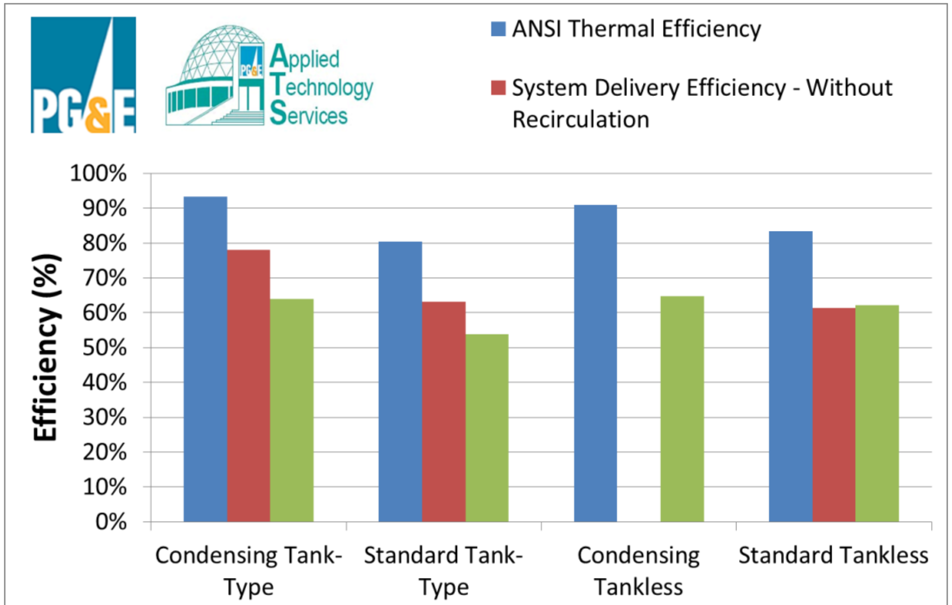
Presentation Objectives

- Describe the history of testing and vision of PG&E's Upgraded Hot Water Technology Performance Laboratory
- Identify how PG&E's laboratory will be modified to support of field performance characterization research
- Summarize the analysis methods and results of the last effort
- Expand on test scenarios for designing and operating water heating systems in commercial food service to support the development of a design tool and cost calculator
- What has the lab tested thus far?

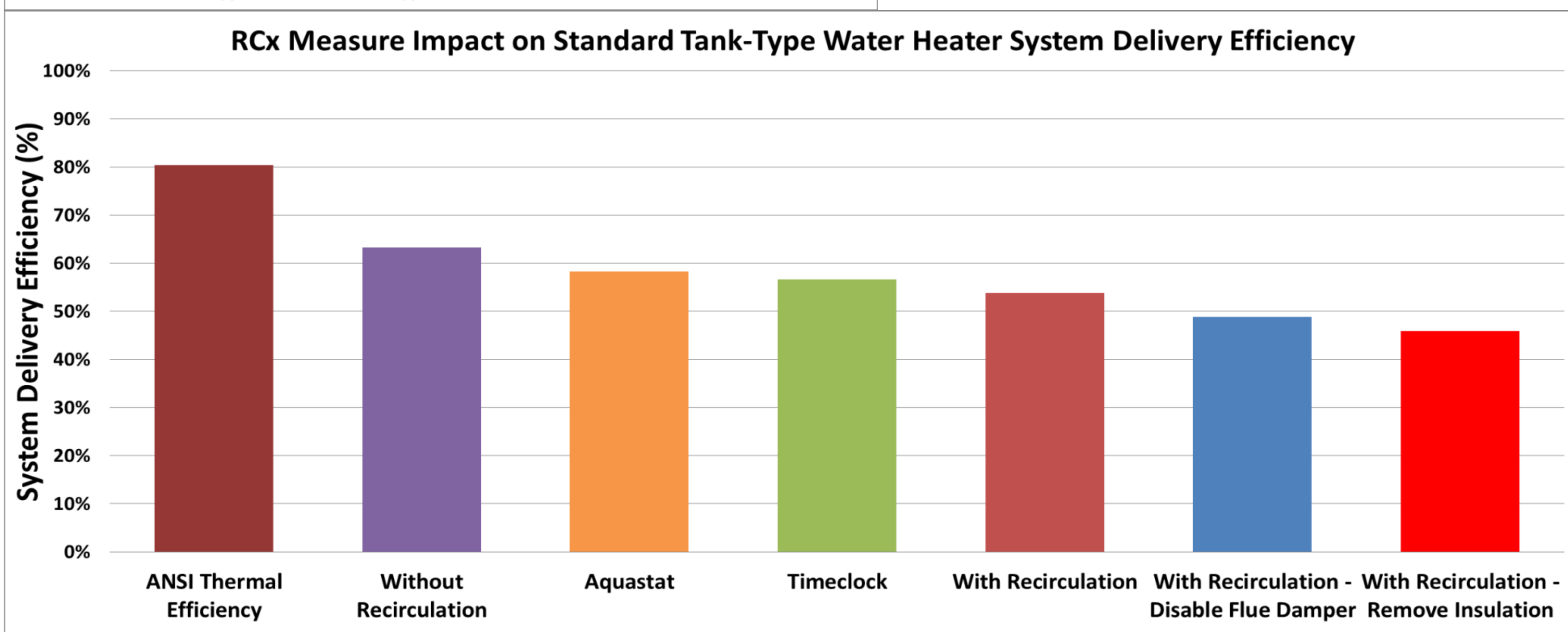
Past California Energy Commission Research Objectives

- Stimulate the purchase of high-efficiency [condensing] water heaters for both retrofit and new construction
- Secure energy savings through a water heater RCx initiative including operational flue-damper, insulation, and optimizing distribution
- Understand the impact that preheating inlet water will have on the performance of high-efficiency water heaters
- Expand on best practice guidelines for designing and operating water heating systems in commercial food service

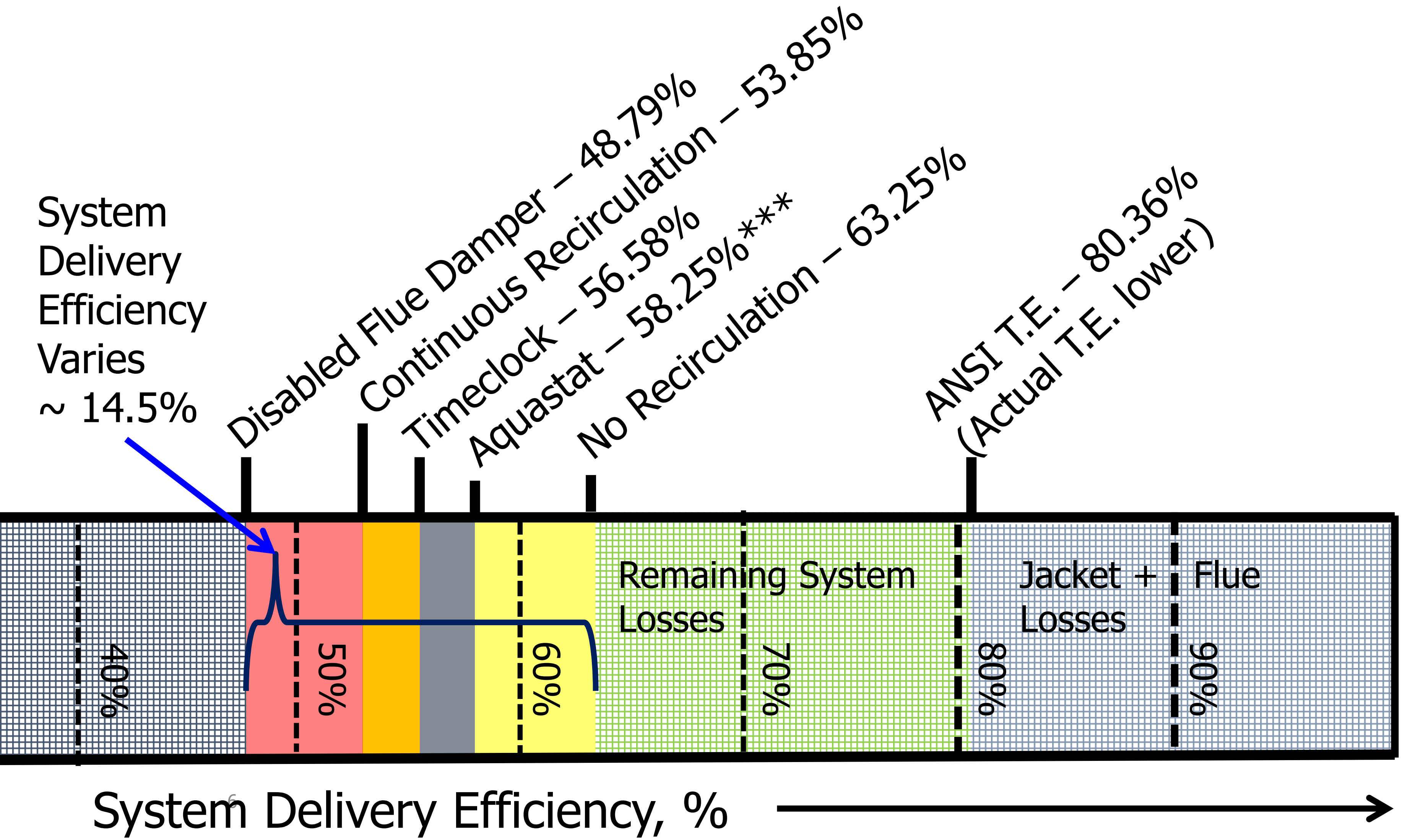
Results - Past PIER Effort (PIER RFP 500-07-503)



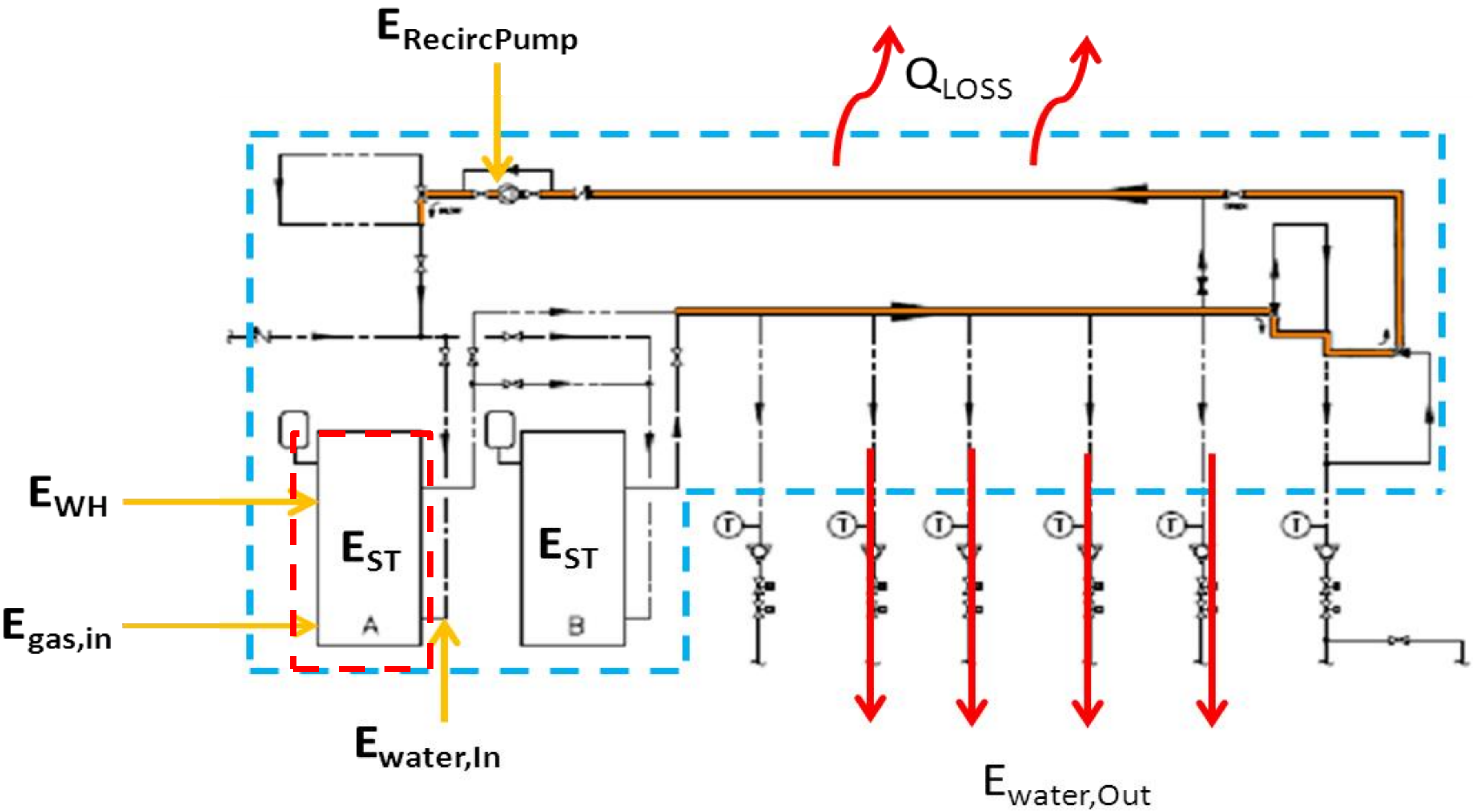
- Condensing Tank-Type Water Heaters supplying insulated systems without recirculation yield System Delivery Efficiencies (S.D.E.) as high as 78%
- Standard Efficiency Tank-Type Water Heaters supplying non-insulated systems yield S.D.E. as low as 46%
- S.D.E. can degrade further below 46% in a non-insulated system with a disabled flue damper (42% S.D.E.)



System Energy Performance Impact – RCx and Retrofit
24 hr. Draw Profile - Standard Efficiency Tank-Type Water Heater Insulated System



Measuring Commercial Water Heater System Performance: System Delivery Efficiency vs. WH Thermal Efficiency



$$\eta_{\cdot DELIVERY-TEST-TANK-TYPE} = \frac{O.E._{TEST} + \Delta E_{Storage}}{I.E._{TEST}} \sim \frac{Output\ Energy}{Input\ Energy}$$

Hot Water Technology Lab Capabilities

Vision for PG&E’s Upgraded Hot Water Technology Laboratory

- Include capabilities of past residential and commercial test systems
- Employ modular laboratory design, easily adaptable to changing test setups, specifically various distribution systems
- Automation of tests via National Instruments Labview DAS
- Continued focus maintaining high instrument accuracy and control of test variables
- Rely on industry for guidance and new ideas, also attempt to develop our own
- Vision focused less on demonstration, more on performance analysis and validation

ATS' Task in Support of EPIC PIR 14-006 (cont'd)

Isolate the performance impact using both the baseline and optimized distribution system:

- **Demand Side**
  - Recirculation loop length
  - Electrical POU Heating
  - Continuous Recirculation
  - Demand circulation control
  - End-use heat recovery (Enhance Condensing)
  - Hand sink aerator selection
  - Vertical branch drop pipe diameter
  - Aquastat
  - Time Clock
  - Insulation

“Wish List”

- Any technologies approaches to include in this study in addition to the current plan?
  - Modulating vs. non-modulating tank type water heaters?
  - Heat trace?
  - Burner orientation (down fired vs. side fired)
  - Fixed vs. Variable Speed Recirculation?
  - Flow profile impact on system efficiency w/ same total volume delivered

System Demand Profiles – Baseline System Field Characterization of Hot Water Use

14 Monitored Hot Water Fixtures		Volume (Gallons)	Average Calcuated Flow Rate (gpm)	Number of Uses per Day	Mass Weighted Temperature (F)
	1-compartment Sink (1C)	36.82	2.99	24	126.2
	Prep Hand Sink	4.25	1.42	23	96.6
	Cookline Hand Sink	6.53	1.88	29	100.6
	Womens Lavatory	9.97	0.61	83	113.0
	Men's Lavatory	8.17	0.45	101	105.0
	Dishroom Hand Sink (Dish HS)	3.66	0.72	22	N/A
	Dishwasher	303.28	4.58	214	128.1
	3-compartment Sink (3C)	154.95	2.59	48	129.6
	Bar Hand Sink	2.95	1.61	12	95.5
	Pitcher Hand Sink	29.88	0.35	698	92.5
	4 Compartment Left Sink (4C L)	16.00	3.20	3	128.1
	4 Compartment Right Sink (4C R)	43.18	3.30	12	117.6
	Mop Sink	40.36	5.27	4	125.0
	Pre Rinse Sink (PR)	61.31	0.50	434	114.9
Sum		721.32		1707	

- Fisher-Nickel conducted a comprehensive field monitoring effort, 14 fixtures in total, at a quick service restaurant to gather a high resolution 24-hour “real world” hot water use profile

System Demand Profiles – Baseline System Field Characterization of Hot Water Use

Combined 8 fixtures:		**Volume (Gallons)**	**Average Calcuated Flow Rate (gpm)**	**Number of Uses per Day**
1	1 Comp Sink, Prep, Cookline	47.61	TBD	76
2	Mens Bathrooms, Womens	18.14	TBD	184
3	Dish HS, Dishwasher	306.94	TBD	22
4	3-compartment Sink (3C)	154.95	TBD	262
5	Bar Hand Sink, **Pitcher HS**	32.83	TBD	710
6	4 Comp L, 4 comp R	59.18	TBD	15
7	Mop Sink	40.36	TBD	4
8	PreRinse (PR)	61.31	TBD	434
Sum		721.32	TBD	1707

- Note the dramatic reduction in system fixtures for lab testing (14 to 8) – to be discussed shortly

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System Demand Profiles – Proposed System Field Characterization of Hot Water Use

Combined 7 fixtures:		**Volume (Gallons)**	**Average Calcuated Flow Rate (gpm)**	**Number of Uses per Day**
1	Mop Sink	40.36	5.27	4
2	3-compartment Sink (3C)	154.95	2.59	48
3	PreRinse (PR)	61.31	0.50	434
4	Bar Hand Sink	2.95	1.61	12
5	Cookline	6.53	1.88	29
6	Prep Hand Sink	4.25	1.42	23
7	1-compartment sink	36.82	2.99	24
Sum		307.18	`	574

- Note the dramatic reduction in proposed system fixtures – to be discussed shortly

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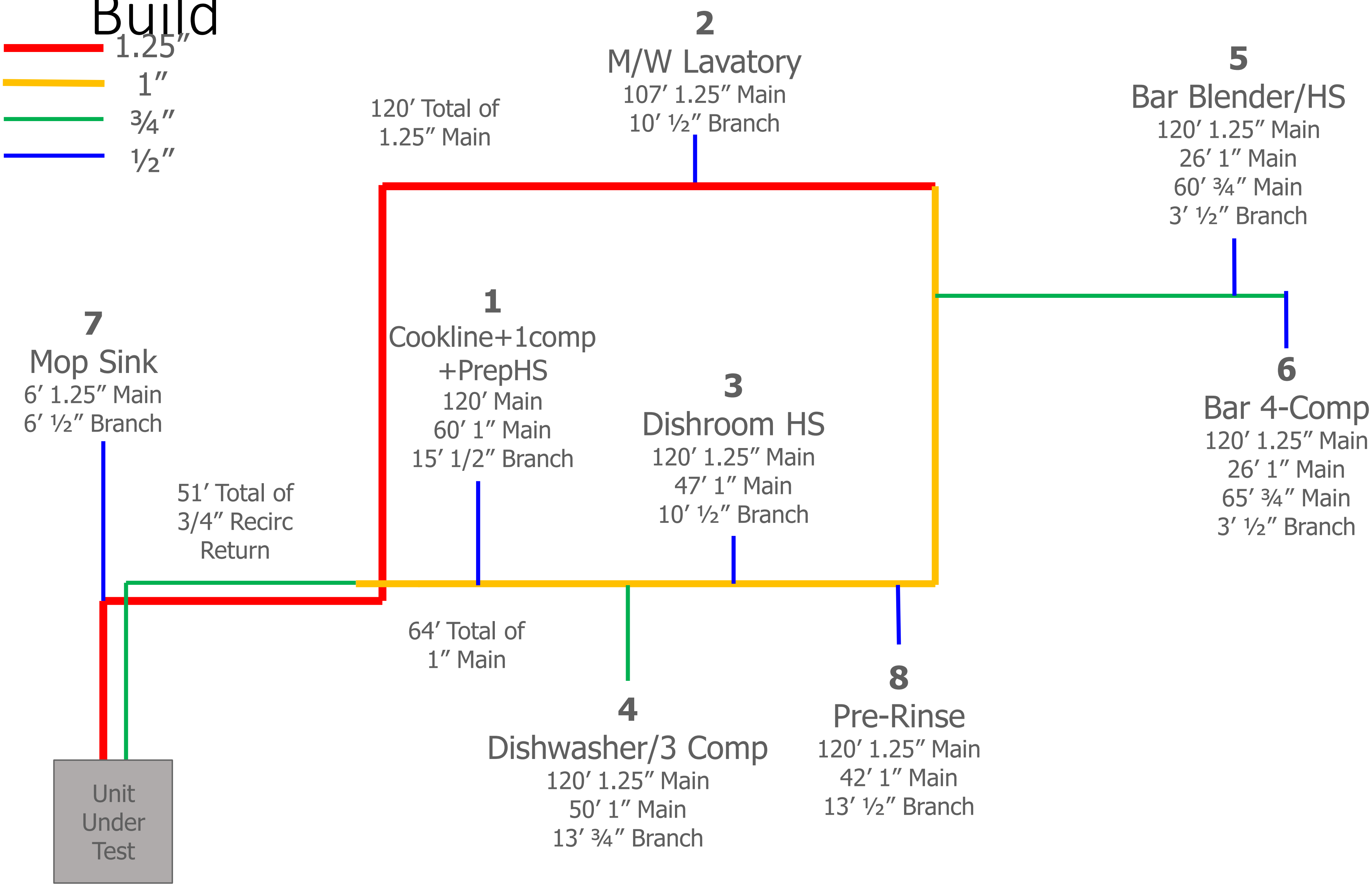
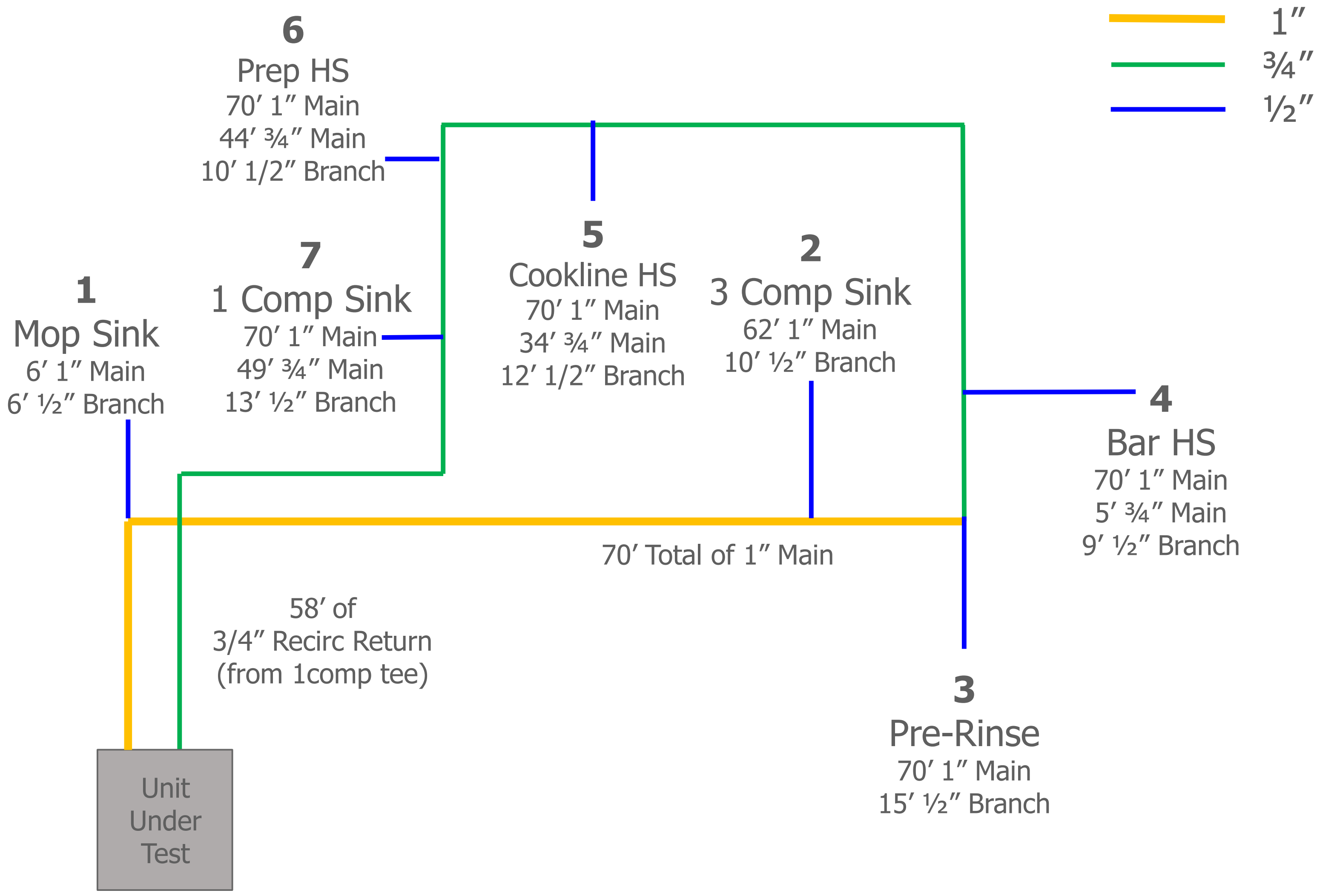
Baseline Distribution System – Laboratory Build



Proposed Distribution System – Laboratory Build



Summary of Test Parameters to Vary

- **Distribution System** – Baseline and Optimized
- **Supply Side** – Up to 4 Water Heater Options
  - (2) Standard Efficiency Tankless Units (199,000 Btuh ea)
  - (1) Condensing Tankless (250,000 Btuh)
  - (1) Standard Efficiency Tank (199,000 Btuh)
  - (1) Condensing Tank (199,000 Btuh)
- **Parameters to vary** - Recirc On/Off, Recirc Return Location, Insulation/No Insulation, Timeclock On/Off, Aquastat On/Off, D'mand circulation (Timeclock + Aquastat)
- **Other Parameters to vary** - Run a variety of flow profiles if time permits, anything else?
- 2 Systems * 4 Heaters * 5 Recirculation Conditions (Recirc All On/All Off/Timeclock On/Aquastat On/Timeclock+Aquastat On) * 2 Insulation Levels (On/Off) + ~5 central return port tests = **85 possible tests**.

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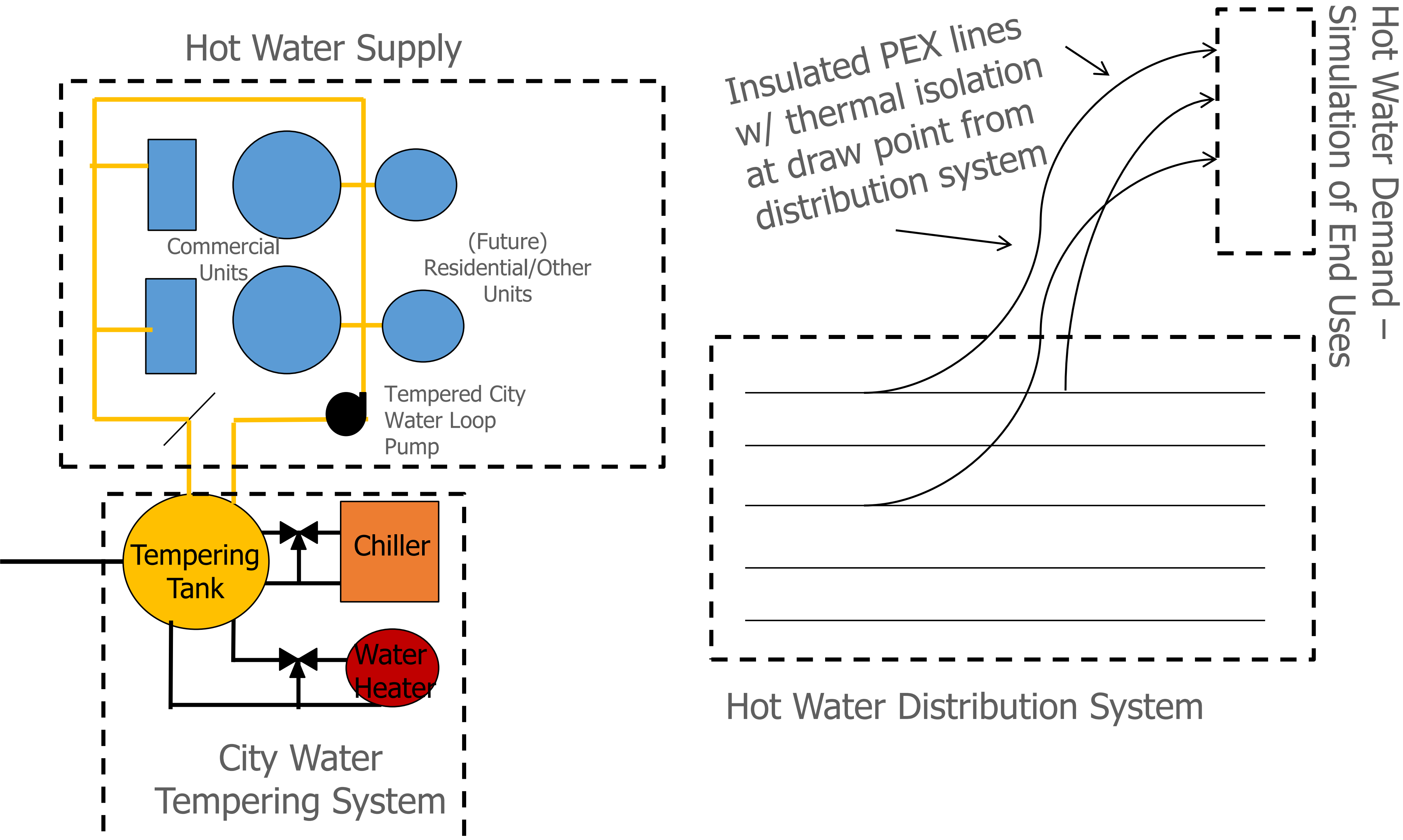
Applying the Vision by Going Modular with Layout



Conditioning City Water – Upgrade to Larger Tempering System to Handle Large Loads

Clustered Tankless and Storage Heaters

Supply Side: Heater 1 – Standard Efficiency Tank

Heater 1 – A.O. Smith Master Fit

- 100 Gallon Tank
- 199,000 Btuh Firing Rate
- Standard Efficiency

Why to Test this Unit?

- Provide a “baseline” representation of what might be commonly found in the field
- Baseline data point for calculation tool

Supply Side: Heater 2 – High Efficiency Tank

Heater 2 – A.O. Smith Cyclone

- 100 Gallon Tank
- 199,000 Btu/h Firing Rate
- High Efficiency-Modulating-Recirc. Return Port

Why to Test this Unit?

- Provide an idea of the benefits of condensing units, and some pitfalls
- Another data point for design tool
- Enables the lab to quantify the efficiency improvements from a modulating burner and central return port

Supply Side: Heater 3 – Paralleled Standard Efficiency Tankless

Heaters 3 – Paralleled Rinnai Tankless

- 199,000 Btuh Firing Rate
- Standard Efficiency

Why to Test this Unit?

- Provide a "baseline" representation of what might be commonly found in the field
- Another data point for calculation tool

Supply Side: Heater 4 (If Available) – High Efficiency Tankless

Heater 4 – High Efficiency Tankless

- 200,000 Btuh Firing Rate
- High Efficiency
- Built-in recirculator
- 0.5 gal tank

Why to Test this Unit?

- Provide information for an efficient wall mounted alternative
- Another data point for calculation tool

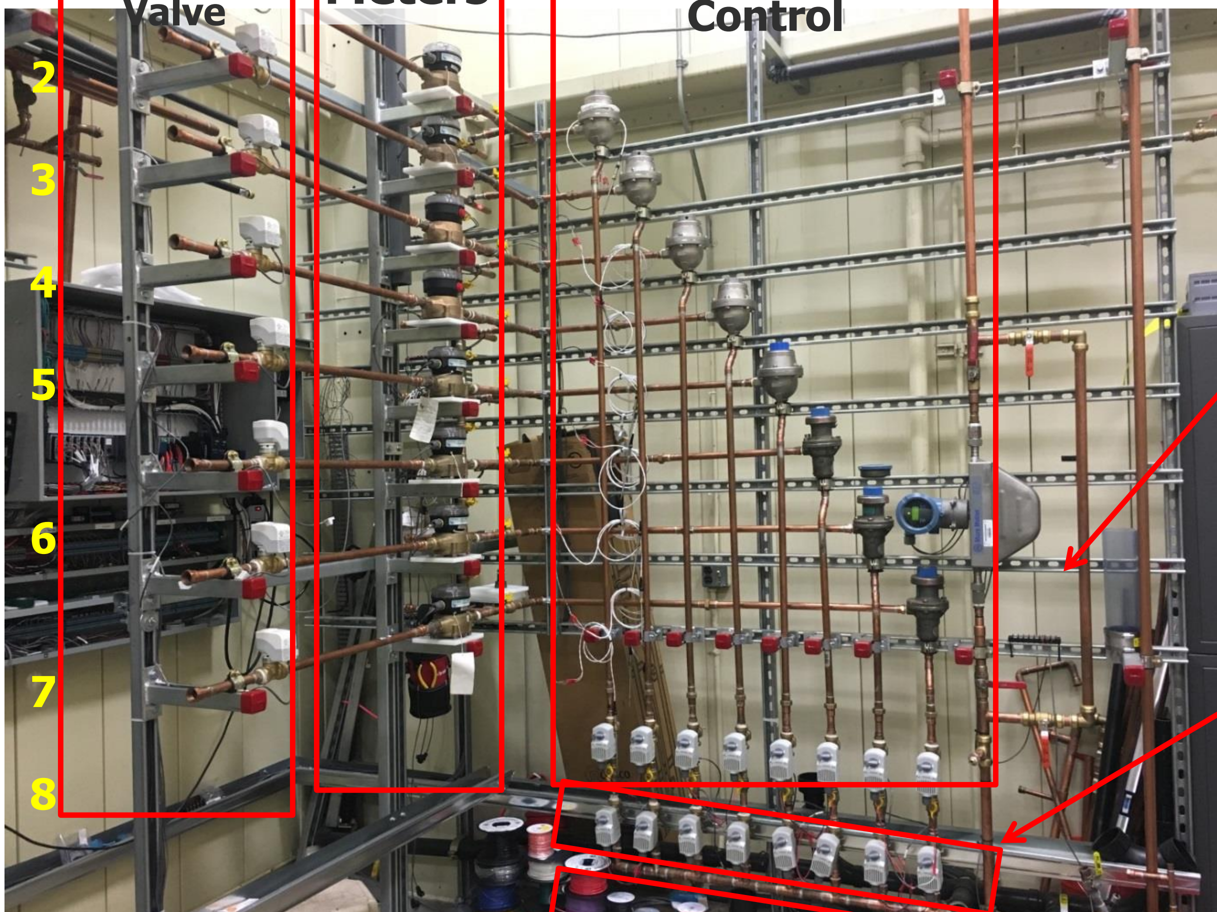
Distribution System – Piping Rack

Baseline distribution system

Optimized insulated distribution system under current testing

Hot Water Draw Simulation – Flow Measurement and Control (Constant, Staged and Variable Volume)

Hot Water Draw Simulation – Flow Measurement and Control (Constant, Staged and Variable Volume)



40 Optimized Test Scenarios – 11 Mod/Con Tank

Test No.	Distribution System (B, P)	Water Heater (CTL, CTK, STL, STK)	Recirc Control (On, Off, DMC, TC, Aq) (Return Location)	Recirc Rate (GPM)	Insulation	System Delivery Efficiency
1	P	CTK	Off	Avg	On	82.2%
2	P	CTK	On, L	Avg	On	65.4%
3	P	CTK	On, M	Avg	On	68.5%
4	P	CTK	On, M	Hi	On	67.3%
5	P	CTK	On, M	Lo	On	71.7%
6	P	CTK	DMC, L	Avg	On	
7	P	CTK	DMC, M	Avg	On	
8	P	CTK	TC, L	Avg	On	68.4%
9	P	CTK	TC, M	Avg	On	70.5%
10	P	CTK	Aq, L	Avg	On	67.6%
11	P	CTK	Aq, M	Avg	On	68.6%

- Test #1 – Highest system delivery efficiency at 82.2% with no continuous recirculation
- Resulted in poor hot water delivery performance – Not Acceptable
- Test #2 – Continuous recirc test to lower inlet port (Industry standard)
- Recirculation pump on medium flow setting of 3.5 gpm results in efficiency of 65.4%

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Test No.	Distribution System (B, P)	Water Heater (CTL, CTK, STL, STK)	Recirc Control (On, Off, DMC, TC, Aq) (Return Location)	Recirc Rate (GPM)	Insulation	System Delivery Efficiency
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4	P	CTK	On, M	Hi	On	67.3%
5	P	CTK	On, M	Lo	On	71.7%
6	P	CTK	DMC, L	Avg	On	
7	P	CTK	DMC, M	Avg	On	
8	P	CTK	TC, L	Avg	On	68.4%
9	P	CTK	TC, M	Avg	On	70.5%
10	P	CTK	Aq, L	Avg	On	67.6%
11	P	CTK	Aq, M	Avg	On	68.6%

- Test #3-5 – Continuous recirc test to upper inlet port (Only available on a few models)
- Changing to upper port resulted in 4.5% efficiency gains at 3.5 gpm flow!
- Test #5 – Recirc test at low flow rate of 1 gpm increased efficiency from 68.5% to 71.7%
- Test #4 – Recirc test at high flow rate of 6 gpm decreased efficiency to 67.3%

40 Optimized Test Scenarios – 11 Mod/Con Tank

Test No.	Distribution System (B, P)	Water Heater (CTL, CTK, STL, STK)	Recirc Control (On, Off, DMC, TC, Aq) (Return Location)	Recirc Rate (GPM)	Insulation	System Delivery Efficiency
1	P	CTK	Off	Avg	On	82.2%
2	P	CTK	On, L	Avg	On	65.4%
3	P	CTK	On, M	Avg	On	68.5%
4	P	CTK	On, M	Hi	On	67.3%
5	P	CTK	On, M	Lo	On	71.7%
6	P	CTK	DMC, L	Avg	On	
7	P	CTK	DMC, M	Avg	On	
8	P	CTK	TC, L	Avg	On	68.4%
9	P	CTK	TC, M	Avg	On	70.5%
10	P	CTK	Aq, L	Avg	On	67.6%
11	P	CTK	Aq, M	Avg	On	68.6%

- Test #6-7 – Demand controlled circulation to farthest fixture has not been completed
- Would allow for 120°F water to reach all fixtures without returning hot water to tank
- Test #8 – Recirc with timeclock test to lower inlet port resulted in 4.5% savings vs no TC
- Test #9 – Recirc with timeclock to upper port resulted in add. 3% savings vs lower port

40 Optimized Test Scenarios – 11 Mod/Con Tank

Test No.	Distribution System (B, P)	Water Heater (CTL, CTK, STL, STK)	Recirc Control (On, Off, DMC, TC, Aq) (Return Location)	Recirc Rate (GPM)	Insulation	System Delivery Efficiency
1	P	CTK	Off	Avg	On	82.2%
2	P	CTK	On, L	Avg	On	65.4%
3	P	CTK	On, M	Avg	On	68.5%
4	P	CTK	On, M	Hi	On	67.3%
5	P	CTK	On, M	Lo	On	71.7%
6	P	CTK	DMC, L	Avg	On	
7	P	CTK	DMC, M	Avg	On	
8	P	CTK	TC, L	Avg	On	68.4%
9	P	CTK	TC, M	Avg	On	70.5%
10	P	CTK	Aq, L	Avg	On	67.6%
11	P	CTK	Aq, M	Avg	On	68.6%

- Test #10-11 – Continuous recirc. with aquastat test
- Test #10 versus #2 – Recirc with aquastat test to **lower** inlet port resulted in 3% savings vs just continuous recirc
- Test #11 versus #3 – Recirc with aquastat test to **upper** inlet port resulted in no savings vs just continuous recirc (Recommend Retest)

6 Condensing Tankless Hybrid Test Scenarios

Test No.	Distribution System (B, P)	Water Heater (CTL, CTK, STL, STK)	Recirc Control (On, Off, DMC, TC, Aq) (Return Location)	Recirc Rate (GPM)	Insulation	System Delivery Efficiency
12	P	CTLHy	Off	Avg	On	
13	P	CTLHy	On	Avg	On	66.0%
14	P	CTLHy	On	Lo	On	65.6%
15	P	CTLHy	DMC	Avg	On	
16	P	CTLHy	TC	Avg	On	
17	P	CTLHy	Aq,	Avg	On	

- Test #13-14 – Continuous recirc. test with average and low flow recirc. rates
- Test #13 – Recirc with 3.5 gpm flow rate resulted in a efficiency of 66.0%
- Test #14 – Recirc with 1.0 gpm flow rate resulted in a efficiency of 65.6%
- Efficiency variation is minimial, could be within the limits of uncertainty for the 24h test

5 Standard Efficiency Tank Test Scenarios

Test No.	Distribution System (B, P)	Water Heater (CTL, CTK, STL, STK)	Recirc Control (On, Off, DMC, TC, Aq) (Return Location)	Recirc Rate (GPM)	Insulation	System Delivery Efficiency
18	P	STK	Off	Avg	On	
19	P	STK	On	Avg	On	50.27%
20	P	STK	DMC	Avg	On	
21	P	STK	TC	Avg	On	52.48%
22	P	STK	Aq,	Avg	On	54.23%

- Test #19 – Recirc. test with average recirculation flows results in an efficiency of 50.3%
- Test #21 – Recirc with timeclock resulted in a efficiency of 52.5%
- Test #22 – Recirc with aquastat resulted in a efficiency of 54.2%
- Overall, major system delivery efficiency reductions with conventional storage heaters

Thank you for your Attention!

I will relay your questions to Eddie!

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