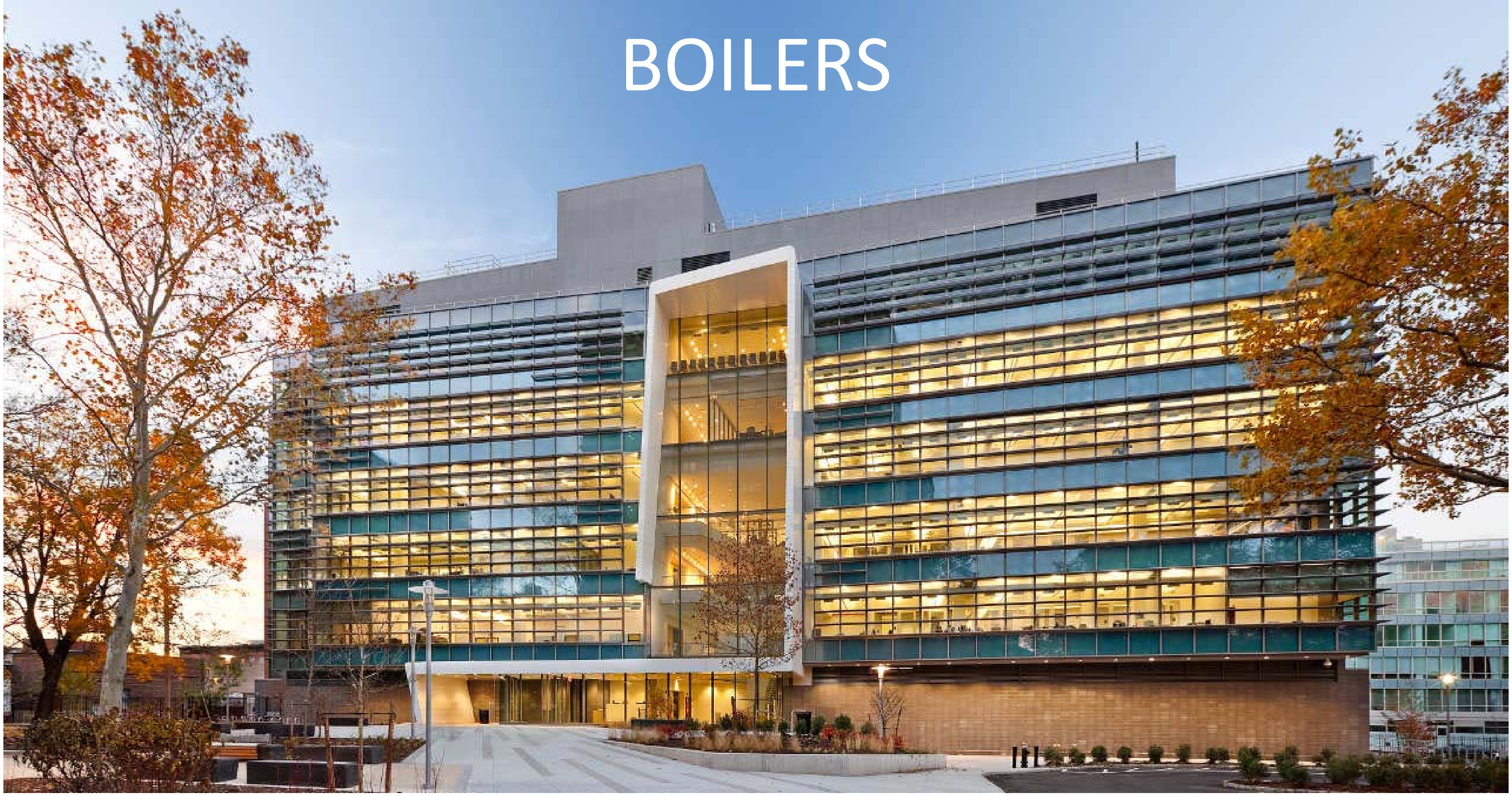
IN-FIELD PERFORMANCE OF CONDENSING BOILERS



March 2012

Lois B. Arena
Steven Winter Associates, Inc.

Why Research Hydronic Heating?

Reasons to Research Boilers

- Approx. 14 million homes (11%) in the US are heated with a steam or hot water system
- Almost 70 percent of existing homes were built prior to 1980
- Boilers built prior to 1980 generally have AFUE's of 0.65 or lower
- Energy savings of 20+% are possible by simply replacing older boilers with standard boilers & up to 30% with condensing boilers.
- Optimizing condensing boilers in new and existing homes could mean the difference of 8-10% savings with little to no additional investment.

Overview of Systems Evaluated

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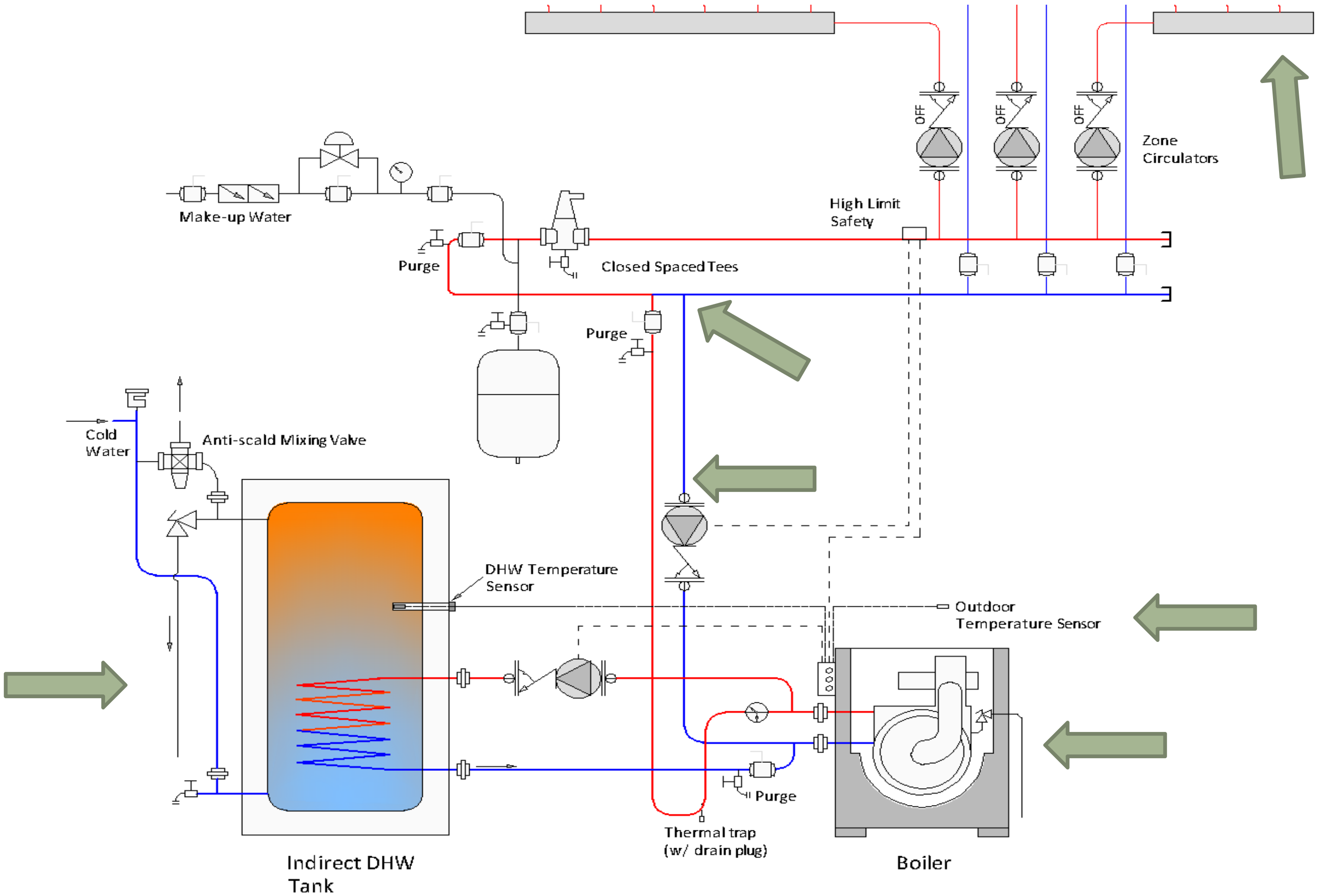
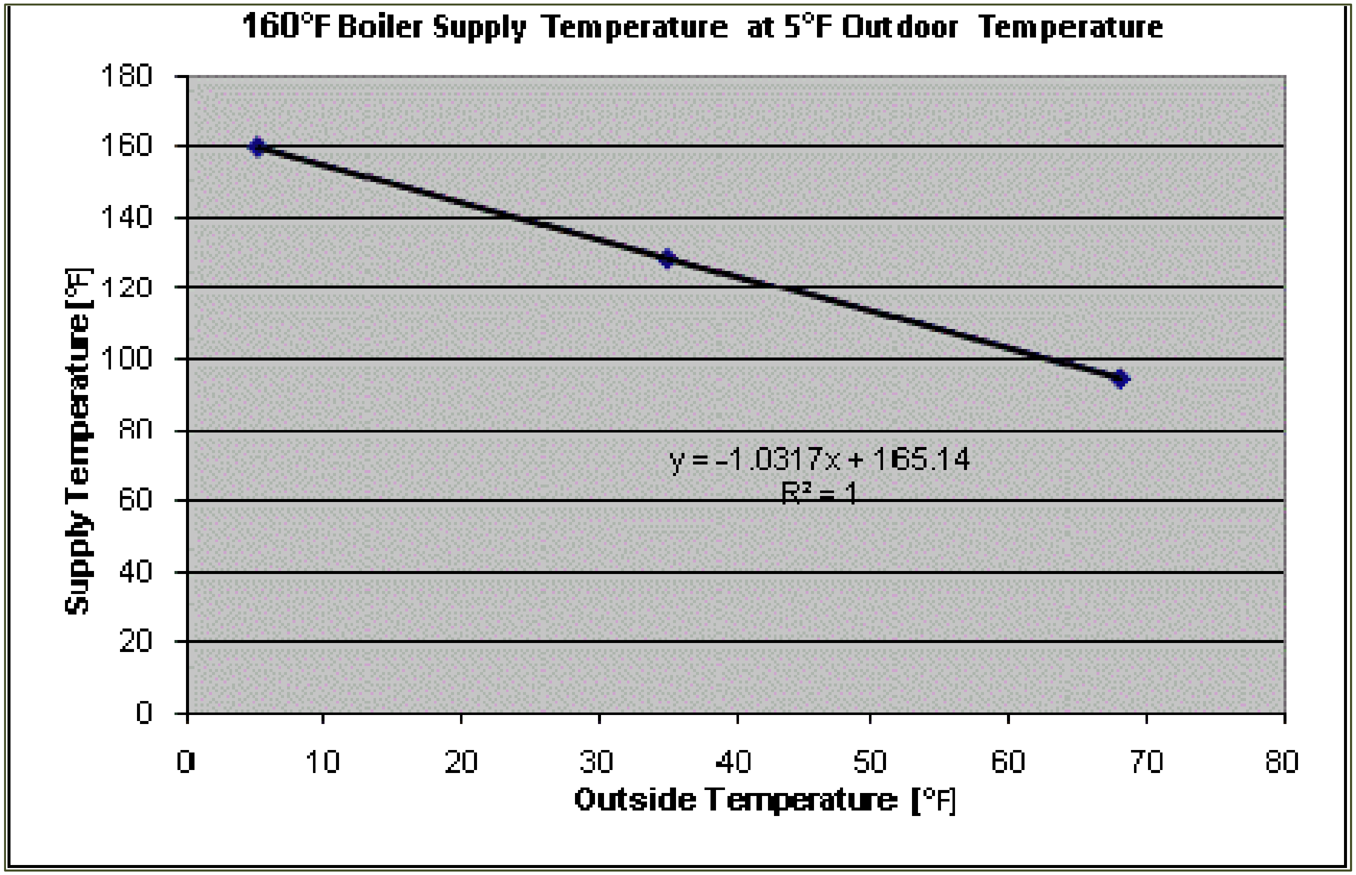
Overview of Previous Research

- Previous Research – 3 Phases:
  - Monitoring and Evaluation of 6 Existing Homes
  - Bench Top Research from Thomas Butcher at BNL
  - Design, Monitoring & Evaluation of 3 New Homes

Basic System Configuration



Outdoor Reset Curve



Gaps Identified

Technology & Industry Gaps

- Installed efficiency lower than rated efficiency
- Most software tools can't properly model hydronic heating
- Lack of guidance for contractors w/ respect to design, controls and commissioning
- Safety features protecting boilers decrease efficiency
- Response time is extremely slow

Critical Parameters Affecting Efficiency

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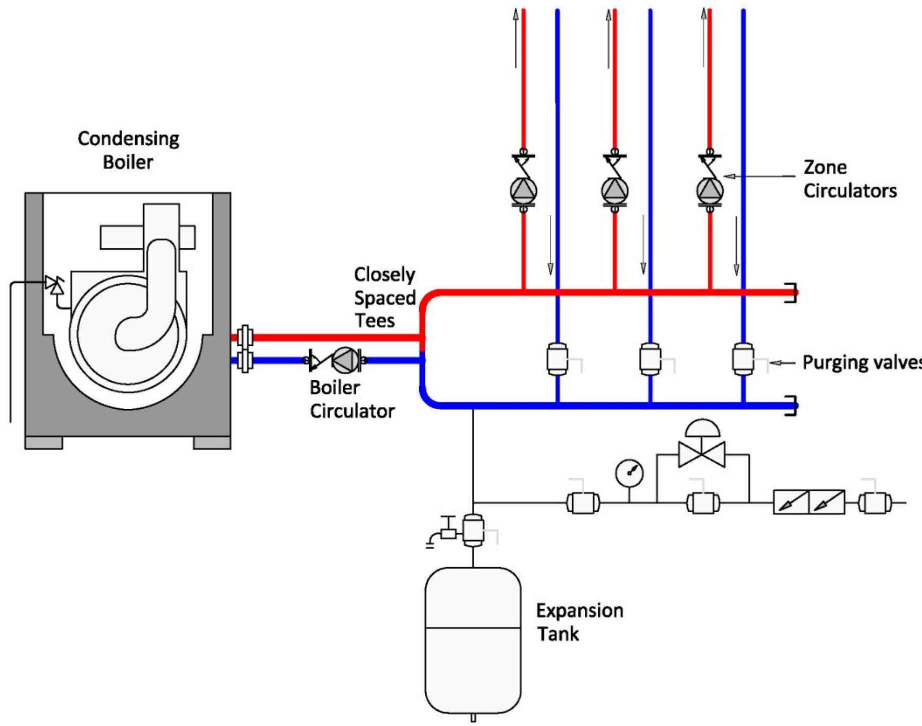
Factors Affecting Efficiency of Installed Systems

- Con - Primary/secondary loop - contributes to higher than optimal return water temperatures to the boiler



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Factors Affecting Efficiency of Installed Systems

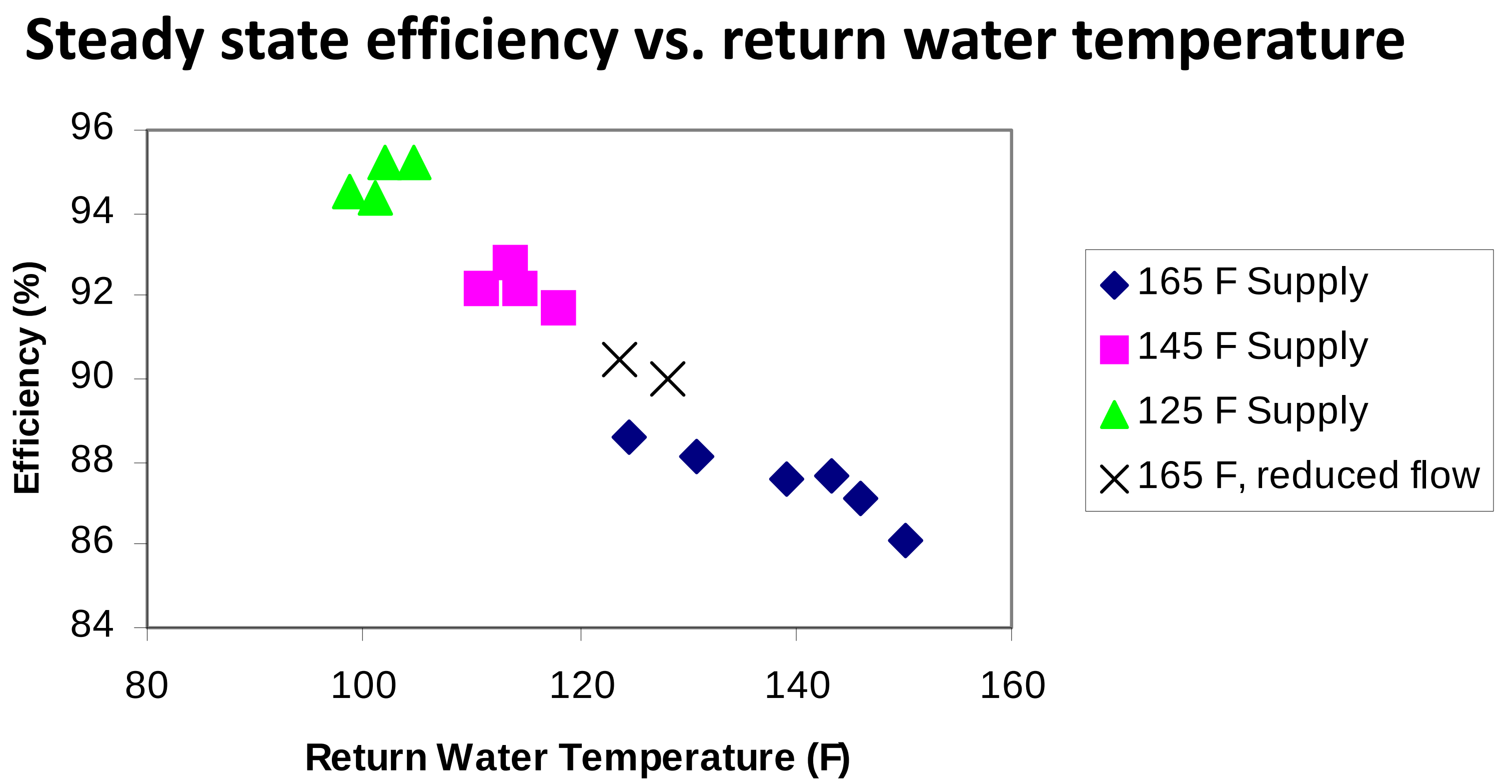
- Con - Flow rates are higher than anticipated, contributing to higher than optimal return water temperatures.

Table 1. Summary of Space Heating Operating Conditions from Existing Home Monitoring

House	Baseboard Length ft	Boiler Capacity kBtuh	# of Zones #	Flow Rate[1] gpm	Frequency of Condensing	Outdoor Reset	Boiler Curve Settings [°F]			
							$T_{s,max}$	$T_{out,min}$	$T_{out,max}$	$T_{s,min}$
#1	52	unknown	1	3.1	69%	Y	180	0	72	95
#2	38.5	50	2	5.3	59%	Y	185	5	68	95
#3	61	80	3	4.8	60%	Y	180	5	68	95
#4	32	80	1	3.3	20%	N[2]	200	5	68	95
#5	41	50	2	5.2	14%	Y[3]	185	5	68	145
#6	54	80	2	4.3	16%	N	201	5	68	95

[1]Flow rate recorded through primary loop.
[2]The outdoor reset, although installed, is not registering in the controller.
[3]The minimum boiler supply temperature was set to 145 °F because the toe kick heater in the kitchen would not activate below that.

Boiler Efficiency vs. Return Water Temp



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Factors Affecting Efficiency of Installed Systems

- Con - Maximum boiler output temperature is typically set to 180°F or higher for both space and domestic hot water heating.

$T_{s,min}$	Frequency of Condensing at Different $T_{s,max}$ (1, 2 & 3 gpm) 150			160			170			180		
95	99%	91%	87%	90%	80%	77%	79%	68%	64%	66%	57%	53%
105	99%	87%	83%	86%	72%	67%	71%	58%	54%	56%	47%	44%
110	99%	84%	79%	82%	66%	60%	62%	50%	45%	48%	41%	39%
115	98%	80%	73%	72%	56%	50%	48%	42%	35%	40%	34%	32%
120	97%	70%	60%	66%	45%	40%	43%	34%	24%	32%	25%	23%

Results for bin temperature profile in Ithaca, NY

Factors Affecting Efficiency of Installed Systems

Any control technique which reduces the return water temperature, including lowering the boiler set point and/or reducing the loop flow rate will significantly improve the achieved efficiency.

Factors Affecting Efficiency of Installed Systems

- Flow Rates were higher than specified:
  - Contractors don’t have standard, simple methods for measuring and/or setting flow rates.
  - Until recently, low flow residential pumps for which the flow can be set, have been difficult to find.

Factors Affecting Response Time

- Recovery from setback
  - Extremely slow in all homes monitored – more than 2 hours for a 5 degree setback.
  - Location of outdoor reset sensor is important to system performance
  - Appears to get worse with increasing outdoor temperatures
  - Differential setting can affect recovery time

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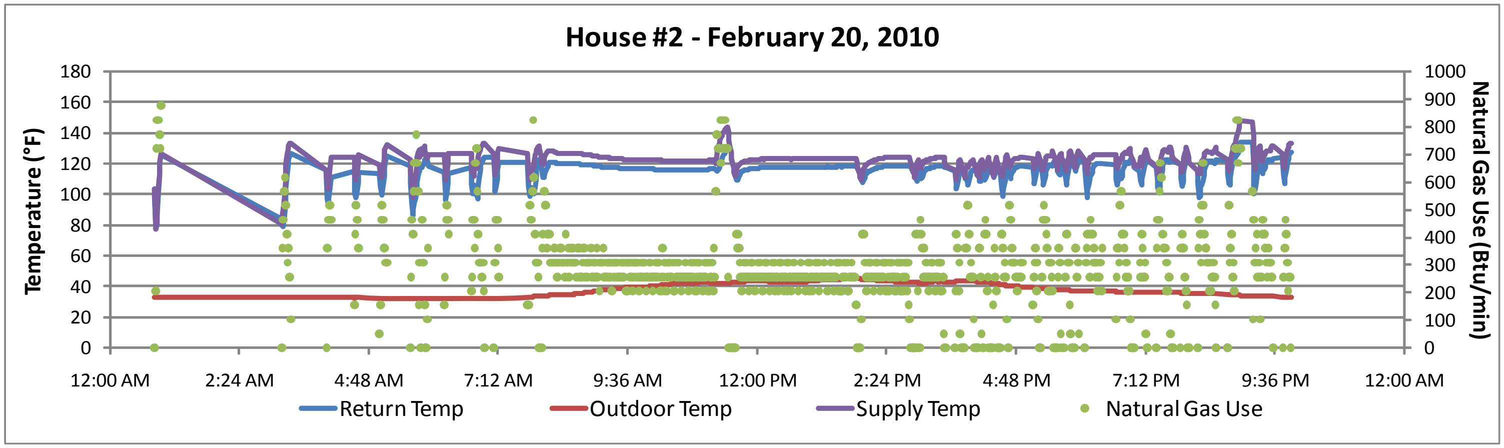
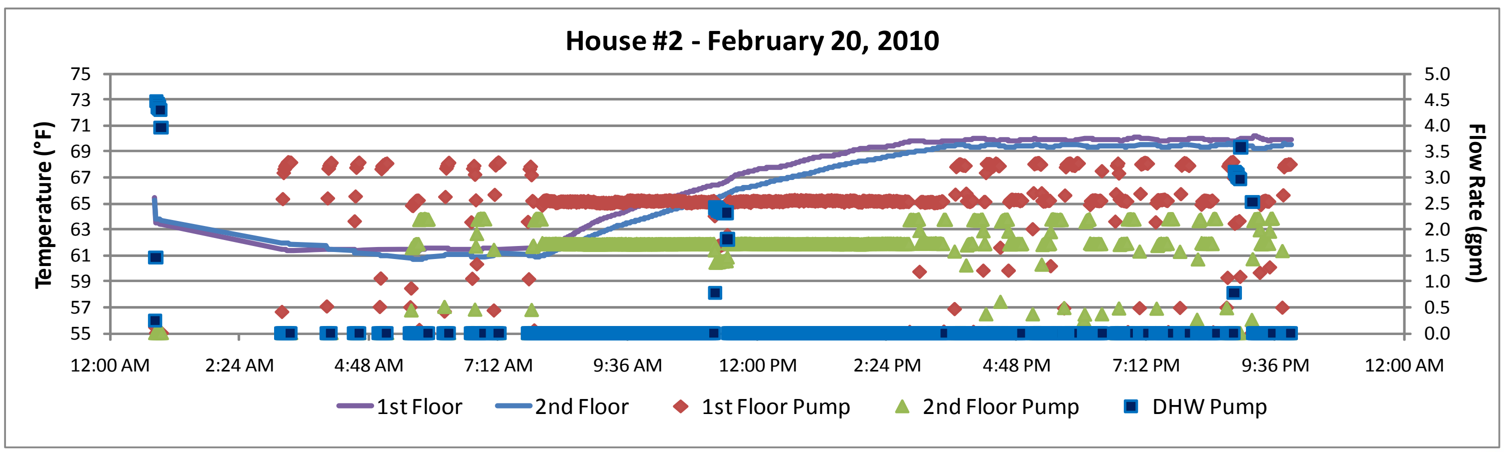
Factors Affecting Response Time





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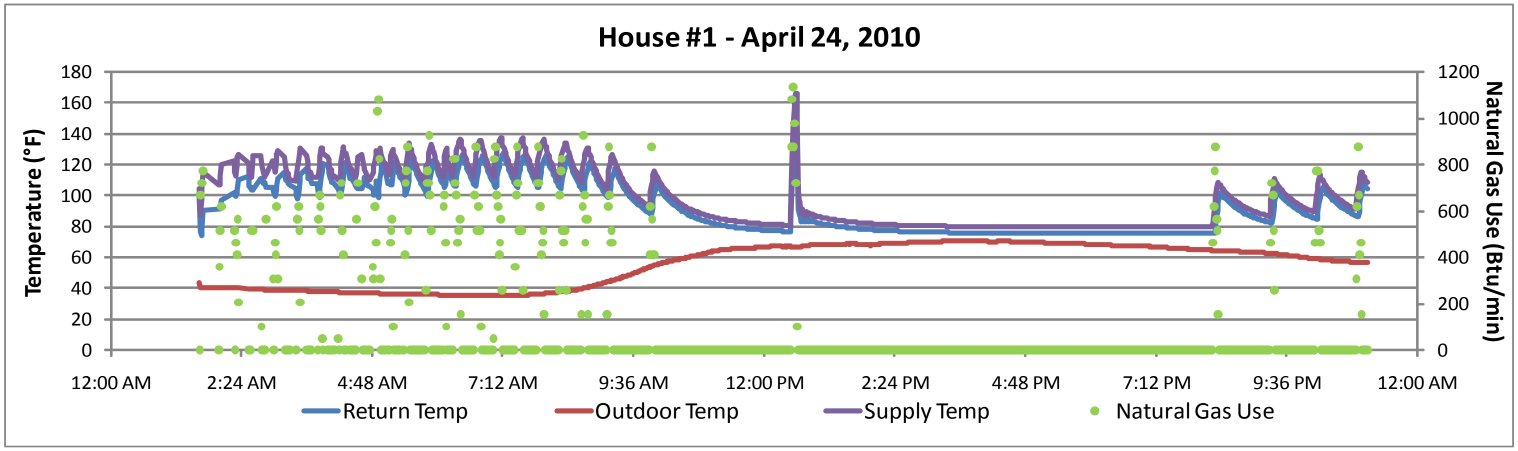
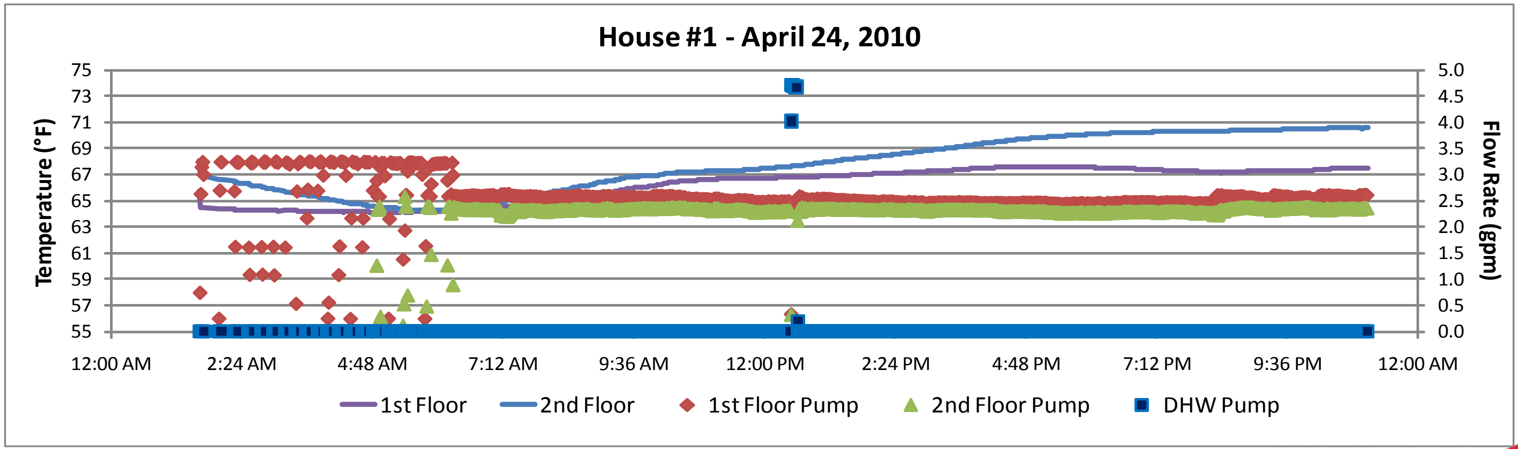
Factors Affecting Response Time





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Improving Efficiency & Response Time

Changes Made in Last Round of Testing

- Proper sizing of boiler mandatory
- Outdoor reset control a must.
- Lower $T_{s,max}$ on reset curve
- Reduce flows to achieve 20° ΔT at design – 30% savings in pump energy going from high to low speed.
- Size baseboard for low-flow & $T_{s,max}$ from above – oversizing is OK.

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Results of Changes Made in Last Round of Testing

- Performance Results:
  - Phase III – all condensed over 96% of year in space heating mode
  - Phase I – 60-69% in space heating mode
- Estimated Savings (<u>remember: small house</u>)
  - Translates to approximately 3% improvement in efficiency for a Phase III house ≈ $20/yr
  - 30% savings in pump power ≈ $10-$15/yr
  - Extra 20’ of baseboard ≈ $160, payback is ≈ 5 years
- **NOTE: w/out outdoor reset, 15-20% condensing.**

Continuing Research

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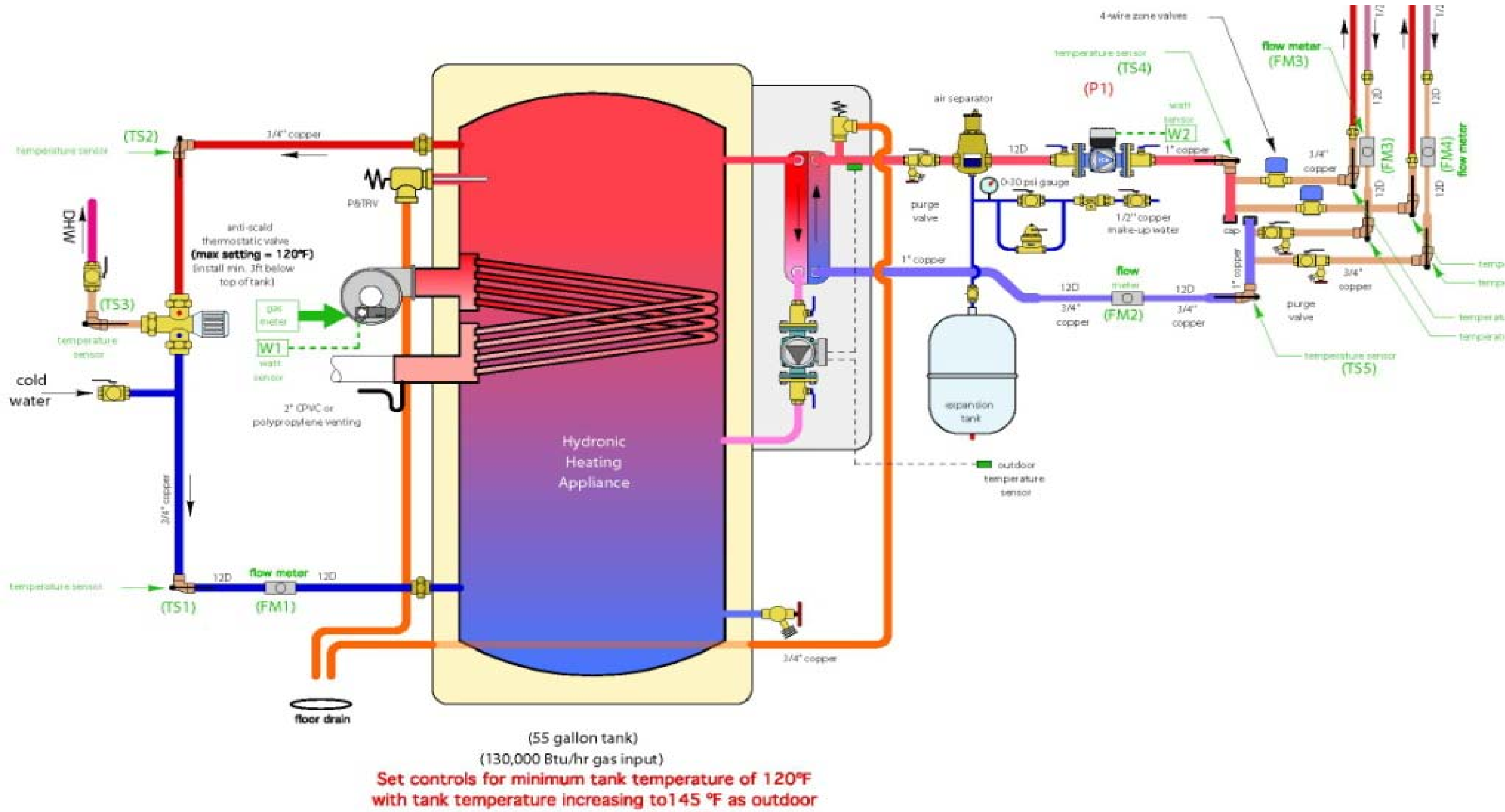
Upcoming Research

- 2 New Homes
- Similar construction to first round of research
- Same climate
- Applicability to retrofit applications
- Industry Sanctioned Designs
- Looking at line losses, baseboard piping, boost vs. setback

Upcoming Research – System A

High mass boiler, zone valves, variable speed pump



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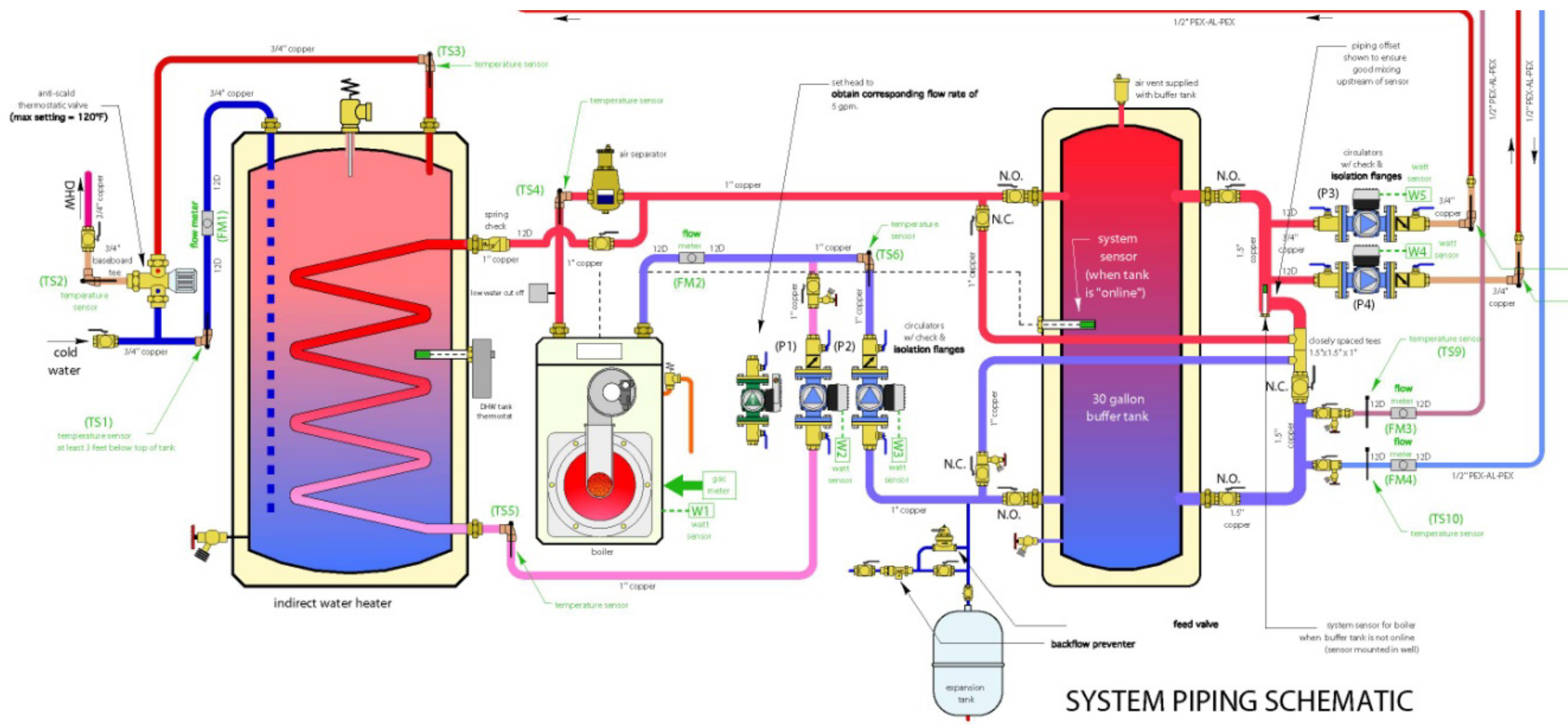
Upcoming Research – System B

Low mass, indirect tank, adjustable speed pumps on zones – compare performance of primary loop vs. a buffer tank



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Recommendations for Improving Response Time & Comfort

- Proper sizing of boiler mandatory
- Raise $T_{out,min}$ on boiler curve slightly
- Proper placement of outdoor reset sensor
- Recommend boost controls or eliminate setback
- If setback is desired, increase length of baseboard to improve response time (will increase efficiency as well)

Questions?

Thank You.

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