U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BUILDING TECHNOLOGIES PROGRAM

Expert Meeting: Optimized Heating Systems Using Condensing Boilers and Baseboard Convectors

L. Arena
Steven Winter Associates

January 2013

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U.S. Department of Energy

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Expert Meeting: Optimized Hydronic Heating Systems Using Condensing Boilers and Baseboard Convectors

Prepared for:

The National Renewable Energy Laboratory

On behalf of the U.S. Department of Energy's Building America Program

Office of Energy Efficiency and Renewable Energy

15013 Denver West Parkway

Golden, CO 80401

NREL Contract No. DE-AC36-08GO28308

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January 2013

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Unless otherwise noted, all tables were created by CARB.

Definitions

BEopt	Building Energy Optimization
BNL	Brookhaven National Laboratory
CARB	Consortium for Advanced Residential Buildings
DOE	U.S. Department of Energy
OAT	Outside air temperature
VFD	Variable-frequency drive

Executive Summary

On August 11, 2011, a Building America Expert Meeting was held to review and discuss results and future plans for research to improve the performance of hydronic heating systems using condensing boilers and baseboard convectors. The meeting was held in Denver, Colorado, in conjunction with the Building America Residential Energy Efficiency Technical Update Meeting. A meeting objective was to create an opportunity for other Building America teams and industry experts to offer feedback and specific suggestions for the planned research.

Lois Arena of Steven Winter Associates summarized the findings from previous Consortium for Advanced Residential Buildings (CARB) field monitoring research and presented the plan for further research to be conducted next year. CARB has been collaborating with Brookhaven National Laboratory (BNL) and industry manufacturing partners to design, install, and monitor condensing boiler space and water heating systems under occupied conditions. Previous research included the monitoring of condensing boilers in six existing homes, targeted bench top testing by BNL, and monitoring of CARB-designed hydronic heating systems in three new homes.

Xia Fang of the National Renewable Energy Laboratory presented preliminary energy simulation results and identified gaps in modeling capability. Additional modeling work was done based upon comments raised during the meeting. An updated presentation of findings is included as an appendix to this report.

1 Introduction

With annual fuel utilization efficiencies around 95%, condensing boilers and furnaces promise significant energy savings by recovering the latent energy of flue gas water vapor. Condensing boilers paired with low-temperature baseboard heating systems are one of the most cost-effective methods for heating high performance, and thus low load, homes. Ducted systems (furnaces and hydro-air systems) are often subject to reduced efficiencies resulting from duct leakage and fan energy requirements, and other hydronic distribution systems, such as radiant-floor systems and some specialized cast-aluminum radiation systems, are far more expensive.

Although condensing boilers promise to deliver substantial improvements over conventional boilers, condensing boilers as typically installed (according to common practice and manufacturer recommendations) do not achieve consistent flue gas condensation. To ensure condensation, the return temperature to the boiler must be below the flue gas saturation temperature, which is generally 54°C (130°F) for natural gas equipment (Butcher 2006).

For Building America to achieve its goals, it is important that applications of condensing boiler technology reliably achieve the intended efficiency and energy savings. In response to this need, CARB teamed with the New York State Energy Research and Development Authority, Ithaca Neighborhood Housing Services, and Brookhaven National Laboratory to evaluate the performance of condensing boilers using baseboard convector delivery systems. Specific research objectives included: (1) evaluating and defining the optimal operating parameters of the condensing-boiler/hot-water baseboard combination; (2) evaluating and defining the optimal operating parameters of the condensing boiler/indirect domestic hot water combination; (3) testing those findings in real-world residential settings; and (4) documenting those parameters in a technically accurate, installer friendly manner.

The initial phase of the project involved monitoring boiler performance in six existing homes in Ithaca, NY, beginning in late January 2009 and concluding in August 2009. In the next phase, information gained from the first phase was used to design and size systems for three new homes also located in Ithaca. Boiler performance in the new homes was tested and monitored to further define the best design parameters to ensure maximum boiler efficiencies.

Research findings were presented to industry leaders at a Building America Expert Meeting in October 2010, and although there was much agreement and acceptance of the issues presented, no agreement as to the best solutions was reached and further research was encouraged. Thus, the objectives of the planned research are as follows:

- Evaluate and define the optimal combinations of components and plumbing configuration to ensure highly efficient, reliable condensing boiler performance.
- Test those findings in real-world residential settings.
- Gain recognition and acceptance from the industry for the new designs.
- Document those parameters in a technically accurate, installer friendly manner.
- Disseminate the results to the larger residential building industry.

During the expert meeting held on August 11, 2011, the details of the test plan were reviewed and discussed. A goal of the meeting was to determine whether the planned research was appropriate and comprehensive.

2 Meeting Agenda

The meeting was held at the Renaissance Hotel in Denver on August 11, the third day of the Building America Residential Energy Efficiency Technical Update Meeting. The meeting agenda and attendees are presented in Tables 1 and 2, respectively.

Table 1. Expert Meeting Agenda

Time	Item	Presenter/Facilitator
9:00–9:05	Welcome and Meeting Overview	Bill Zoeller, CARB
9:05–10:00	Previous Research: monitoring and evaluations of 6 homes (Phase I and Phase II) Benchtop research conducted by Dr. Thomas Butcher, Brookhaven National Laboratory Conclusions and open questions based on Phase I and Phase II results Emerging Technologies (VFD pumps, Versa-Hydra, etc.) Phase III: Proposed designs, collaboration with w/ industry partners. 3 new homes with 3 different systems.	Lois B. Arena, CARB
10:00–10:30	Analysis of condensing boiler modeling in homes using BEopt/DOE-2 vs. BEopt/EnergyPlus Addressing Issues with OAT reset with respect to modeling Performance curve implementation issues in EnergyPlus vs. DOE-2	Xia Fang, NREL
10:30–10:55	Feedback, questions, suggestions from teams/attendees	All
10:55–11:00	Closing Remarks and Next Steps	Bill Zoeller, CARB

Notes: VFD, variable-frequency drive; BEopt, Building Energy Optimization; OAT, outside air temperature; DOE, U.S. Department of Energy

Table 2. Expert Meeting Attendees

Name	Company	E-Mail Address
Charles Adams	A.O. Smith Corporate Technology Center, Milwaukee, WI	cadams@aosmith.com
Lois Arena	Steven Winter Associates, Inc., Norwalk, CT	larena@swinter.com
David Bohac	Center for Energy and Environment, Minneapolis, MN	dbohac@mncee.org
Larry Brand	Gas Technology Institute, Des Plaines, IL	larry.brand@gastechnology.org
Kim DeVoe	City of Fort Collins, CO	kdevoe@fcgov.com
Cheryn Engebrecht	National Renewable Energy Laboratory, Golden, CO	Cheryn.engebrecht@nrel.gov
Xia Fang	National Renewable Energy Laboratory, Golden, CO	xia.fang@nrel.gov
Dianne Griffiths	Steven Winter Associates, Inc.	dgriffiths@swinter.com
Philip Kerrigan	Building Science Corporation	phil@buildingscience.com
Bill Zoeller	Steven Winter Associates, Inc.	wzoeller@swinter.com

3 Presentations

Lois Arena's presentation (Appendix A) reviewed the earlier research findings and detailed the specific designs to be installed and monitored in the next phase of research. She had given a more detailed presentation of the research findings the previous day as part of the Technical Update Meeting.

Xia Fang's presentation reviewed her initial effort to model the performance of condensing boilers and control strategies using EnergyPlus. A work-around using performance curves was utilized for the current version of EnergyPlus. Xia noted that more data should be gathered to validate the performance map used. Preliminary modeling results did not demonstrate substantial energy savings, but the system capacities were not optimized for each alternative modeled.

4 Discussion

The modeling results were presented as preliminary and several suggestions were made. The performance specifications for the modeled home, specifically the infiltration assumption, were questioned, and it was recommended that two house models would be appropriate—a new, tightly constructed home and an existing home. Utilities need to understand the impacts of different parameters to justify their programs. This additional modeling work was done after the meeting. Those findings are presented in the updated presentation located in Appendix B.

There was also a concern that the cost of the OAT reset control applied for the cost-effectiveness analysis was too high. The preliminary conclusions on cost effectiveness have been removed from the updated presentation.

Zone valve reliability was discussed with the group. The builder partnering with CARB for this research prefers to use circulators for each heating zone as opposed to zone valves. He believes that zone valves fail every few years and the cost to replace them outweighs the savings of installing high efficiency systems. The group was asked their opinion on this issue. None of the participants had experience or direct knowledge with the reliability of zone valves versus circulators.

Larry Brand noted that the Gas Technology Institute has tested pumps in its laboratory and agreed that the trades believe in the “bigger pump is better” philosophy.

Installing condensing boilers in a retrofit application was discussed. It was agreed that, while baseboard convectors are probably adequate in existing homes because they are traditionally grossly oversized, existing high mass radiators may not be a feasible heat emitter when combined with a condensing boiler in a retrofit application.

Charles Adams noted that AO Smith has acquired Lochinvar, and they might be interested in partnering with us during the next phase. It was mentioned that Lochinvar boilers have a built-in primary loop, which is one of the design elements that CARB is trying to eliminate because it contributes to higher return water temperatures and lower installed efficiencies. The designs currently under consideration eliminate primary/secondary loop configurations all together.

The application of hydrocoil systems was briefly discussed and, while of interest, it was acknowledged that they are not within the scope of this research.

5 Summary

During this expert meeting, the details of the test plan to be implemented by CARB during the 2011/2012 winter were reviewed and discussed. Meeting attendees were asked if the test plan was appropriate and comprehensive and if there were other design configurations that should be considered. Attendees supported the test plan and no alternative design suggestions were made at, or subsequent to, the meeting. Meeting attendees were invited to provide input to the test plan and proposed designs at any time.

References

Butcher, T. (2006). "Condensing Boilers and Baseboard Hydronic Systems." *ASHRAE Transactions* (112:part 1).

Appendix A: Presentation by Lois Arena, Steven Winter Associates, Inc.

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"Experts Meeting"
Condensing Boilers

August 11, 2011

9:00 am – 11:00 pm

Denver, CO

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Overview of Presentation

- Why research boilers?
- 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
- Next Round:
  - Close collaboration w/ Industry Partners
  - 3 New Homes, 3 Different Systems

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WHY RESEARCH BOILERS?

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Relevance of Research

- 115 million existing homes in the US - 14 million (11%) are heated with a steam or hot water system
- Modulating capability makes them an excellent option for low-load homes
- Combined with baseboard convectors = low-cost, energy efficient solution for high-efficiency residential space heating in cold climates

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PREVIOUS RESEARCH

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Phase I – Space Heat Summary

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

							Boiler Curve Settings [°F]			
House	Baseboard Length ft	Boiler Capacity kBtuh	# of Zones #	Flow Rate[1] gpm	Frequency of Condensing	Outdoor Reset	$T_{s,max}$	$T_{out,min}$	$T_{out,max}$	$T_{s,min}$
#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.

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Phase I – DHW Summary

Table 1. Summary of DHW Operating Conditions from Existing Home Monitoring

House	$T_{s,DHW}$* °F	Tank Setpoint °F	Tank Size gallons	Flow gpm	# of Occupants	% of Time Condensing	Data Interval minutes
#1	180	125	30	3.3	2	60%	15
#2	180	115	30	5.6	2	65%	5
#3	180	125	40	4.2	4	44%	5
#4	145	115	30	6.0	4	36%	5
#5	180	?	30	5.4	3	18%	5
#6	185	115	30	2.7	1	35%	15

*Boiler supply temperature setpoint for DHW

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Phase I – Key Findings

- Primary/secondary loop plumbing configuration contributes to higher than optimal return water temperatures to the boiler
- Flow rates are higher than recommended, contributing to higher than optimal return water temperatures.
- Baseboard lengths being installed in these homes are consistent with the lengths needed for a low temperature, low flow system.
- Maximum boiler output temperature is typically set to 180°F or higher.
- Boiler supply temps to the domestic hot water tank were set at 180°F or higher for 5 of the 6 homes.

Phase II Bench Top w/ BNL – Objective

- Blow up the boiler!

Phase II Bench Top – Key Findings

- Particularly difficult to blow up the boiler!
- Low mass boiler tested can be operated with:
  - flow rates significantly lower, and
  - temperature rises significantly higher than the manufacturer's recommendations.
- The boiler pressure should be maintained at the high end of its allowable range.

Phase III - Objectives

- Evaluate the plans and specifications for three new homes
- Make design recommendations based on information gained from Phase I
- Monitor the performance of these systems once installed

Phase III – Design Recommendations

- Maximum boiler supply temperature should be set to 160°F;
- Flow rate through each zone should be 1 gpm;
- Baseboard sizing was based on an average water temperature of 150°F;
- 30 gallon, indirect storage tanks controlled by Vision I controller;
- The primary loop should be removed.

Phase III –Recommended vs. Installed Spec's

Address	Recommended Spec's			Installed Spec's		
	Boiler	Baseboards	DHW	Boiler	Baseboards	DHW
House #1	50 kBtuh Munchkin Contender	26' - 1st floor, 22' – 2nd floor	30 gallon indirect tank, Vision I controlled	80 kBtuh Munchkin	31' - 1st floor 23' - 2nd floor	40 gal indirect tank, Vision I controlled but not compatible
House #2	50 kBtuh Munchkin Contender	21' - 1st floor 18'- 2nd floor	30 gallon indirect tank, Vision I controlled	As Recommended	29' - 1st floor + 12" toe kick heater in the kitchen* 32.5' - 2nd floor	As Recommended
House #3	50 kBtuh Munchkin Contender	19' - 1st floor 16' – 2nd floor	30 gallon indirect tank, Vision I controlled	As Recommended	27.5' - 1st floor + 12" toe kick heater in kitchen* 30.5' - 2nd	30 gal indirect tank, aquastat controlled

*The toekick heaters provide approximately 3,100 Btuh at 140°F inlet on low speed. This is approximately equal to 3.5 times the calculated load for that space.

Phase III – "Final" Settings

Settings		House #1	House #2	House #3
Thermostats (°F)				
on thru Fri	6:00 am	68	68	68
	8:00 am	65	62	65
	6:00 pm	68	68	68
	10:00 pm	65	62	65
Sat & Sun	8:00 am	70	70	70
	10:00 pm	62	62	65
Boiler Settings (°F)				
	Supply to Zones at 5°F outside	150	150	150
	Supply to zones at 68°F outside	95	95	95
	Differential to zones	30	30	30
	Supply to DHW	160	180	160
	DHW Tank Setpoint	95*	119	130
Pump Speeds (gpm)				
	Zone 1(alone/+Zone2)	3.1/2.4(low)	3.0/2.6(low)	3.2/2.3(low)
	Zone 2(alone/+Zone1)	3.0/2.4(low)	1.9/1.4(high)	2.5/2.1(low)
	DHW (alone)	4.5**	4.0 (low)	4.2(low)

*This is a temporary setting until tank is fixed/replaced. Final setting should supply 120°F water at the tap.

**DHW pump at House #1 was a Taco. Speed was not adjustable. All other pumps were Grundfos, 3-speed pumps. All pumps set to "low" except zone 2 at House #2.

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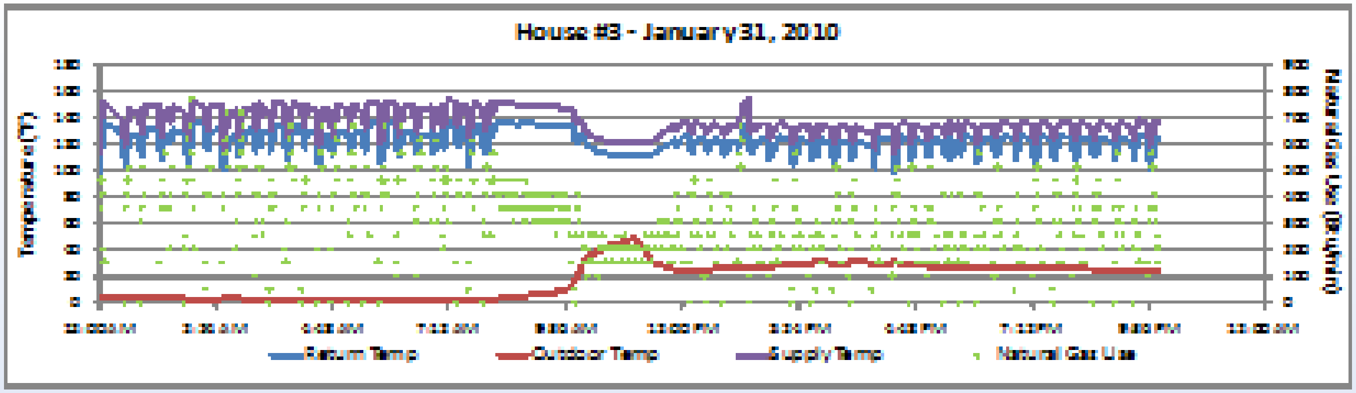
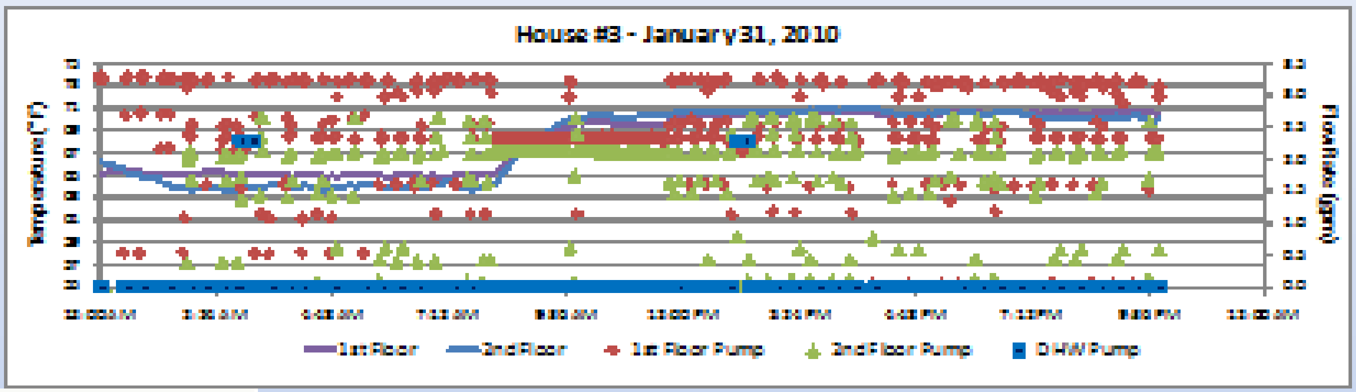
Phase III – Operation Under Design Conditions





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Phase III – General Observations at Design

- Once setpoint is reached, systems don't have trouble maintaining the indoor temperature.
- Boilers often modulate to higher rates even though the lowest rate is over design load.
- Boilers rarely reach maximum firing rates unless DHW calls for heat

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Phase III – General Overview of Performance

	Frequency of Condensing (%)			% of Time Boiler Fires During Call for Heat
	Space Heat Only	DHW Only	Overall	
House #1	97	64	97	34
House #2	96	56	93	68
House #3	96	64	94	75

97% of Temps fell in Bins where condensing was predicted.

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Phase III – Recovery From Setback

- Recovery was never achieved at House #1 on the 1st floor.
- Location of outdoor reset sensor is important to system performance
- Recovery time appears to get worse with increasing outdoor temperatures
- Differential setting can affect recovery time
- 2-story configuration may be contributing to recovery lag of the first floor

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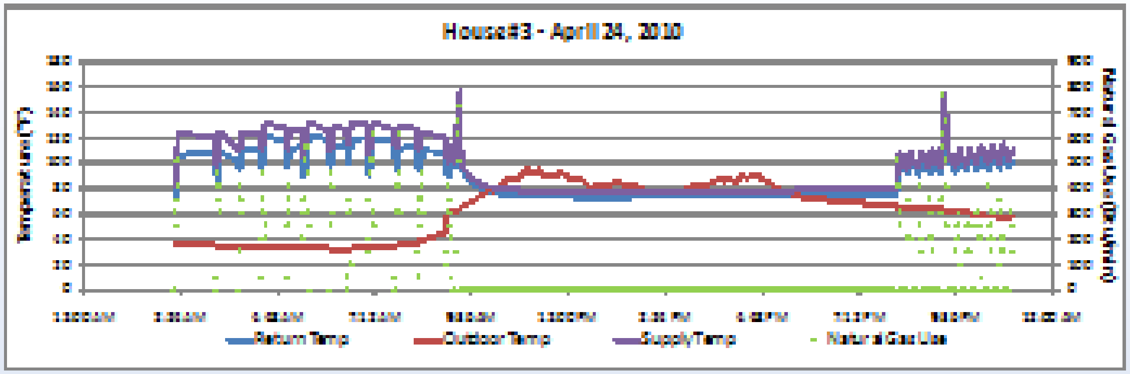
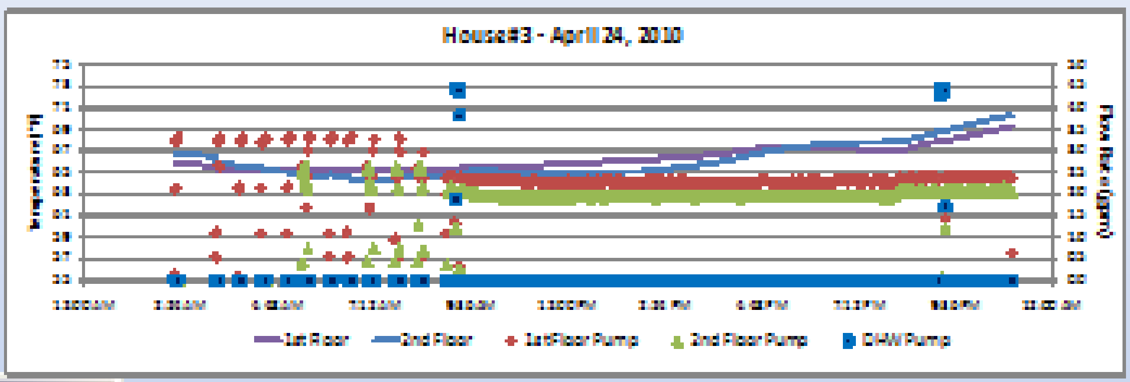
Phase III – No Heat in Swing Seasons





Phase III – Affects of Adjusting $T_{out,max}$

$T_{out,max}$	Frequency of Condensing at Different $T_{s,max}$ (1, 2 & 3 gpm) 150			160			170			180		
68	99%	91%	87%	90%	80%	77%	79%	68%	64%	66%	57%	53%
70	99%	90%	87%	89%	79%	76%	78%	66%	64%	64%	54%	52%
72	99%	90%	86%	88%	78%	74%	77%	64%	61%	63%	52%	51%

Phase III – Flow Rates

Barriers to achieving specified, low-flow rates.

- 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.

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Phase III – Comparison of Boiler Operation at Different Flow Rates

Pump Flows (gpm) Zone1/Zone2	Average ΔT	$T_{s,ave}$	$T_{out,ave}$	Max Firing Rate	Average Firing Rate	% Firing During Call for Heat	Recovery Time
	°F	°F	°F	kBtuh	kBtuh		°F/hour
2.5/2.4	13	126.2	29.6	65	32	31	0.5/0.9
0.9/1.1	19.3	125.5	33.5	49	21	47	0.35/0.35

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Conclusions

- Little advice on controlling flow rates or setting the boiler response curve;
- Severe over-sizing = excessive cycling and reduced comfort.
- Spike in T_{out} could lead to no heat.
- 1st floor zones ran approximately 22 - 35% more often than 2nd floor zones.

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Conclusions

- Primary/secondary loop configuration reduces the frequency of condensing.
- Extreme delays in recovery from setback.
- Outdoor reset and low limit settings on the boiler curve affect response time.
- Components requiring minimum supply water temperature should be spec'd properly.

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Conclusions

Lots of info on individual components,

BUT

<u>little information explaining best combination of settings when these technologies are combined.</u>

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UPCOMING RESEARCH

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Upcoming Research - Goals

Create system designs that:

- increase condensing frequency,
- reduce recovery time,
- increase reliability, and
- reduce installation complexity with regard to controls and piping configurations.

Upcoming Research - Goals

Proven, repeatable, reliable, industry-sanctioned designs.

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Upcoming Research

- 3 New Homes
- Similar construction to first round of research
- Applicability to retrofit applications

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Research Question

- What combination(s) of components – pumps, high efficiency heat sources, plumbing configurations and controls – will result in the highest overall efficiency for a hydronic system where baseboard convectors are used as the heat emitter?

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Research Questions

- What is the trade-off in efficiency associated with decreased recovery times following setback? Which would result in lower overall energy use - employing thermostat setback with a boost to speed recovery or simply maintaining a constant temperature in the home?

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Upcoming Research

Will monitor both:

- No setback, constant temperature
- Boost control to override boiler

Research Questions

- What is the value of thermal mass in high efficiency boiler systems?

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Research Questions

- What is the value of thermal mass in high efficiency boiler systems?

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Upcoming Research

Do these offer:

- Increased annual efficiency?
- Less cycling?
- Increased response time?
- Simplified install?

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Questions.

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Appendix B: Updated Presentation by Xia Fang, National Renewable Energy Laboratory

NATIONAL RENEWABLE ENERGY LABORATORY

Innovation for Our Energy Future

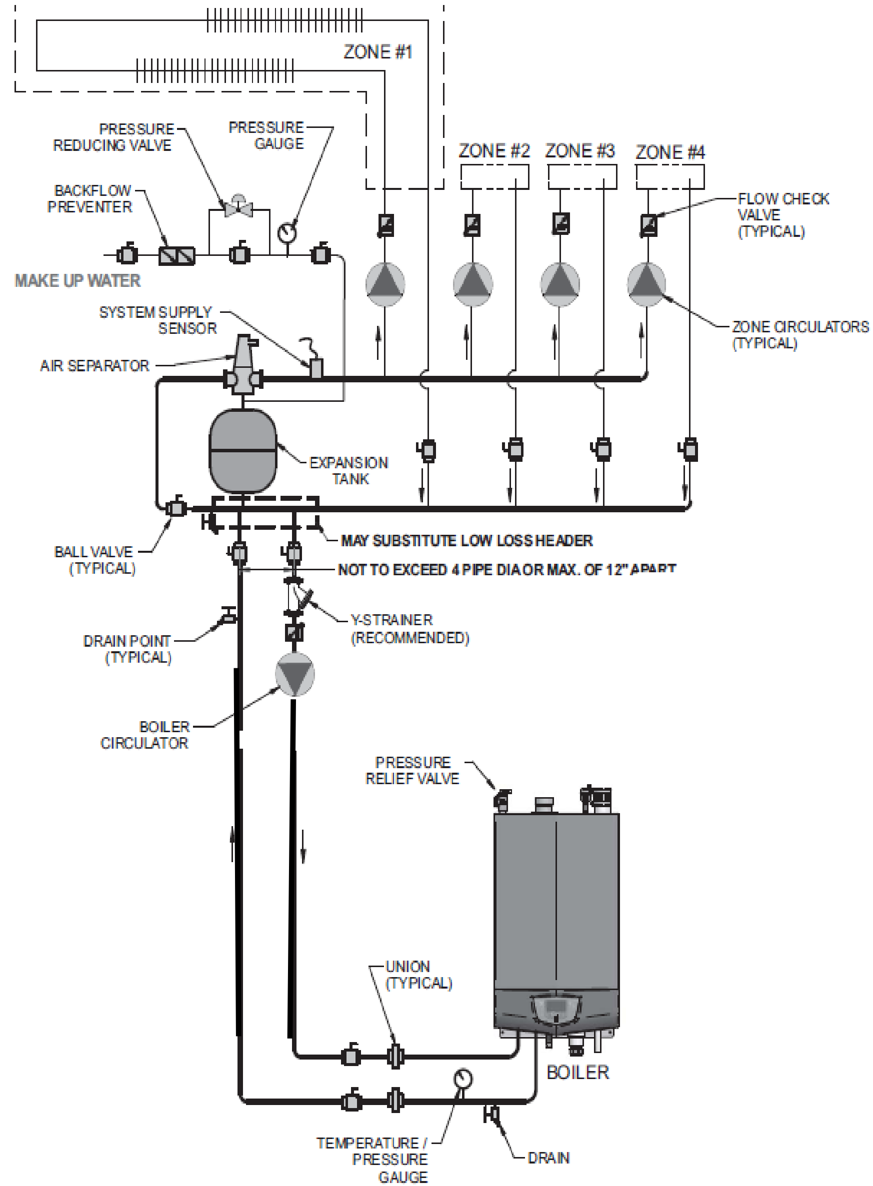
CONDENSING BOILER MODELING IN BA HOMES

Condensing Boiler Expert Meeting

Xia Fang

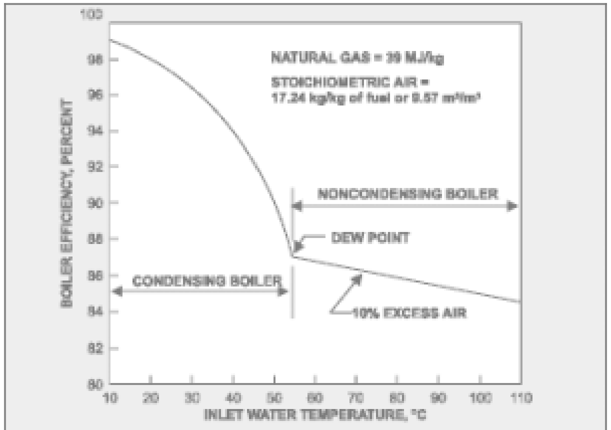
Rev 1: 11-18-2011

Residential Condensing Boilers

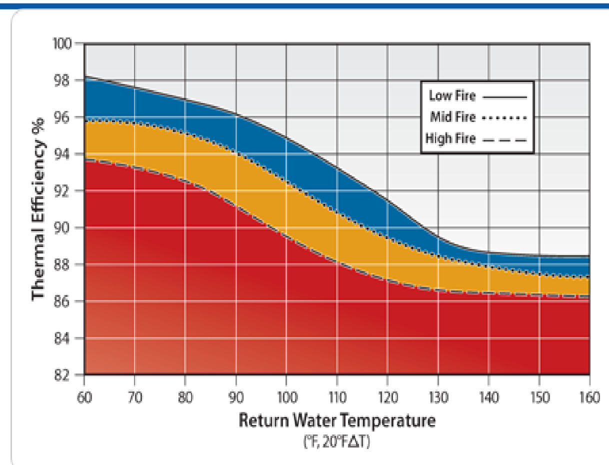


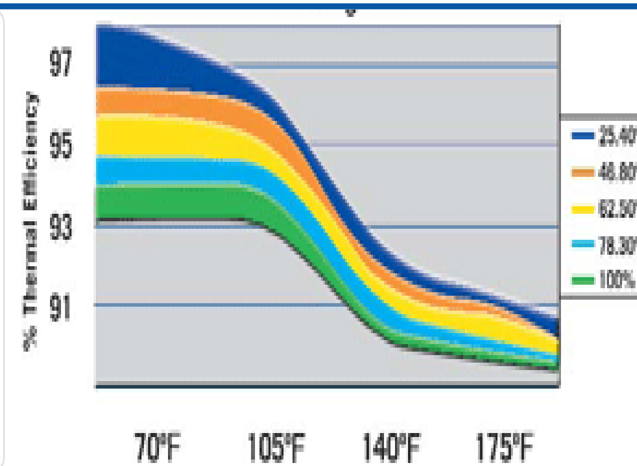
- •Thermal efficiency 93%~98%
- •Fully Modulating 5:1 Turn Down

Condensing Performance

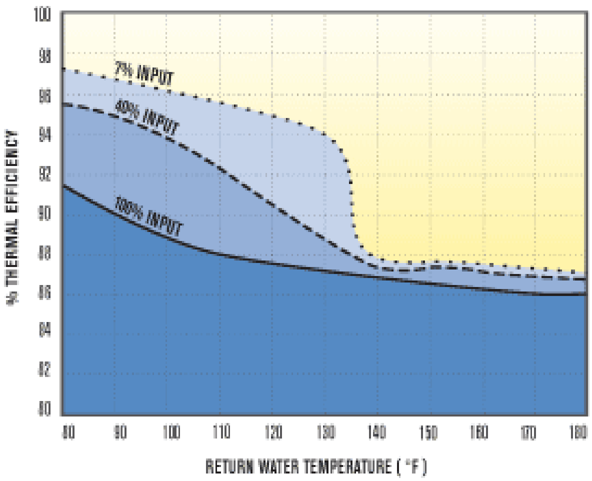


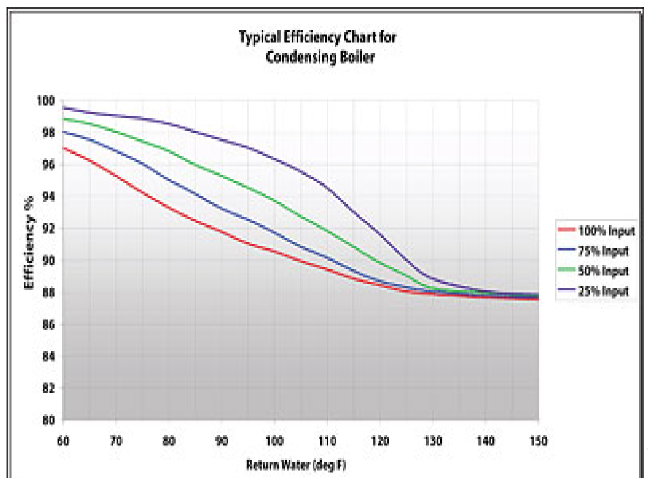
Effect of Inlet Water Temperature on Efficiency of Boilers
(Source: ASHRAE Guide)

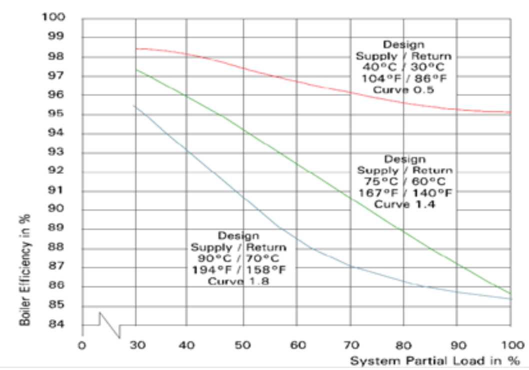




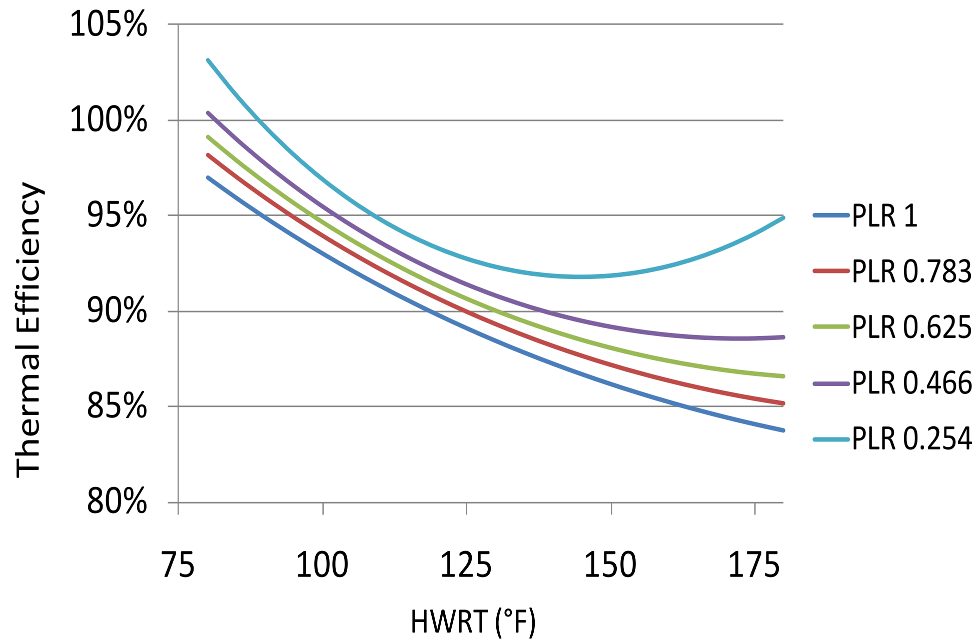
Inverse Efficiency Curve





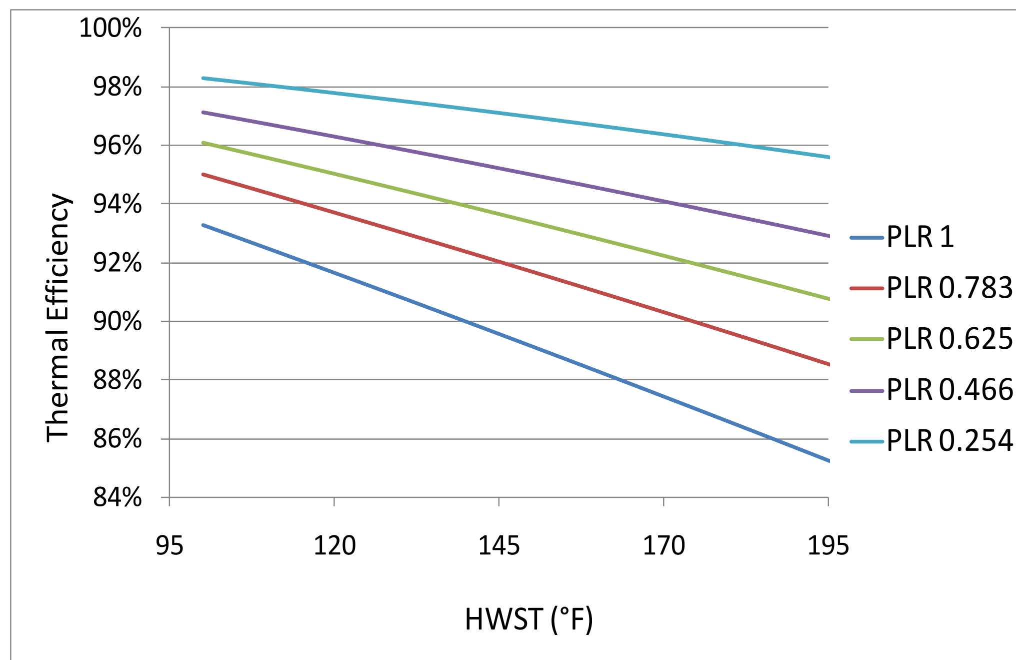


DOE2:
Thermal Efficiency is a function of return water temperature, default efficiency is rated at 80 F HWRT.

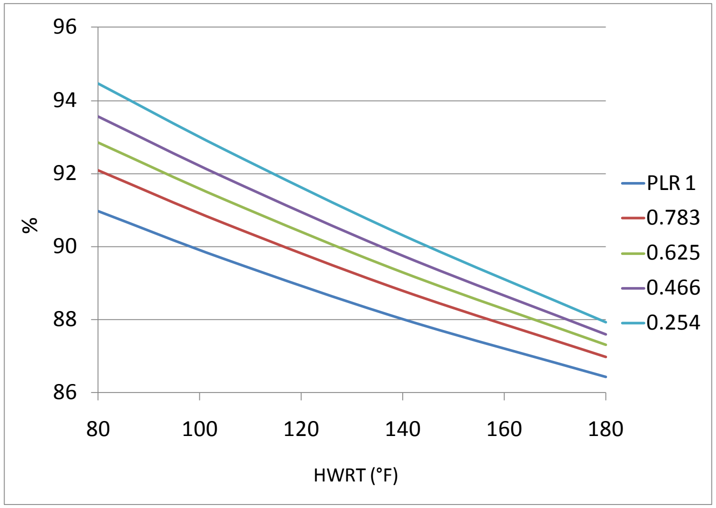


EnergyPlus:
EnergyPlus v6.0 uses condensing efficiency as a function of supply water temp instead of return water temp.

New release of E+ v7 coming in Dec. Custom EMS program on performance curve as current work round.



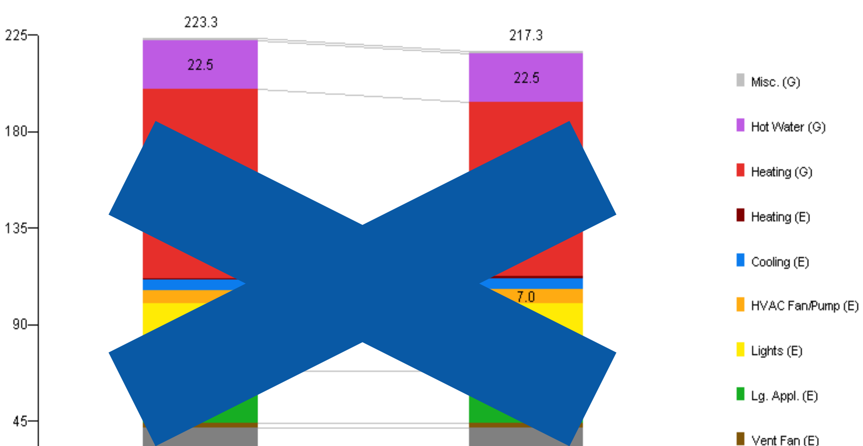
Condensing Performance



Created a regression fit of Boiler thermal efficiency as biquadratic function of part load ratio and return water temperature.

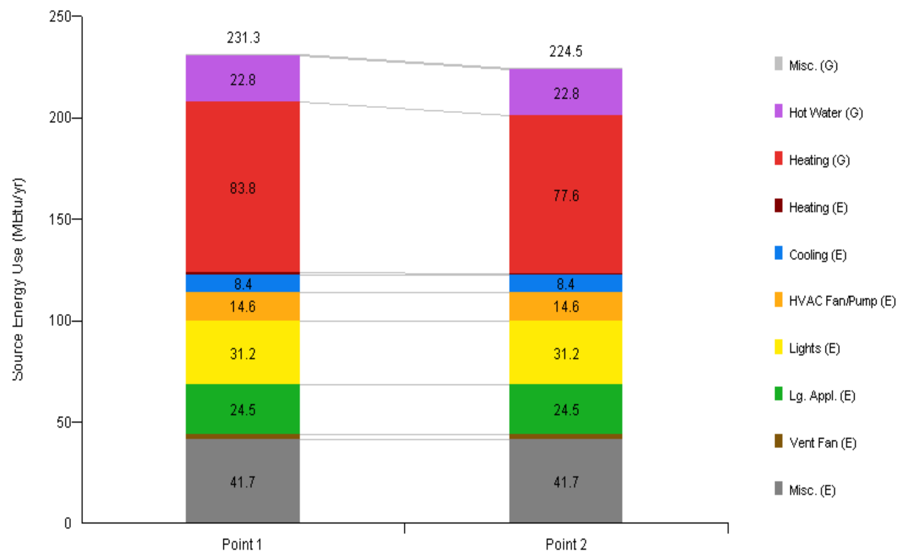
TE = 87% @160 F HWRT

DOE2



DOE2 models loads and system separately: interactions caused by OAT reset cannot be properly captured.

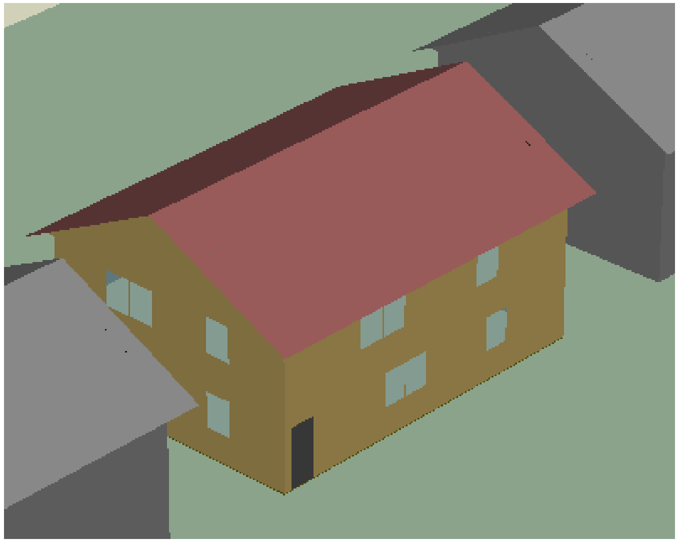
EPLUS



85% TE

95% TE

Modeled House Syracuse, NY (EnergyPlus)

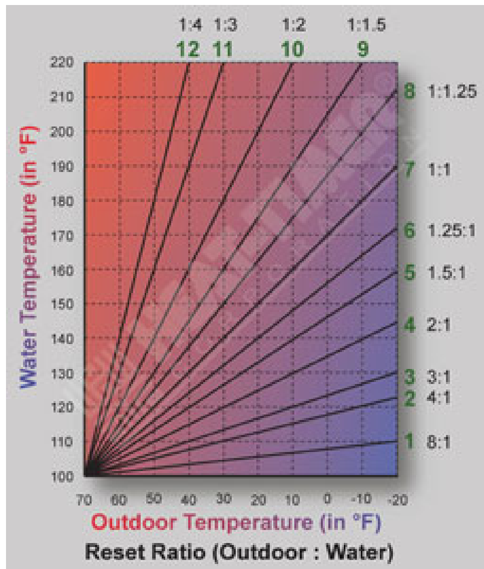


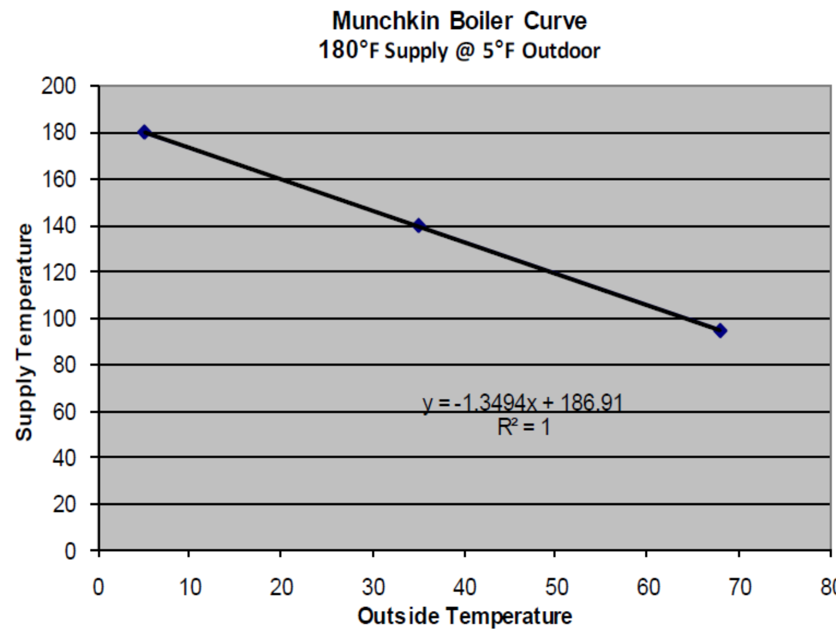
Efficient House	Typical House
Tightest 1.9ACH50	Leaky 14.5ACH50
2x6 24" OC stud, R21 batts with 1" foam - R24.2	2x6 24" OC stud, R21 batts with 1" foam - R24.2
Vented Attic R60 cellulose blown in	Vented Attic R11 cellulose blown in
Low-E Low-SHGC window	Dbl-pane Std window
CFL lighting, EnergyStar Appliance	40% Fluorescent Lighting, Std Appliance
R10 Whole Slab Insulation	2ft R5 Perimeter
Hydronic Heating, SEER 16 AC	Hydronic Heating, SEER 16 AC
Gas Premium Water Heater EF0.67	Gas Standard Water Heater EF0.59

Building America House Simulation Protocol assumptions on operating conditions.
Thermostat Setpoint: heating setpoint 71 F w/setback 65 F 11PM – 6AM.

Control Strategies to Boost Performance

Claims: "For every 4°F the boiler water temperature is reduced, there is a 1% energy savings. Thus, if the boiler was run based on a fixed set point of 180°F vs. running the boiler using outdoor reset at 120°F will provide a minimum saving of 15%."….





OAT (F)	HWST (F)
5	180
68	95

Note: 95F is higher than the monitored houses which drops down to 80F.

- Baseline 0: Boiler 80% TE
- Baseline 1: Boiler 85% TE
- ECM-1: Condensing up to ~95% Efficient
- ECM-2: ECM-1 + Outside air Temperature Reset
- ECM-3: ECM-2 + 160F HWST Baseboard Doubling Area
- ECM-4: ECM-3 + OAT Reset
- ECM-5: ECM-4+VFD Pumping

Convective Baseboards in EnergyPlus

Convective BB: air is pulled in and out based on natural convection effect.

$$\varepsilon = 1 - e^{\left(\frac{NTU^{0.22}}{C_{ratio}} e^{\left(-C_{ratio} NTU^{0.78}\right)} - 1\right)}$$

$$T_{air,outlet} = T_{air,inlet} + \varepsilon\left(T_{water,inlet} - T_{air,inlet}\right) C_{\min} / C_{air}$$

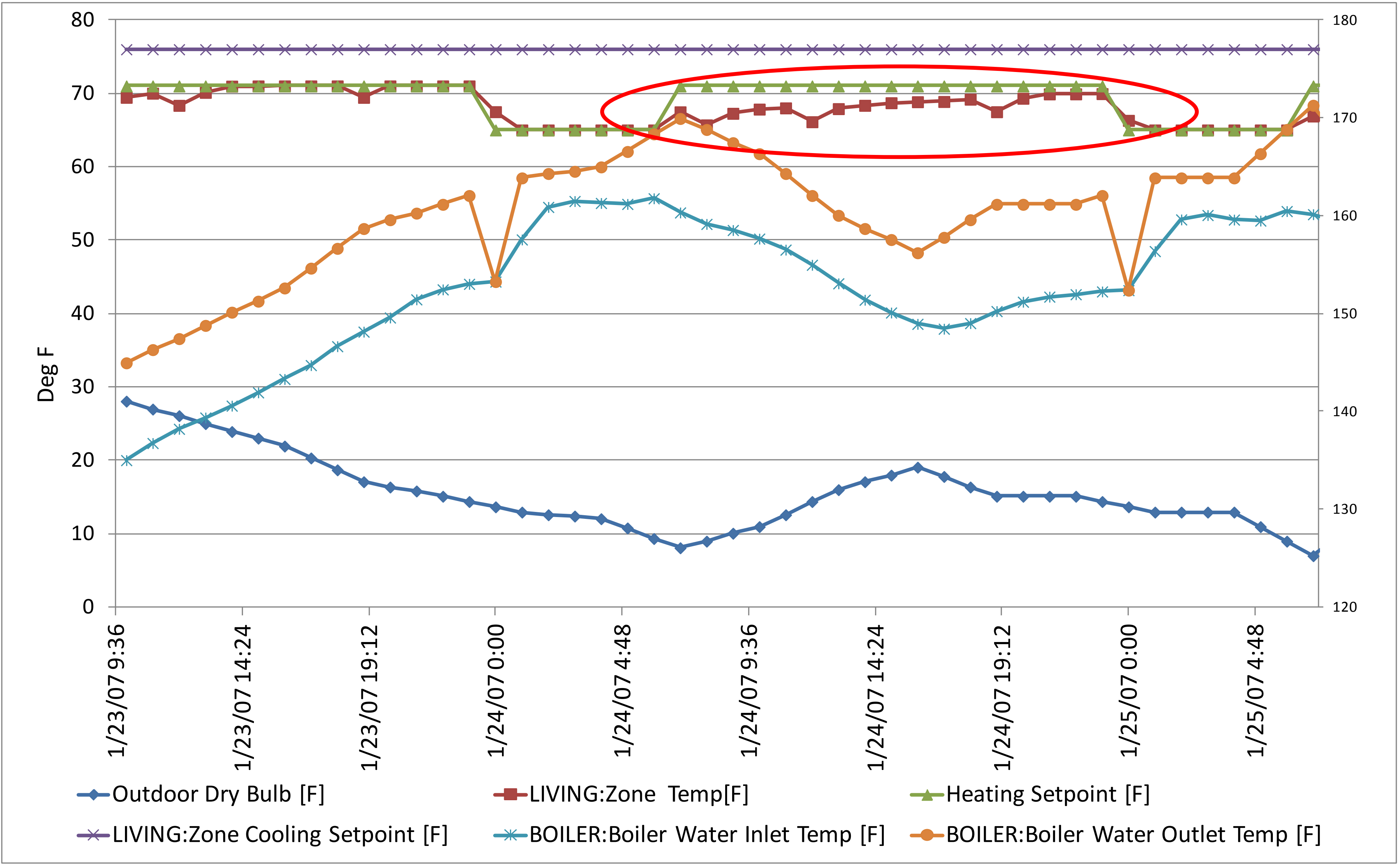
$$T_{water,outlet} = T_{water,inlet} - \left(T_{air,outlet} - T_{air,inlet}\right) C_{air} / C_{water}$$

$$Output\left(Convective\right) = C_{water}\left(T_{water,inlet} - T_{water,outlet}\right)$$

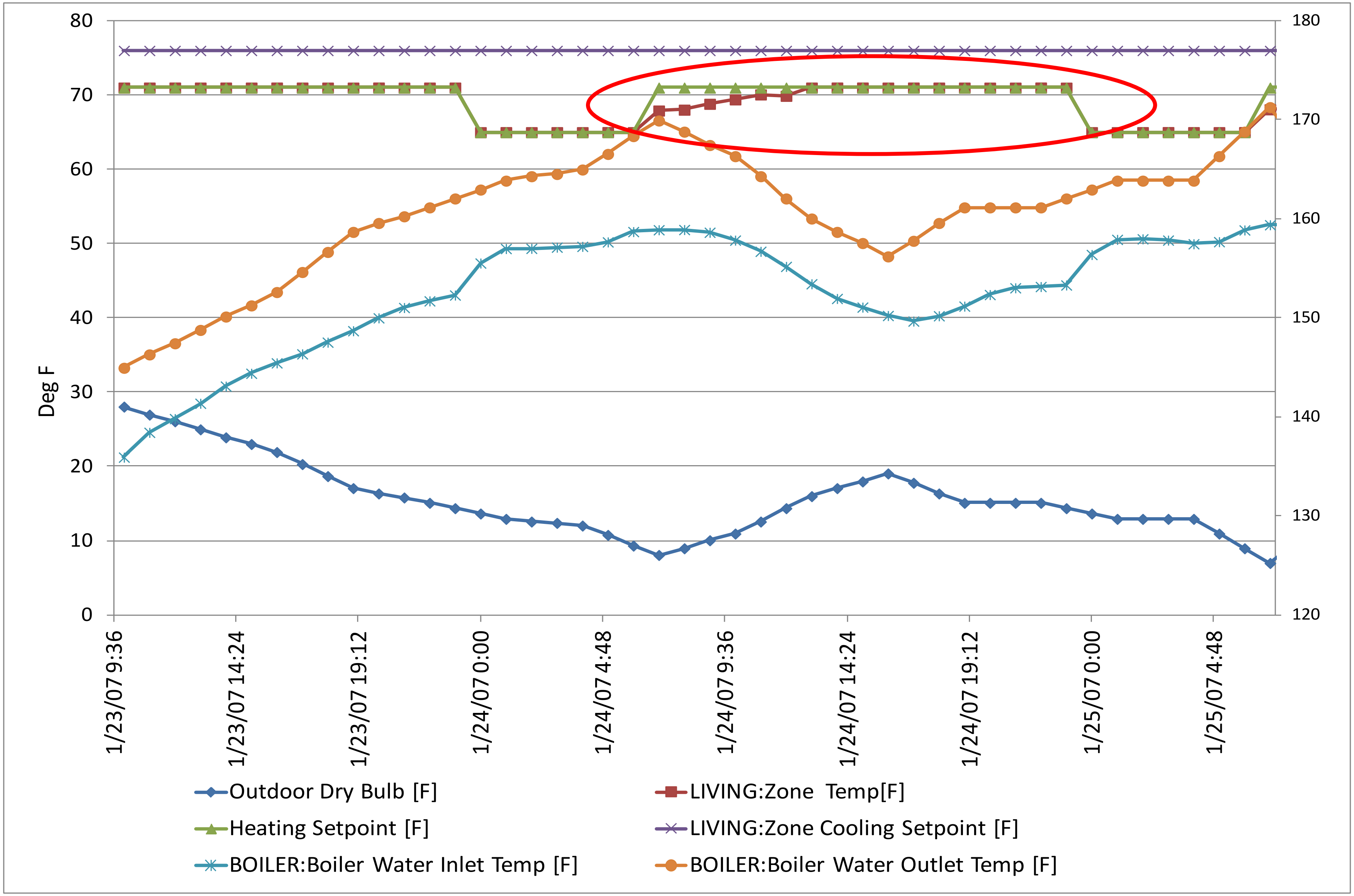
At the same BB surface area, or heat transfer effectiveness ε: when boiler supply temp to BB ($T_{water,inlet}$)↓, BB outlet air temp ($T_{air,outlet}$)↓, and BB leaving water temp ($T_{water,outlet}$)↑. This modeling capability in E+ confirms:

- When designing condensing boiler HWST: in order to maintain BB outlet air temp, BB length / surface area needs to be properly increased for lower HWST.
- When operating: convective BB heat transfer effectiveness will change as a result of changing $T_{water,inlet}$, resulting in changing $T_{air,outlet}$. This effect can be properly captured in EnergyPlus.

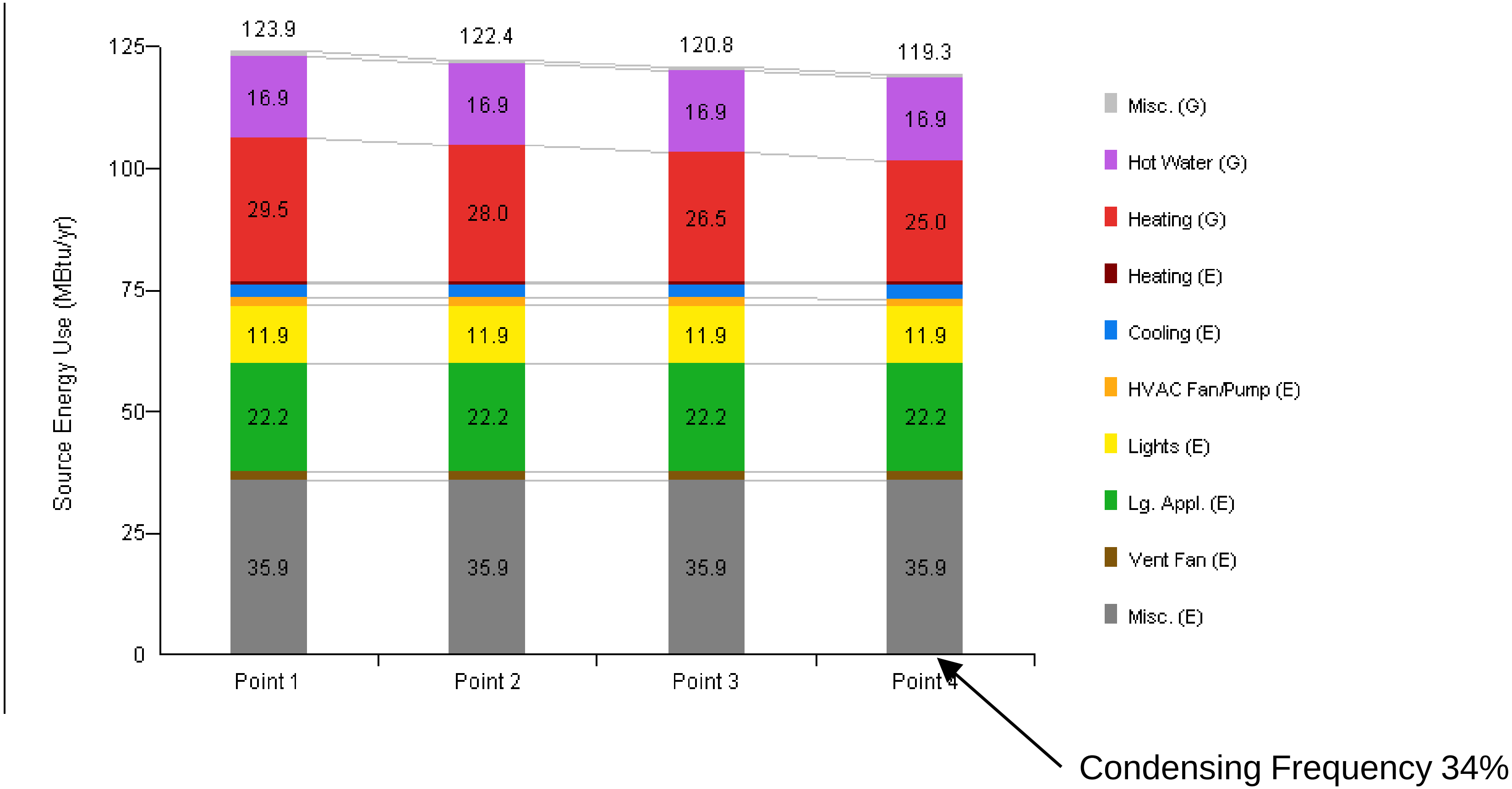
Efficient House Modeled Recovery– Jan 24th.



Typical House Modeled Recovery– Jan 24th.

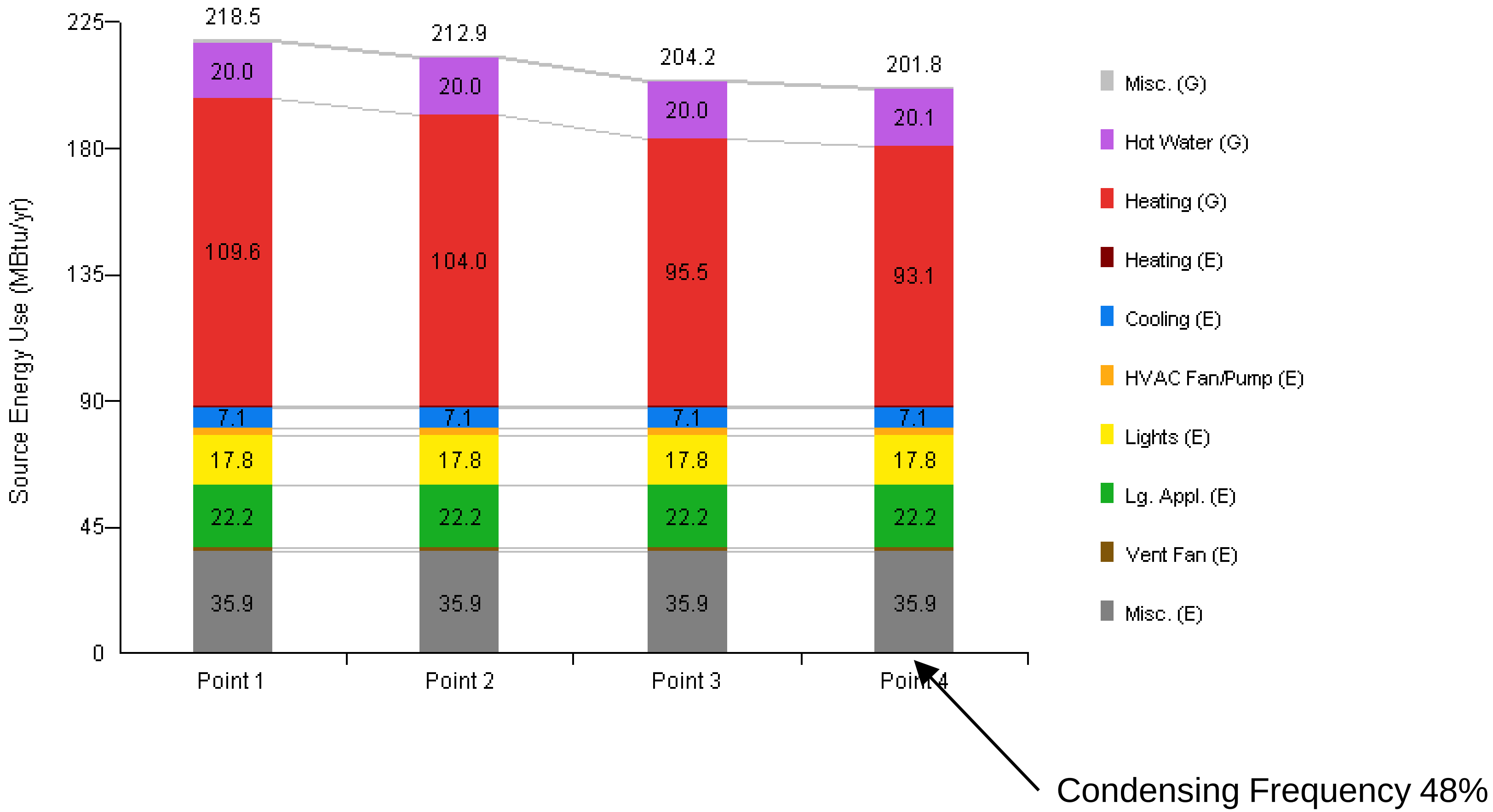


Efficient House Source Energy Consumption



Point 1: Gas 80% AFUE boiler
Point 2: Gas 85% AFUE boiler
Point 3: Gas 95% AFUE boiler, 180F HWST
Point 4: Gas 95% AFUE boiler, OAT reset on HWST control

Typical House Source Energy Consumption



Point 1: Gas 80% AFUE boiler
Point 2: Gas 85% AFUE boiler
Point 3: Gas 95% AFUE boiler, 180F HWST
Point 4: Gas 95% AFUE boiler, OAT reset on HWST control

Summary

1. OAT reset increases condensing efficiency when boiler is left at the factory setting of 180 F.
2. OAT reset control on condensing boilers overrides space thermostat reset control, so the boiler does not know to fully fire to catch up the space heating setpoint. This system and load interaction is only captured in EnergyPlus.
3. The problem gets worse in efficient houses where space heating loads are less responsive to OA condition. It’s less of a problem in typical houses.
4. To increase condensing frequency without sacrificing thermal comfort, optimization can be further explored among system options of thermostat reset, OAT reset, VFD pumping etc.
5. Condensing boiler savings ~10% source energy.
6. Future work: zoning for 2 story bldg; space heating and domestic hot water heating combined systems.

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