IN-FIELD PERFORMANCE OF CONDENSING BOILERS

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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
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

![Graph showing the relationship between outside temperature and supply temperature for a 160°F boiler supply at a 5°F outdoor temperature. The equation is $y = -1.0317x + 165.14$ with $R^2 = 1$.](image)
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
Factors Affecting Efficiency of Installed Systems

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

<table>
<thead>
<tr>
<th>House</th>
<th>Baseboard Length ft</th>
<th>Boiler Capacity kBtuh</th>
<th># of Zones</th>
<th>Flow Rate $^1$ gpm</th>
<th>Frequency of Condensing</th>
<th>Outdoor Reset</th>
<th>Boiler Curve Settings [$^\circ$F]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$T_{s,\text{max}}$</td>
</tr>
<tr>
<td>#1</td>
<td>52</td>
<td>unknown</td>
<td>1</td>
<td>3.1</td>
<td>69%</td>
<td>Y</td>
<td>180</td>
</tr>
<tr>
<td>#2</td>
<td>38.5</td>
<td>50</td>
<td>2</td>
<td>5.3</td>
<td>59%</td>
<td>Y</td>
<td>185</td>
</tr>
<tr>
<td>#3</td>
<td>61</td>
<td>80</td>
<td>3</td>
<td>4.8</td>
<td>60%</td>
<td>Y</td>
<td>180</td>
</tr>
<tr>
<td>#4</td>
<td>32</td>
<td>80</td>
<td>1</td>
<td>3.3</td>
<td>20%</td>
<td>N$^2$</td>
<td>200</td>
</tr>
<tr>
<td>#5</td>
<td>41</td>
<td>50</td>
<td>2</td>
<td>5.2</td>
<td>14%</td>
<td>Y$^3$</td>
<td>185</td>
</tr>
<tr>
<td>#6</td>
<td>54</td>
<td>80</td>
<td>2</td>
<td>4.3</td>
<td>16%</td>
<td>N</td>
<td>201</td>
</tr>
</tbody>
</table>

$^1$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

Steady state efficiency vs. return water temperature

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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.

<table>
<thead>
<tr>
<th>T_{s,min}</th>
<th>150</th>
<th>160</th>
<th>170</th>
<th>180</th>
</tr>
</thead>
<tbody>
<tr>
<td>95</td>
<td>99%</td>
<td>90%</td>
<td>79%</td>
<td>66%</td>
</tr>
<tr>
<td>105</td>
<td>99%</td>
<td>86%</td>
<td>71%</td>
<td>56%</td>
</tr>
<tr>
<td>110</td>
<td>99%</td>
<td>82%</td>
<td>62%</td>
<td>48%</td>
</tr>
<tr>
<td>115</td>
<td>98%</td>
<td>72%</td>
<td>48%</td>
<td>40%</td>
</tr>
<tr>
<td>120</td>
<td>97%</td>
<td>66%</td>
<td>43%</td>
<td>32%</td>
</tr>
</tbody>
</table>

Frequency of Condensing at Different T_{s,max} (1, 2 & 3 gpm)

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
Factors Affecting Response Time

House #2 - February 20, 2010

Return Temp
Outdoor Temp
Supply Temp
Natural Gas Use

Temperature (°F)
Natural Gas Use (Btu/min)
0 100 200 300 400 500 600 700 800 900 1000
12:00 AM 2:24 AM 4:48 AM 7:12 AM 9:36 AM 12:00 PM 2:24 PM 4:48 PM 7:12 PM 9:36 PM 12:00 AM

Temperature (°F)
Flow Rate (gpm)
0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0
55 57 59 61 63 65 67 69 71 73 75
12:00 AM 2:24 AM 4:48 AM 7:12 AM 9:36 AM 12:00 PM 2:24 PM 4:48 PM 7:12 PM 9:36 PM 12:00 AM

1st Floor
2nd Floor
1st Floor Pump
2nd Floor Pump
DHW Pump
Factors Affecting Response Time

House #1 - April 24, 2010

Temperature (°F)

Natural Gas Use (Btu/min)

Return Temp
Outdoor Temp
Supply Temp
Natural Gas Use

12:00 AM 2:24 AM 4:48 AM 7:12 AM 9:36 AM 12:00 PM 2:24 PM 4:48 PM 7:12 PM 9:36 PM 12:00 AM

Flow Rate (gpm)

1st Floor
2nd Floor
1st Floor Pump
2nd Floor Pump
DHW Pump

12:00 AM 2:24 AM 4:48 AM 7:12 AM 9:36 AM 12:00 PM 2:24 PM 4:48 PM 7:12 PM 9:36 PM 12:00 AM

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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 $T_{s,\text{max}}$ 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 & $T_{s,\text{max}}$ from above – oversizing is OK.
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 (remember: small house):**
  - 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
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
Upcoming Research – System B

Low mass, indirect tank, adjustable speed pumps on zones – compare performance of primary loop vs. a buffer tank
Recommendations for Improving Response Time & Comfort

- Proper sizing of boiler mandatory
- Raise $T_{\text{out, min}}$ 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.

Lois B. Arena

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