Installed Performance of High-Efficiency Gas Furnaces

Larry Brand
Gas Technology Institute

Bill Rose
University of Illinois Building Research Council

August 10, 2011
Building America Technical Update Meeting
Denver, Colorado
Test Plan

- Problem Statement
- Experiment
- Analysis
- Expected Results and Follow-on Work

Expected Conclusions

Research Question
How do we get the rated furnace performance in the field?
Installed performance of gas furnace and AFUE measurement can be quite different

- Uncontrolled environment vs. controlled environment
- Typical residential distribution systems and filters vs. lab ductwork tuned for the test
- Field measurement accuracy vs. laboratory measurement techniques
Background

- ASHRAE Standard 103 – 2007 current method of test for AFUE
  - Prescribed accuracy of test devices
  - External static pressure guidelines
  - Jacket loss analysis
  - Latent and sensible heat transfer analysis
  - Tests under 3 modes
Cost-effectiveness

- Three common options:
  - Single stage furnace with single speed motor at 90% AFUE
  - Two stage furnace with multi-speed motor up to 96% AFUE
  - Step modulating furnace with variable speed ECM or multi-tap permanent split capacitance blower motor up to 98% AFUE

<table>
<thead>
<tr>
<th>Replacing Furnace (AFUE)</th>
<th>With Furnace (AFUE)</th>
<th>Installed Cost (80,000 Btu/hr Capacity)</th>
<th>Incremental Cost from 78% AFUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>78%</td>
<td>78%</td>
<td>$1040</td>
<td>$0</td>
</tr>
<tr>
<td>78%</td>
<td>90%</td>
<td>$2400</td>
<td>$1360</td>
</tr>
<tr>
<td>78%</td>
<td>92%</td>
<td>$2640</td>
<td>$1600</td>
</tr>
<tr>
<td>78%</td>
<td>94%</td>
<td>$2880</td>
<td>$1840</td>
</tr>
<tr>
<td>78%</td>
<td>96%</td>
<td>$3120</td>
<td>$2080</td>
</tr>
</tbody>
</table>

Source: NREL National Residential Efficiency Measures Database
Problem Statement

Cost-effectiveness

- Cost/benefit:
  - For $1000 annual heating cost
    - 78% AFUE to 90% AFUE has a 9 year payback
    - $500 utility rebate and 25% tax credit reduces payback to 5 years

*Economics look good for cold climates.*

*But how can we get the rated AFUE in the field?*

---

**Annual Estimated Savings for Every $100 of Fuel Costs by Increasing Your Heating Equipment Efficiency**

<table>
<thead>
<tr>
<th>Existing System AFUE</th>
<th>55%</th>
<th>60%</th>
<th>65%</th>
<th>70%</th>
<th>75%</th>
<th>80%</th>
<th>85%</th>
<th>90%</th>
<th>95%</th>
</tr>
</thead>
<tbody>
<tr>
<td>50%</td>
<td>$9.09</td>
<td>$16.76</td>
<td>$23.07</td>
<td>$28.57</td>
<td>$33.33</td>
<td>$37.50</td>
<td>$41.24</td>
<td>$44.24</td>
<td>$47.36</td>
</tr>
<tr>
<td>55%</td>
<td>----</td>
<td>$8.33</td>
<td>$15.38</td>
<td>$21.42</td>
<td>$26.66</td>
<td>$31.20</td>
<td>$35.29</td>
<td>$38.88</td>
<td>$42.10</td>
</tr>
<tr>
<td>60%</td>
<td>----</td>
<td>----</td>
<td>$7.69</td>
<td>$14.28</td>
<td>$20.00</td>
<td>$25.00</td>
<td>$29.41</td>
<td>$33.33</td>
<td>$37.80</td>
</tr>
<tr>
<td>65%</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>$7.14</td>
<td>$13.33</td>
<td>$18.75</td>
<td>$23.52</td>
<td>$27.77</td>
<td>$31.57</td>
</tr>
<tr>
<td>70%</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>$6.66</td>
<td>$12.50</td>
<td>$17.64</td>
<td>$22.22</td>
<td>$26.32</td>
</tr>
<tr>
<td>75%</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>$6.50</td>
<td>$11.76</td>
<td>$16.66</td>
<td>$21.10</td>
</tr>
<tr>
<td>80%</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>$5.88</td>
<td>$11.11</td>
<td>$15.80</td>
</tr>
<tr>
<td>85%</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>$5.55</td>
<td>$10.50</td>
</tr>
<tr>
<td>90%</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>$5.30</td>
</tr>
</tbody>
</table>

Source: DOE EERE
**Scope**

In the lab, test all 3 furnace types under standard conditions and conditions that simulate field installation problems:

1. Oversized furnace
2. Undersized ducts
3. MERV (high performance) filters

Recommend best practices for installation
Test detail

• Oversized furnace
  – 70% oversize (standard)
  – 100% oversize
  – 120% oversize

• High external static tests (tight ducts)
  – 0.2 inches water column pressure rise (standard)
  – 0.3 inches WC
  – 0.5 inches WC

• High Efficiency Filter
  – MERV 8 filter

• Four tests in the standard:
  1. Steady-state test
  2. Cool-down test
  3. Heat-up test
  4. Condensate heat loss under cycling conditions test
## Equipment needed and required accuracy

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Equipment Needed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas flow rate</td>
<td>Gas flow meter calibrated to be accurate within 1% of flow volume</td>
</tr>
<tr>
<td>Electric consumption</td>
<td>Watt meters with an accuracy of 1% of measured energy</td>
</tr>
<tr>
<td>Temperatures</td>
<td>Bead thermocouples with an accuracy of $\pm 2^\circ \text{F}$</td>
</tr>
<tr>
<td>Air pressure</td>
<td>Manometer or pressure gage with an accuracy of $\pm 0.01$ inches of water column</td>
</tr>
<tr>
<td>Power conditioning</td>
<td>Voltage to be controlled within 1% of nameplate requirement on the furnace</td>
</tr>
<tr>
<td>$\text{CO}_2$ concentration</td>
<td>Within $\pm 0.1%$</td>
</tr>
<tr>
<td>Weight of water</td>
<td>Scale accurate to $\pm 0.5%$ of quantity</td>
</tr>
<tr>
<td>Time</td>
<td>Stopwatch or timer accurate to $\pm 0.5$ sec/hr</td>
</tr>
<tr>
<td>Tracer gas</td>
<td>Gas Chromatograph accurate to $\pm 2%$ of measured concentration</td>
</tr>
<tr>
<td>Gas heating value</td>
<td>Gas Calorimeter $\pm 1%$ in Btu/scf</td>
</tr>
<tr>
<td>Air flow rate</td>
<td>Pitot tube flow station</td>
</tr>
</tbody>
</table>
Analysis methods prescribed in the Standard

11.4.12 Annual Fuel Utilization Efficiency. The annual fuel utilization efficiency, AFUE, for each $Effy_{HS}$ shall be expressed as a percentage and defined as

$$AFUE = \frac{5200Effy_{SS,W}Effy_{HS}}{5200Effy_{SS,W} + 2.5(1 + \alpha)(4600)Effy_{HS}(Q_p/Q_{IN})}$$

where

- $5200$ = annual average heating degree-days,
- $Effy_{SS,W}$ = weighted average steady-state efficiency as defined in 11.4.8.9,
- $Effy_{HS}$ = heating seasonal efficiency as defined in 11.4.11.3,
- $Q_{IN}$ = maximum fuel input rate as defined in 11.4.8.1.1,
- $\alpha$ = oversizing factor for furnaces and boilers as defined in 11.4.8.2,
- $Q_p$ = pilot flame fuel input in Btu/h,
- $4600$ = average non-heating-season hours per year.
Lab Photos
Installation Photos
Expected results

- AFUE values not expected to vary significantly with ESP changes if proper fan speed adjustments are made
- AFUE values will be lower with at lower part-load associated with oversizing
- Power consumption will increase with increasing ESP

Follow-on tests

- Expand test parameters to include improper field adjustment of burners and blowers, improper vent system design, and leaky ductwork.
- Compare results with field results on the same equipment
Expected Conclusions

• High-efficiency furnaces are cost-effective, especially with rebates and tax credits
• AFUE rating is calculated under controlled laboratory conditions that may vary significantly in the field
• Proper installing contractor adjustments will produce the best field performance
• Blower power may vary significantly with tight ducts, depending on the furnace type chosen
• Training of contractors on the proper installation techniques is critical:
  – Gas valve and fan speed adjustments
  – Vent sizing
  – Furnace capacity
  – Distribution systems adjustments