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

BUILDING TECHNOLOGIES OFFICE

Improving Gas Furnace Performance: A Field and Laboratory Study at End of Life

L. Brand, S. Yee, and J. Baker
Partnership for Advanced Residential Retrofit

August 2013

Building America
U.S. Department of Energy

Available electronically at http://www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

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

Improving Gas Furnace Performance: A Field and Laboratory Study at End of Life

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

Prepared by:

Partnership for Advanced Residential Retrofit

Gas Technology Institute

1700 South Mount Prospect Road

Des Plaines IL 60018

NREL Technical Monitor: Stacey Rothgeb

Prepared under Subcontract No. KNDJ-0-40346-03

August 2013

[This page left blank]

Contents

List of Figures

Unless otherwise noted, all figures were created by PARR.

List of Tables

Unless otherwise noted, all tables were created by PARR.

Acknowledgments

PARR would like to thank Energy Stewards International (ESI) for collecting the furnaces and field data used in this project.

Definitions

AFUE	Annual fuel utilization efficiency
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
Btu	British thermal unit
DOE	U.S. Department of Energy
EPCA	Energy Policy and Conservation Act
ESP	External static pressure
HVAC	Heating, ventilation, and air conditioning
HVAC SAVE	HVAC System Adjustment & Verified Efficiency
kWh	Kilowatt hour
MEEA	Midwest Energy Efficiency Alliance
w.c.	Water column

Executive Summary

Natural gas furnaces account for 92% of natural gas used for space heating, or about 3.1 quadrillion Btu in 2010, according to the U.S. Department of Energy (DOE) Energy Book. A better understanding of installed performance is a key to energy savings for this significant resource. Furnace performance is rated by annual fuel utilization efficiency (AFUE) using the DOE test procedure, a rating supplied by the manufacturer to the consumer with each product. AFUE is also used in most energy modeling tools as the basis for energy savings calculations. It is common for modeled pre-retrofit energy consumption and retrofit energy savings to exceed that of actual energy consumption and savings. This is especially true in homes that are leaky, poorly insulated, and that have older mechanical systems (Polly 2011). Two theories for this discrepancy that are tested in this study are that the performance of equipment tested under laboratory conditions differs from field performance, and that performance degrades with time.

The objective of this project is to examine the impact that common installation practices and age-induced equipment degradation may have on the installed performance of natural gas furnaces, as measured by steady-state efficiency and AFUE. PARR identified 12 furnaces of various ages and efficiencies that were operating in residential homes in the Des Moines, Iowa metropolitan area and worked with a local heating, ventilation, and air conditioning contractor to retrieve them and test them for steady-state efficiency and AFUE in the lab. Prior to removal, system airflow, static pressure, equipment temperature rise, and flue loss measurements were recorded for each furnace. After removal from the field, the furnaces were transported to the Gas Technology Institute laboratory, where PARR conducted steady-state efficiency and AFUE testing. Nine of the 12 furnaces could be tested in the lab without significant repair. Steady-state efficiency was calculated for each furnace from the field data. Each furnace was then tested for steady-state efficiency and AFUE under field conditions and under test conditions specified in the ASHRAE 103-2007 (consensus) test standard, based on furnace type. For the purposes of this project, the difference between the DOE and ASHRAE test procedures are not significant.

The test results show that steady-state efficiency in the field was 6.4% lower than that measured for the same furnaces under standard conditions in the lab, which included tuning the furnace input and airflow rate to the conditions recommended by the manufacturer. Comparing AFUE measured under ASHRAE standard conditions with the label value shows no reduction in efficiency for the furnaces in this study over their 15 to 24 years of operation when tuned to standard conditions. Further analysis of the data showed no significant correlation between efficiency change and the age or the rated efficiency of the furnace.

The conclusion is that AFUE labeled values can be used as a good indicator of the performance of natural gas furnaces throughout their useful lives if they are installed according to the manufacturers' installation instructions. Installing the furnace correctly in the lab or in the field is a key assumption in this finding: increase the blower speed to provide the correct airflow to match the manufacturer's recommended temperature rise without exceeding the manufacturer's design static pressure. If the fan speed cannot be adjusted properly, changes to the distribution system will need to be made.

1 Problem Statement

1.1 Introduction

Natural gas furnaces are rated for efficiency using the U.S. Department of Energy (DOE) annual fuel utilization efficiency (AFUE) test standard under controlled laboratory test conditions. In the home, these furnaces are then installed under conditions that can vary significantly from the standard, require adjustment by the installing contractor to adapt to field conditions, may or may not be inspected over their useful lifetimes, and can operate with little maintenance over a 30-year period or longer. At issue is whether the installation practices, field conditions, and wear over the life of the furnace reduce the efficiency significantly from the rated efficiency. In this project, nine furnaces, with 15–24 years of field service, were removed from Iowa homes and tested in the lab under four conditions to determine the effects of installation practices, field operating conditions, and age on efficiency.

1.2 Background

As required by the Energy Policy and Conservation Act (EPCA) of 1975, the National Bureau of Standards developed test procedures to establish methods of energy consumption of certain appliances. On May 10, 1978, DOE promulgated the test procedures for furnaces and boilers. Those procedures and the amendments of August 10, 1980 provided the basis for ASHRAE standard 103, the gas furnace and boiler AFUE test standard. ASHRAE developed the standard using the American National Standards Institute (ANSI) consensus process. It was approved by the ASHRAE Standards Committee on June 27, 1982. The original standard was ANSI/ASHRAE 103-1982 (ASHRAE 1982). ASHRAE 103-2007 will be referred to as "Standard" in this document.

Minimum appliance efficiency came into effect in the mid-1980s. Upon the amendment of EPCA, DOE was required to promulgate energy conservation standards for certain major appliances, including residential furnaces. In 1987, the National Appliance Energy Conservation Act established initial minimum efficiency standards for residential gas furnaces at 78% AFUE for most gas furnaces effective January 1, 1992. The minimum efficiency for furnaces was revised upward in 2007—gas furnaces produced after 2015 are required to have an AFUE of 80% or greater.

The DOE AFUE test standard and the ASHRAE 103 Standard are not developed in tandem. In 1997, DOE published a final rule that amended the original test procedure for furnaces incorporating provisions contained in test procedure waivers granted to several manufacturers from 1985 to 1996 and adding test procedures for new product designs. In 2010, DOE published a final rule that amended the original test procedure for residential furnaces to include standby and off mode energy use. ASHRAE re-evaluates the 103 Standard on a five-year interval and published the most recent version in 2007.

ASHRAE SPC 103 is currently reviewing the Standard for the next publication cycle, and DOE has issued a Request for Information seeking input on the DOE AFUE test procedure. Since the timeline for the ASHRAE and DOE standards activities are not coincident, the furnaces tested in this report under ASHRAE 103 2007 may have originally been listed according to an older DOE test procedure. The authors believe the differences in the ASHRAE and DOE AFUE test procedures over time are not significant and are within the 0.1% experimental error of the laboratory test setup in this report (Brand and Rose 2012).

Previous Building America research has shown that correct sizing and proper installation of heating, ventilation, and air conditioning (HVAC) systems are crucial to achieving the desired occupant comfort and efficiency levels (Burdick 2011; Brand 2012). However, while there are several directly applicable and well-known installation, sizing, and distribution design guidelines, PARR has observed that these guidelines are often not followed in the field by installing contractors, especially during an upgrade of existing equipment. It is common practice within the HVAC industry to replace existing equipment without determining if the existing distribution system is properly designed and sized to match the needs of the new equipment, or to fail to adjust the new equipment to match the existing distribution system. The result is equipment installed and operating at conditions outside of the manufacturer's recommended range.

This project explores the effects these adverse operating conditions have on equipment performance ratings through conducting several measurements:

- Calculated steady-state efficiency based on field reported conditions
- Measured steady-state efficiency in the lab at the same field conditions without adjusting the furnaces
- Measured steady-state efficiency in the lab at the Standard conditions used for AFUE
- Measured AFUE in the lab under conditions reported from the field and without adjusting the furnaces
- Measured AFUE in the lab under the Standard conditions.

AFUE measurements are as described in ANSI/ASHRAE 103-2007. PARR has evaluated the performance of each furnace according to this Standard and has modified the test to simulate conditions found in the field for some furnace test cases.

1.3 Installation Conditions

In retrofit situations HVAC installers regularly fail to address the existing distribution system when installing new equipment, resulting in equipment operating outside the manufacturer's specifications. Ductwork that was installed many years ago to meet the previous load and match the original equipment (generally higher delivered air temperature at lower flow rates) often is not able to handle the airflow requirements of newer high efficiency units. Manufacturers address this situation in their installation instructions by providing guidelines on setting the fan speed so the furnace operates in its rise range (air temperature rise across the furnace). A second field adjustment that is common is to set the input rate on the furnace to match the value on the label. This is done by adjusting the gas valve pressure setting and measuring the gas flow rate by observing the meter. Some installers fail to perform these adjustments and the performance is impacted.

1.4 Relevance to Building America's Goals

Overall, the goal of DOE's Building America program is to reduce home energy use by 30%–50% compared to the 2009 International Energy Conservation Code for new homes and pre-retrofit energy use for existing homes. To this end, Building America conducts research to "develop market-ready energy solutions that improve efficiency of new and existing homes in each U.S. climate zone, while increasing comfort, safety, and durability."[1]

This project directly aligns with Building America's objectives, as it addresses commonly observed deficiencies in forced-air natural gas furnace installations, which are likely increasing energy use in many American homes. Presumably, following the furnace manufacturer's installation instructions carefully and employing industry-approved methods for equipment sizing, duct design, and filter selection should result in the unit achieving its rated performance, while failure to do so may reduce performance, thus increasing energy use. Further, degradation of AFUE over time due to drift of component settings or other factors is assumed and this project provides data to test those assumptions.

1.5 HVAC SAVE Program

The furnaces analyzed in this study were taken from homes participating in Iowa's HVAC System Adjustment & Verified Efficiency (SAVE) program, a statewide HVAC training and certification program (Yee 2013). The HVAC SAVE program was developed by MEEA to train contractors in the skills necessary to determine in-place performance of functioning systems, including equipment and distribution systems. Energy Stewards International has been training HVAC professionals for many years on how contractors can use static pressures, system temperatures, and airflows to identify existing system deficiencies, allowing them to make targeted repairs or adjustments. The furnaces being analyzed in this study, which were removed from the field, help to test the hypothesis that previously installed equipment is performing in less than optimal installation conditions.

1.6 Performance Degradation with Age

In addition to studying how installed conditions affect energy use, this project examines potential degradation in equipment performance over time by conducting a second round of AFUE testing on each unit under conditions specified in the Standard and comparing these results with the original rating. Building America Simulation protocols (Hendron and Engebrecht 2010) once used a degradation factor for furnace efficiency in BEopt, although that has been discontinued. The equation below provides the calculation evaluated in this project:

$$\text{AFUE} = (\text{Base AFUE}) \times (1\text{-M})^{\text{age}}$$

where

Base AFUE = Typical efficiency of pre-retrofit equipment when new

M = Maintenance factor

0.005 annual professional maintenance

0.015 seldom or never maintained

age = Age of equipment in years, up to a maximum of 20 year

---

[1] www1.eere.energy.gov/buildings/residential/ba_research.html

2 Objective

The objective of this project is to examine the impact that common installation practices and age-induced equipment degradation may have on the installed performance of natural gas furnaces, as measured by steady-state efficiency and AFUE. Recommendations will be made on methods to improve field performance.

3 Research Methodology

3.1 Research Questions

The research conducted in this project addresses the following questions:

1. What is the degradation in furnace efficiency for typical field installation compared to the rated performance?
2. How should AFUE be modified in models (such as BEopt) to account for differences between the field and the laboratory, especially for retrofit situations?
3. How do rated and measured AFUE compare for vintage furnaces?

3.2 Technical Approach—Data Collection and Analysis

PARR identified 12 working furnaces of various production years installed in the field, gathered operating condition information, transported each furnace to a laboratory, and tested each furnace for steady-state efficiency and for AFUE as described in ANSI/ASHRAE Standard 103-2007.

The Standard provides test methods, instrumentation tolerances, and calculation techniques to determine AFUE. The following basic tests were conducted:

1. Steady-state test (used for both the steady-state and AFUE results)
2. Cool down test
3. Heat up test
4. Condensate heat loss under cyclic conditions test (condensing furnaces)

In addition to the test conditions recommended in the Standard, PARR also ran the above tests mimicking the operating conditions of each furnace, as found in the field. These conditions differ from furnace to furnace as each field installation does vary. Based on MEEA's recent experience with the HVAC SAVE, a regional contractor training and certification initiative based on National Comfort Institute principles, some common conditions seen in the field are as follows:

- High external static pressures (ESPs) due to either undersized or restrictive distribution systems: For testing, the ASHRAE Standard recommends a minimum external static of 0.2 in. w.c. depending on the furnace size; 0.7–0.9 is commonly observed in the field. External static was be measured in the field for each furnace and used for testing.
- Oversized equipment: ASHRAE 103 accounts for oversizing by simulating burner on and off time per cycle; Standard testing is conducted under conditions that represent a 70% oversized unit. In this project it was not possible to test oversizing because house characteristics were not logged and utility bills are not available. In previous work done by PARR (Brand and Rose 2012), it was determined that oversizing is not a significant factor for high-efficiency furnaces.
- Equipment that is off rate: The testing Standard recommends that burner input rate be adjusted to within 2% of the hourly Btu input rating specified by the manufacturer. The gas input to the equipment was measured in the field and then tested under the same

conditions in the laboratory during the field conditions round of testing. In the Standard conditions testing, input rate was corrected.

The original test plan for this project included collecting furnaces with a range of ages and designs: 1960s–1990s, ribbon burners and in-shot burners, atmospheric and fan-assisted combustion, lower efficiency and higher efficiency. The furnaces in this study covered all the cases except the very early years. The year of manufacture of the nine furnaces tested ranges from 1987–1998, three are ribbon burners, and the rest are in-shot burners, two are atmospheric combustion systems, and two are high efficiency (condensing) furnaces. This range of ages and types is fairly representative of the installed base and is sufficient for this research.

Furnaces were sourced from the Des Moines, Iowa metropolitan area, leveraging MEEA's work on HVAC SAVE. Twelve furnaces were collected; only nine could be tested without significant repair. PARR chose not to test the furnaces requiring significant repair as the performance could be altered.

Prior to the removal of each furnace from the field, several measurements were taken to determine actual operating conditions. PARR is aware that measurements taken in the field are difficult to obtain within the accuracy of that recommended by the Standard. These measurements were not used to determine AFUE, but rather as a general guide for determining field steady-state conditions and field conditions for laboratory testing. Table 1 provides information that was collected in the field.

Table 1. Data Collected in the Field

Data	Notes
Nameplate Data	Units, coils, fans, etc.
Temperature Rise Across the Equipment	°F, radiation shielded
Static Pressure	Using a manometer or digital gage
O_2% in Flue Gases	Concentration, %
Airflow Rate	Flow plate replacing the filter

Once the initial evaluation of the equipment was completed in the field, each furnace was shipped to the Gas Technology Institute laboratory. Table 2 shows the major data points that were collected as part of the efficiency testing, in accordance with ASHRAE 103:

Table 2. Data Collected in the Laboratory

Data	Notes
Room Temperature	Average of 4 points, radiation shielded
Jacket Loss	Thermocouples in 6 × 6 in square on furnace jacket except for blower housing (contact temperature sensor may be used)
Power to Burner and Blower	kWh
Dry CO_2 in Flue Gases	Concentration, ppm
Room Humidity Level	Must be less than 80% RH
Time for Several Events	Seconds
Flue Gas Temperature	In a grid pattern using beaded thermocouples
Supply and Return Temperatures	Thermocouples

Gas Consumption	Cubic feet
Weight of Condensate	Using a clean non-scaling container
Gas Heating Value	Btu/standard cubic feet
Tracer Gas Concentration	Within 2% of value

Table 3 provides measurement tolerances from the Standard. Instruments were selected and power conditioning was applied to meet these requirements.

Table 3. Measurement Tolerances

Measurement	Tolerance
Temperature	2°F
Gas Pressure	0.2 in. w.c.
Air Pressure	0.01 in. w.c.
CO_2	0.1%
Weight	0.5%
Volume	0.5%
Time	0.5 s/h
Tracer Gas	2%
Electricity	1%
Voltage	1%
Gas	1%
Gas Heating Value	1%

3.3 Measurement Methods

Laboratory steady-state and AFUE testing for this project has been conducted according to the Standard. Table 4 provides a summary of the measurements required for each step in the Standard.

Table 4. Test Procedure and Measurements

Section in the Standard	Test Name	Description	Measurements
9.1	Steady-state test	Measure energy into the furnace from natural gas and energy lost from the vent system and condensate system	Measure CO_2, flue gas temperature, condensate production, gas consumption, and jacket losses under steady-state conditions.
9.5	Cool down test	Measure energy lost to the flue gasses during the post-purge or cool-down period	Flue gas temperature and time under cool-down conditions
9.6	Heat up test	Measure energy lost to the flue gasses during heat up with delayed blower start	Flue gas temperature and time during heat-up
9.8	Condensate heat loss under cyclic conditions	Measure thermal energy lost to condensate	Fuel input, heating value, temperature and pressure of the gas, and weight of condensate for each cycle

3.4 Equipment

Table 5 provides the basic set of equipment used to perform these tests.

Table 5. Equipment Table

Measurement	Equipment Needed
Gas Flow Rate	Gas flow meter calibrated to be accurate within 1% of flow volume
Electric Consumption	Watt meters with an accuracy of 1% of measured energy. (Not included in energy balance).
Temperatures	Bead thermocouples with an accuracy of ± 2°F
Air Pressure	Manometer or pressure gage with an accuracy of ± 0.01 in. w.c.
Power Conditioning	Voltage to be controlled within 1% of nameplate requirement on furnace
CO_2 Concentration	Within ± 0.1%
Time	Stopwatch or timer accurate to ± 0.5 s/h
Tracer Gas	Gas chromatograph accurate to ± 2% of measured concentration
Gas Heating Value	Gas calorimeter ± 1% in Btu/ft^3

3.5 Analysis Methodology

The full analysis procedure is described in detail in ASHRAE Standard 103-2007. Section 11 was followed for calculating the AFUE based on the type of furnace under test. For non-condensing and non-modulating furnaces, Section 11.2 describes the procedures used to calculate steady-state efficiency, heating seasonal efficiency, maximum fuel input rate, and oversizing factor, all of which will be used in step 11.2.12 to calculate the AFUE. The same process applies for condensing furnaces as described in Section 11.3, non-condensing modulating furnaces as described in Section 11.4, and condensing modulating furnaces as described in Section 11.5. The two equations used to calculate AFUE are shown in Figure 1 for non-modulating furnaces and Figure 2 for modulating furnaces.

11.2.12 Annual Fuel Utilization Efficiency. The annual fuel utilization efficiency (AFUE) shall be expressed as a percent and defined as follows:

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

where

5200	=	average annual heating degree-days,
$Effy_{HS}$	=	value as defined in 11.2.11,
$Effy_{SS}$	=	value as defined in 11.2.7,
α	=	value as defined in 11.2.8.2,
4600	=	average non-heating-season hours per year.

Figure 1. Section 11.2.12 excerpt from ASHRAE Standard 103-2007

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

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

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,
α	=	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.

Figure 2. Section 11.4.12 excerpt from ASHRAE Standard 103-2007

3.6 Furnaces Tested

Twelve furnaces were collected from the field. Only nine could be tested in the lab without significant repair. A short description of each furnace, a photograph, nameplate information, and field measurements are included in this section.

3.6.1 InterCity Products GN100A016AIN

The GN100A016AIN model is a mid-efficiency gas furnace with an induced draft combustion system. The unit was built in April 1992 and removed from service in September 2012.

Figure 3. Furnace #1 InterCity Products

Table 6. Furnace #1 InterCity Products

Specifications			
Manufacturer	InterCity Products	**Height, in.**	40.125
Model	GNI100A016AIN	**Width, in.**	22.75
Serial Number	R921600151	**Depth, in.**	28.25
Year	April 1992	**Duct Depth, in.**	18.5
Input Capacity	100,000	**Duct Width, in.**	21.25
Output Capacity	80,400		
AFUE	80.5		
Field Data Reported			
Airflow (CFM)	920	**Temperature Rise, °F**	84
O_2%	9.6	**ESP, in. w.c.**	0.9
Flue Temperature, °F	467		

3.6.2 InterCity Products GUI100A012GIN

The GUI100A012GIN model is a mid-efficiency gas furnace with an induced draft combustion system. This unit was built in March 1991 and removed from service in September 2012.

Figure 4. Furnace #2 InterCity Products

Table 7. Furnace #2 InterCity Products

Specifications			
Manufacturer	InterCity Products	**Height, in.**	39.25
Model	GUI100A012GIN	**Width, in.**	19.25
Serial Number	L931034889	**Depth, in.**	28.25
Year	March 1991	**Duct Depth, in.**	18.5
Input Capacity	100,000	**Duct Width, in.**	17.75
Output Capacity	80,000		
AFUE	80.1		
Field Data Reported			
Airflow (CFM)	878	**Temperature Rise, °F**	73
O_2%	11.3	**ESP, in. w.c.**	0.7
Flue Temperature, °F	504		

3.6.3 Lennox G12QE382-10

The G12QE382-10 model is an atmospheric gas furnace using indoor combustion air, a draft diverter, and an atmospheric burner. The unit was built in June 1989 and removed from service in September 2012.

Figure 5. Furnace #3 Lennox

Table 8. Furnace #3 Lennox

Specifications			
Manufacturer	Lennox	**Height, in.**	49
Model	G12QE382-10	**Width, in.**	16.5
Serial Number	5889607663	**Depth, in.**	26.25
Year	June 1989	**Duct Depth, in.**	17.75
Input Capacity	82,000	**Duct Width, in.**	14.25
Output Capacity	None Found		
AFUE	72.5		
Field Data Reported			
Airflow (CFM)	947	**Temperature Rise, °F**	88
O_2%	13.2	**ESP, in. w.c.**	0.6
Flue Temperature, °F	548		

3.6.4 InterCity Products GN100A016CIN

The GN100A016CIN model is a mid-efficiency gas furnace using an induced-draft combustion system. The unit was manufactured in October 1993 and removed from service in September 2012. The front panels of this furnace were missing. New panels were fabricated for the test.

Figure 6. Furnace #4 InterCity Products

Table 9. Furnace #4 InterCity Products

Specifications			
Manufacturer	InterCity Products	**Height, in.**	40.625
Model	GN100A016CIN	**Width, in.**	23
Serial Number	L934418652	**Depth, in.**	28.25
Year	October 1993	**Duct Depth, in.**	18.25
Input Capacity	100,000	**Duct Width, in.**	21.25
Output Capacity	80,400		
AFUE	80.5		
Field Data Reported			
Airflow (CFM)	792	**Temperature Rise, °F**	84
O_2%	9.6	**ESP, in. w.c.**	0.9
Flue Temperature, °F	467		

3.6.5 Fraser Johnston PBKM-L016N080A

The PBKM-L016N080A model is a mid-efficiency furnace using an induced draft combustion system. This furnace was received without a front panel, so one was fabricated. The unit was built in February 1994 and removed from service in September 2012.

Figure 7. Furnace #5 Fraser Johnston

Table 10. Furnace #5 Fraser-Johnston

Specifications			
Manufacturer	Fraser-Johnston	**Height, in.**	40.25
Model	PBKM-L016N080A	**Width, in.**	22.25
Serial Number	EBCM101513	**Depth, in.**	28.25
Year	February 1994	**Duct Depth, in.**	19.5
Input Capacity	80,000	**Duct Width, in.**	21.125
Output Capacity	64,000		
AFUE	80		
Field Data Reported			
Airflow (CFM)	619	**Temperature Rise, °F**	86
O_2%	10.8	**ESP, in. w.c.**	0.9
Flue Temperature, °F	511		

3.6.6 Lennox G23Q4/5-100-4

The G23Q4/5-100-4 model is a mid-efficiency furnace using an induced draft combustion system. The unit was built in January 1998 and removed from service in September 2012.

Figure 8. Furnace #6 Lennox

Table 11. Furnace #6 Lennox

Specifications			
Manufacturer	Lennox	**Height, in.**	46.25
Model	G23Q4/5-100-4	**Width, in.**	22.25
Serial Number	5898A 35920	**Depth, in.**	28.5
Year	January 1998	**Duct Depth, in.**	18.75
Input Capacity	100,000	**Duct Width, in.**	19
Output Capacity	80,000		
AFUE	80		
Field Data Reported			
Airflow (CFM)	841	**Temperature Rise, °F**	89
O_2%	13.3	**ESP, in. w.c.**	0.8
Flue Temperature, °F	562		

3.6.7 Amana GUC090X50B

The GUC090X50B model is a high efficiency direct vent condensing gas furnace. The front panels for this furnace were missing and new panels were fabricated. The unit was built in September 1996 and removed from service in September 2012.

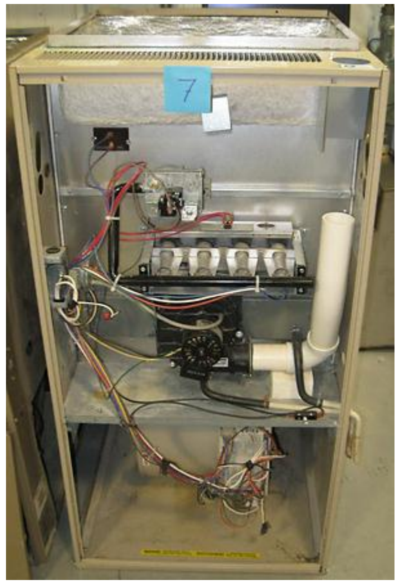

Figure 9. Furnace #7 Amana

Table 12. Furnace #7 Amana

Specifications			
Manufacturer	Amana	**Height, in.**	48
Model	GUC090X50B	**Width, in.**	24.625
Serial Number	9609152460	**Depth, in.**	28
Year	September 1996	**Duct Depth, in.**	19.75
Input Capacity	90,000	**Duct Width, in.**	23.125
Output Capacity	85,000		
AFUE	94.4		

Field Data Reported			
Airflow (CFM)	1071	**Temperature Rise, °F**	53
O_2%	12.9	**ESP, in. w.c.**	0.8
Flue Temperature, °F	144		

3.6.8 Rheem RGOA100CER

The RGOA100CER model is an atmospheric gas furnace with a draft diverter. This furnace could not be tested due to the furnace being damaged beyond repair during shipping. The unit was built in August 1991 and removed from service in September 2012.

Figure 10. Furnace #8 Rheem

Table 13. Furnace #8 Rheem

Specifications			
Manufacturer	Rheem	**Height, in.**	46.25
Model	RGOA100CER	**Width, in.**	17.5
Serial Number	MN3D104 F3491 0205	**Depth, in.**	28.125
Year	August 1991	**Duct Depth, in.**	20
Input Capacity	100,000	**Duct Width, in.**	16
Output Capacity	65,000		
AFUE	65		
Field Data Reported			
Airflow (CFM)	997	**Temperature Rise, °F**	84
O_2%	10	**ESP, in. w.c.**	0.8
Flue Temperature, °F	497		

3.6.9 Armstrong GUK075D14-18

The GUK075D14-18 model is a direct vent high-efficiency condensing gas furnace. It was manufactured in September 1994 and removed from service in September 2012.

Figure 11. Furnace #9 Armstrong

Table 14. Furnace #9 Armstrong

Specifications			
Manufacturer	Armstrong	**Height, in.**	46
Model	GUK075D14-18	**Width, in.**	22
Serial Number	8494J33762	**Depth, in.**	28
Year	September 1994	**Duct Depth, in.**	19.5
Input Capacity	75,000	**Duct Width, in.**	20.75
Output Capacity	67,000		
AFUE	90		
Field Data Reported			
Airflow (CFM)	693	**Temperature Rise, °F**	86
O_2%	12.2	**ESP, in. w.c.**	0.9
Flue Temperature, °F	555*		

*Reported value

3.6.10 Trane TUS060A936AO

The TUS060A936AO model is an atmospheric gas furnace with a draft diverter. Front panels were fabricated to replace those lost in shipment. The center heat exchanger mounting screw was replaced. The unit was manufactured in September 1987 and removed from service in September 2012.

Figure 12. Furnace #10 Trane

Table 15. Furnace #10 Trane

Specifications			
Manufacturer	Trane	**Height, in.**	49
Model	TUS060A936AO	**Width, in.**	18.125
Serial Number	B36599305	**Depth, in.**	28.125
Year	September 1987	**Duct Depth, in.**	20
Input Capacity	60,000	**Duct Width, in.**	17
Output Capacity	None Found		
AFUE	68.4		
Field Data Reported			
Airflow (CFM)	604	**Temperature Rise, °F**	87
O_2%	11.3	**ESP, in. w.c.**	0.8
Flue Temperature, °F	497		

3.6.11 Lennox G16Q3757

The G16Q3757 model is a mid-efficiency gas furnace using an induced draft combustion system. This was damaged beyond repair during shipping and could not be tested. It was manufactured in March 1989 and removed from service in September 2012.

Figure 13. Furnace #11 Lennox

Table 16. Furnace #11 Lennox

Specifications			
Manufacturer	Lennox	**Height, in.**	49
Model	G16Q3757	**Width, in.**	16.25
Serial Number	5889C07272	**Depth, in.**	26.25
Year	March 1989	**Duct Depth, in.**	18
Input Capacity	75,000	**Duct Width, in.**	14
Output Capacity	None Found		
AFUE	78.5		
Field Data Reported			
Airflow (CFM)	720	**Temperature Rise, °F**	76
O_2%	13.2	**ESP, in. w.c.**	0.8
Flue Temperature, °F	531		

3.6.12 Lennox GH6D 100M

The GH6D 100M model is an atmospheric gas furnace that uses a draft diverter. This furnace could not be tested because the height exceeded the test chamber capability. The unit was manufactured in May of 1963 and was removed from service in September 2012.

Figure 14. Furnace #12 Lennox

Table 17. Furnace #12 Lennox

Specifications			
Manufacturer	Lennox	**Height, in.**	60.75
Model	GH6D 100M	**Width, in.**	21
Serial Number	None Found	**Depth, in.**	27.5
Year	May 1963	**Duct Depth, in.**	17
Input Capacity	100,000	**Duct Width, in.**	19
Output Capacity	80,000		
AFUE	N/A		
Field Data Reported			
Airflow (CFM)	861	**Temperature Rise, °F**	88
O_2%	11.5	**ESP, in. w.c.**	0.8
Flue Temperature, °F	485		

4 Analysis

Gas furnace efficiency was determined using five different metrics to compare laboratory and field performance. Table 18 below shows the efficiency metrics.

Table 18. Efficiency Measurements

Efficiency Metric	Description
SSE FC Calc	Steady-state efficiency under field conditions calculated from field data
SSE FC LM	Steady-state efficiency under field conditions as measured in the lab
SSE SC LM	Steady-state efficiency under ASHRAE Standard 103 test conditions measured in the lab. Airflow and input rate adjusted.
AFUE FC LM	AFUE under field conditions measured in the lab
AFUE SC LM	AFUE under ASHRAE Standard 103 test conditions measured in the lab. Airflow and input rate adjusted.

4.1 Steady-State Efficiency

Steady-state efficiency was measured under constant load conditions in the field and in the lab (thermostat calling for heat). Field data were reported by the HVAC contractor. Lab testing included the Gas Technology Institute rack-mounted combustion analyzer system that is calibrated daily and the instruments used in the Standard test procedure as discussed earlier in this report. Field conditions are based on handheld combustion analyzers, digital static pressure transducers for external static pressure, and a flow plate for airflow rate.

Table 19 shows the data collected in the field and the manufacturer-recommended temperature rise. Note that in almost every case, the furnaces were operating in the field above the manufacturer's temperature rise recommendation.

Table 19. Furnace Field Data and Steady-State Efficiency

Number	Manufacturer	O_2 (%)	ESP (in. w.c.)	Airflow Rate (CFM)	Flue Temperature (°F)	Temperature Rise (°F)	Manufacturer Temperature Rise Range (°F)
1	ICP	9.6	0.9	920	467	84	30–60
2	ICP	11.3	0.7	878	504	73	40–70
3	Lennox	13.2	0.6	947	548	88	70–100
4	ICP	12	0.9	792	433	90	30–60
5	Fraser-Johnston	10.8	0.9	619	511	86	20–50
6	Lennox	13.3	0.8	841	562	89	30–60
7	Amana	12.9	0.8	1071	144	53	35–65
9	Armstrong	12.2	0.9	693	555	86	50–80
10	Trane	11.3	0.8	604	497	87	40–70

Although AFUE cannot be measured in the field, a comparison can be made with the calculated steady-state efficiency value from field data and steady-state efficiency under the ASHRAE

Standard conditions as measured in the lab, SSE SC LM. Table 20 shows the steady-state efficiency calculated from the field data and SSE SC LM measured in the lab under ASHRAE Standard test conditions of 0.2 in. w.c. ESP. In all cases, the field value is below the laboratory-measured value.

Table 20. Steady-State Efficiency Comparison

Number	Manufacturer	SSE FC Calc	SSE SC LM
1	ICP	76.8	**80.4**
2	ICP	73.3	**81.4**
3	Lennox	67.5	**77.2**
4	ICP	75.1	**80.5**
5	Fraser Johnston	73.7	**79.7**
6	Lennox	66.5	**81.2**
7	Amana	87.0	93.7
9	Armstrong	88.1	**88.6**
10	Trane	73.5	**76.3**

Figure 15 compares the steady-state efficiency between the field and Standard conditions. The 45-degree line represents perfect agreement, above the line means the lab measured value is greater or conversely that the calculated value from field measurement is lower. The difference between the means is 6.4%. A paired t-test of the null hypothesis that the sample means are not different from each other at $p < .05$ is rejected based on a statistical analysis. The means are significantly different for these two datasets, indicating poor performance in the field due to poor installation practices or misadjustment.

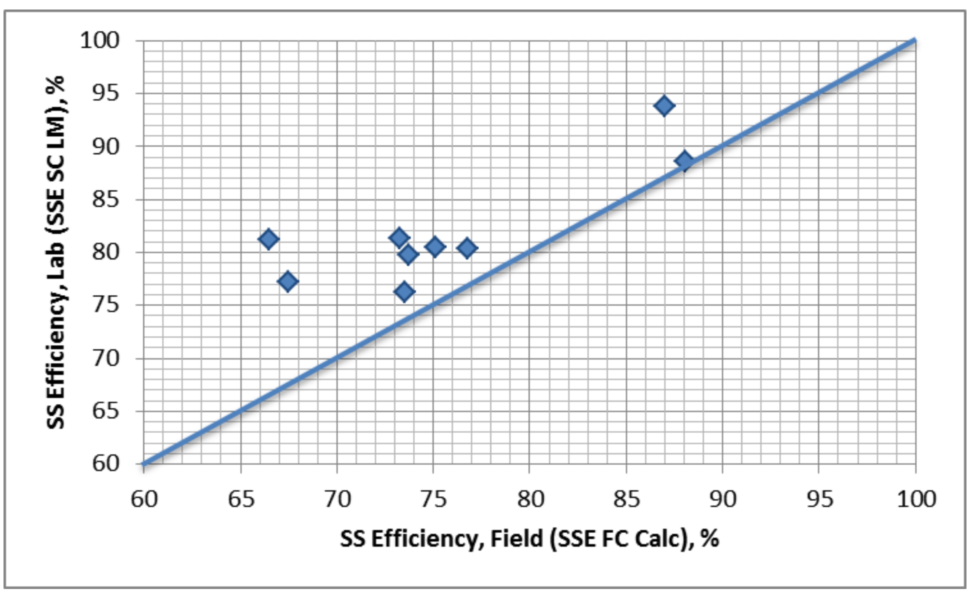

Figure 15. Steady-state efficiency field and lab standard conditions

Field installation parameters were evaluated to determine the root cause for this difference. The airflow rate measured in the field and in the Standard steady-state efficiency measurement (not the same static pressure) is provided in Table 21, below. Note that the Standard numbers are significantly greater than in the field due to improper air distribution system design.

Table 21 Airflow in the Field and at Standard Conditions

Number	Manufacturer	Field Airflow (CFM)	Standard Conditions Airflow (CFM)
1	ICP	920	1925
2	ICP	878	1635
3	Lennox	947	943
4	ICP	792	1754
5	Fraser Johnston	619	1488
6	Lennox	841	1664
7	Amana	1071	1516
9	Armstrong	693	1389
10	Trane	604	945

An indirect measure of how well the field airflow is adjusted is to measure the temperature rise across the furnace and identify where it lies in the manufacturer's recommended "rise range" as follows: The midpoint value is the target; higher values result in decreased efficiency and lower values increase the risk of corrosion in the heat exchanger. Table 22 below shows the rise values from the field and Standard test along with the manufacturers' recommendation. Note that fan speed adjustments are very coarse and it is not always possible to meet the requirement.

Table 22 Furnace Rise Range

Number	Manufacturer	Manufacturer Temperature Rise Range (°F)	Field Temperature Rise (°F)	Standard Temperature Rise (°F)
1	ICP	30–60	84	43
2	ICP	40–70	73	49
3	Lennox	70–100	88	69
4	ICP	30–60	90	47
5	Fraser-Johnston	20–50	86	45
6	Lennox	30–60	89	52
7	Amana	35–65	53	66
9	Armstrong	50–80	86	58
10	Trane	40–70	87	51

Airflow was not set within the rise range for many of these furnaces in the field, or the ductwork was too small to achieve the required airflow. Note that most field furnaces were operating at the top or above the rise range at lower efficiency.

As a final note on field adjustments, input rate adjustments were not required for laboratory testing of the furnaces except for furnace #10. This furnace was received set at 76,000 Btu/h compared to the 60,000 Btu/h on the label. There was no individual test to determine the efficiency change associated with adjusting the input in isolation, but adjusting both the input rate and airflow improved the steady-state efficiency by 2.8% for this furnace.

PARR attempted to measure the steady-state efficiency of the furnaces under field airflow and static pressure conditions (SSE FC LM) to determine if the field conditions could be replicated in the lab. Table 23 below shows the field-measured airflow rate and the lab measured airflow rate when the furnaces were installed to the same reported ESP conditions needed to replicate the ductwork pressure drop from the field. There is a significant discrepancy between these two values, for reasons unknown to the investigator. It is likely that either the reported field ESP or field airflow measurements are not reliable. Potential causes are that the flow plate replaced a dirty filter or that the return duct geometry was not suitable for use with the flow plate.

Table 23. Airflow Rate Differences in the Field and Lab at the Same Static Pressure

Furnace	Field Measured Airflow Rate (CFM)	Lab Measured Airflow Rate (CFM)
1	920	1,288
2	878	1,206
3	947	661
4	792	1,048
5	619	938
6	841	1,407
7	1,071	1,516
9	693	955
10	604	665

PARR elected to set up the furnaces in the lab according to the static pressure reading rather than the airflow reading because it was considered to be the more accurate of the two field measurements. SSE FC LM was compared to the steady-state efficiency under the conditions in the Standard (SSE SC LM). Recall that that the Standard condition test is done after airflow adjustments are made and the input rate is adjusted.

Table 24 below shows the differences between the two values.

Table 24. Steady-State Efficiency Measured in the Lab

Furnace	Field Conditions Lab Measured Steady-State Efficiency (SSE FC LM), %	Standard Conditions Lab Measured Steady-State Efficiency (SSE SC LM), %
1	79.3	80.4
2	80.6	81.4
3	74.8	77.2
4	77.2	80.5
5	79.1	79.7
6	80.9	81.2
7	90.9	93.7
9	88.3	88.6
10	76.7	76.3

Figure 16 shows the two efficiency values on a chart; the 45-degree line represents perfect agreement.

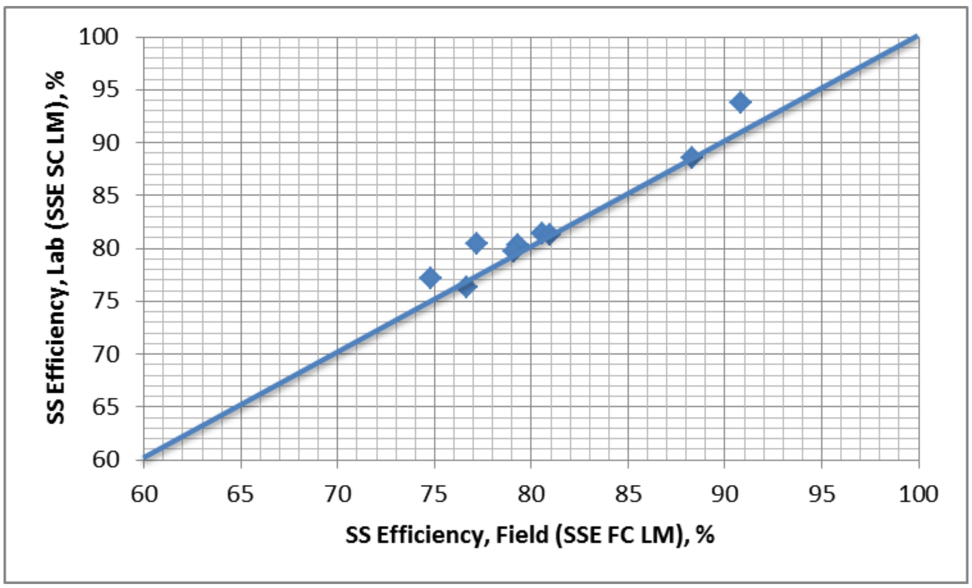

Figure 16. Steady-state efficiency field and lab field conditions

The test results show that there is still a statistically significant difference between these two means, but it is only on the order of 1.2% due to the difficulty in replicating the field environment in the lab.

4.2 Annual Fuel Utilization Efficiency

Annual fuel utilization efficiency is the industry standard measurement for gas furnace performance. Three metrics for AFUE are used in this study: AFUE under field conditions (AFUE FC LM), AFUE under the ASHRAE Standard conditions (AFUE SC LM), and AFUE according to the label. Table 25, below, provides the test results.

Table 25. AFUE Under Field and Standard Conditions

Furnace	AFUE Field Conditions (AFUE FC LM), %	AFUE Standard Conditions (AFUE SC LM), %
1	80.47	81.04
2	82.7	82.9
3	70.6	73.0
4	79.1	81.3
5	80.5	81.1
6	81.5	82.5
7	92.7	94.9
9	91.3	91.8
10	71.7	69.6

Figure 17 below shows the data in graphical form where the 45-degree line indicates perfect agreement.

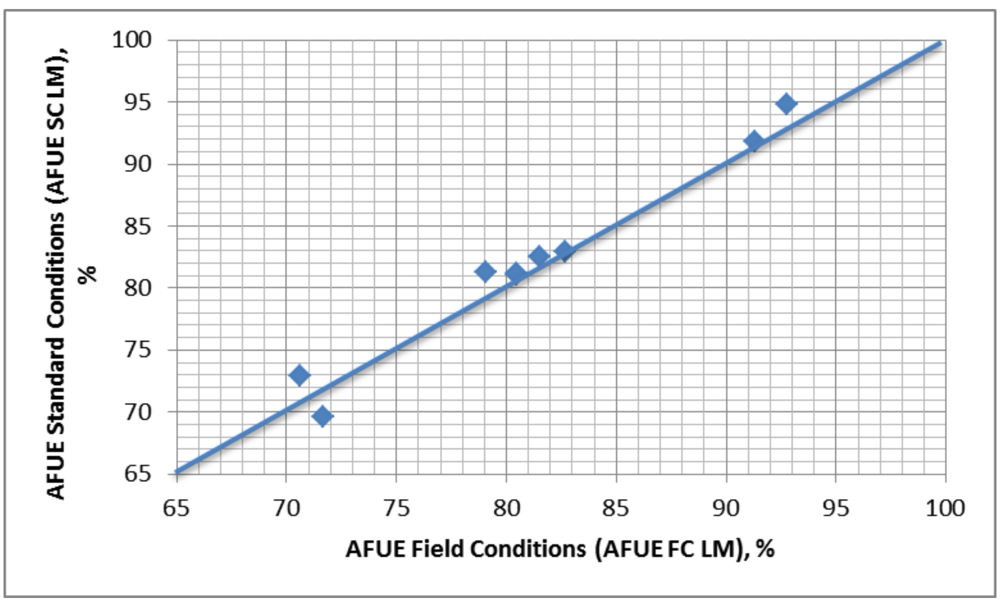

Figure 17. AFUE under field and standard conditions

Using the same paired t-test for significance with this dataset, the mean difference of 0.8% is not significant when testing AFUE under field and Standard conditions in the lab. The difficulty associated with setting up field conditions in the lab, as mentioned in the steady-state efficiency analysis, coupled with the four heat up, cool down, and condensate collection parts of the test masks the differences.

Table 26 below shows the difference between the labeled AFUE on the furnace and the lab-measured value under the Standard conditions (AFE SC LM). This test does not rely on replicating the field conditions in the lab.

Table 26. AFUE From Label and Standard Conditions

Furnace	AFUE Label (%)	AFUE Standard Conditions (AFUE SC LM), %
1	80.5	81.0
2	80.1	82.9
3	72.5	73.0
4	80.5	81.3
5	80.0	81.1
6	80.0	82.5
7	94.4	94.9
9	90.0	91.8
10	68.4	69.6

Figure 18 below shows the data in graphical form.

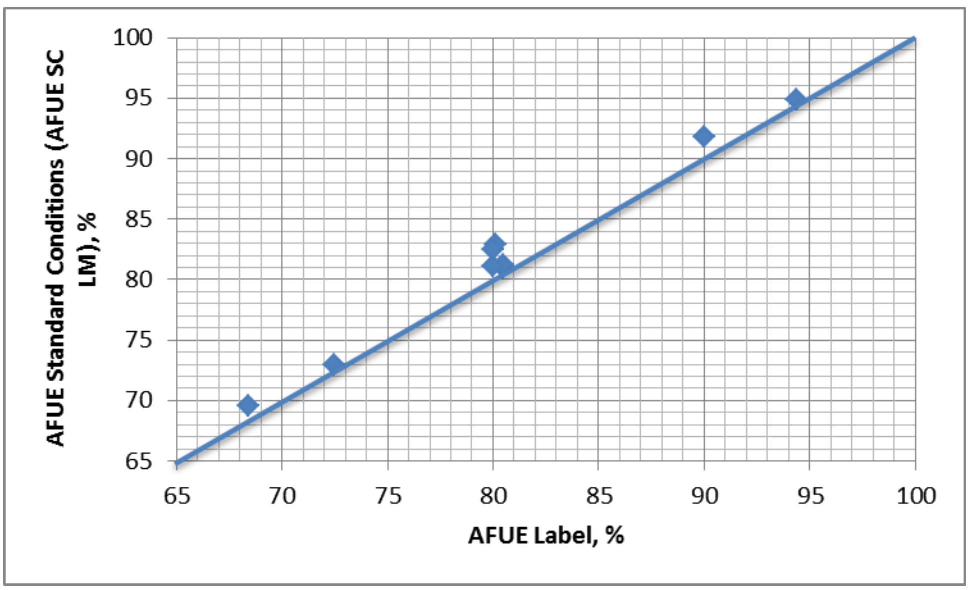

Figure 18. AFUE from the label compared to lab measurement

Using the same hypothesis testing, there is a significant difference between the DOE AFUE from the label and the lab-measured AFUE from ASHRAE 103 for this dataset, at 1.3%. This value represents an increase in furnace efficiency from the label value over the life of the furnace, an unexpected result.

There are several potential reasons for the slight difference, including changes to the standards over time, sampling differences, bias in the test, or emissivity changes from oxidation of the heat exchangers. The ASHRAE Standard is revised every 4 years and the DOE standard also undergoes periodic revision, so it is possible that the older equipment was measured under a different standard. Manufacturers acknowledge that oxidation of the heat exchanger will increase emissivity and improve performance.

The hypothesis that there is a time-dependence to furnace efficiency is tested in Section 4.3, below.

4.3 Efficiency Change With Time

The efficiency measurements for the furnaces collected from the field provide a unique opportunity to evaluate changes to the efficiency of furnaces with time.

Figure 19 below plots the age of the furnace versus percent change per year of furnace AFUE measured in the lab (AFUE SC LM), which is independent of field measurement.

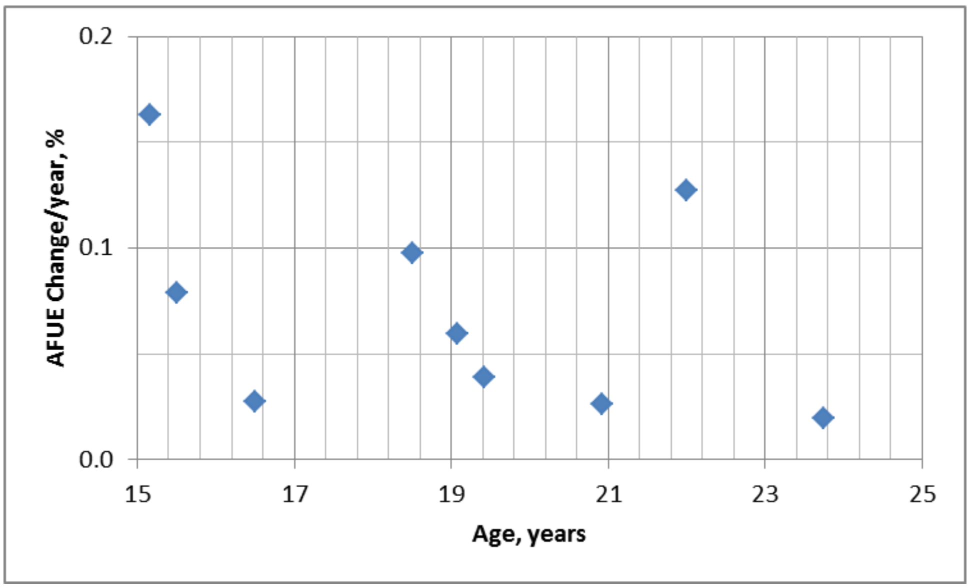

Figure 19. AFUE change with age

A linear fit of the data did not result in a slope or intercept value that was statistically significant. The implications are that there is a non-zero increase in measured AFUE from the DOE label, but it does not appear to be time dependent, indicating that the change happens in the first 15 years of field use. It is also possible that there is some bias in the lab test compared to the DOE standard, as mentioned earlier. At minimum, these data can be used to conclude that there is no degradation in efficiency over time for the natural gas furnaces in this sample when compared with their DOE label AFUE. The degradation predicted by Equation 1 is not supported in this research.

A final comparison was made between AFUE change with age versus AFUE from the label to determine if there was a relationship between the two. The graph is provided in Figure 20.

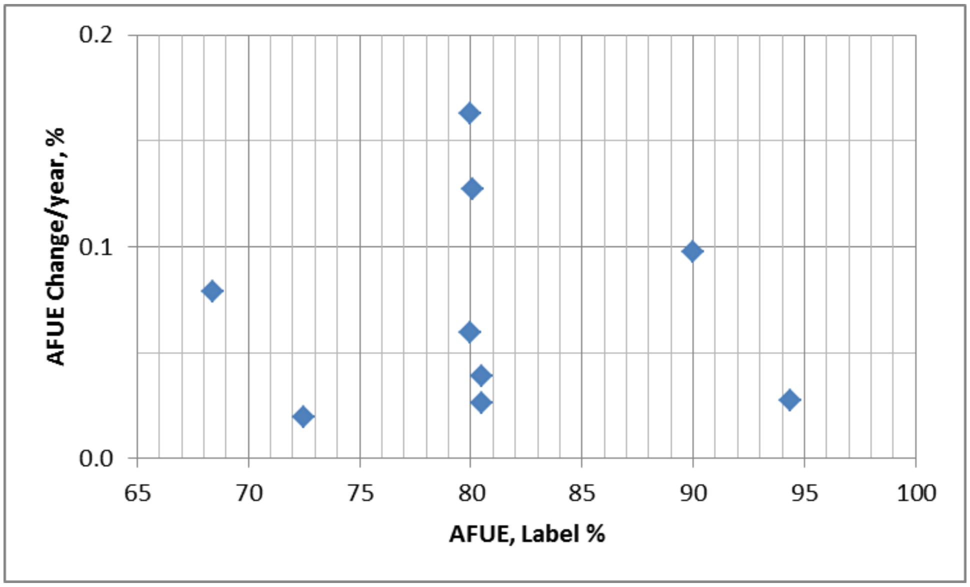

Figure 20. AFUE label versus AFUE change per year

This analysis shows that there is no relationship between the efficiency of the furnace and efficiency change with time.

5 Results and Discussion

The primary objective of this project is to determine how age and adverse installation conditions affect natural gas field performance as measured by AFUE. The results from this study are summarized below:

1. There is a significant difference between the steady-state efficiency calculated from field data and the steady-state efficiency measured in the lab under Standard conditions, which replicates the Standard conditions in the AFUE test. The difference in the mean is 6.4%. An analysis of the nine data points in Figure 16 using a paired student t-test and $p < .05$ for significance indicates that the two datasets are significantly different. The implication is that field performance is 6.4% lower than rated conditions for this sample due to poor installation practices or misadjustment.

2. There is a significant difference between steady-state efficiency measured in the lab under field conditions and ASHRAE Standard conditions, at 1.2%. Replicating the field environment proved to be difficult in this test. Since the furnaces were removed from their installation sites, additional field data could not be collected.

3. There is no significant difference between AFUE under field and Standard conditions measured in the lab. The difficulty associated with setting up field conditions in the lab, as mentioned above, coupled with the four heat up, cool down, and condensate collection parts of the test may mask the difference.

4. The mean lab-measured AFUE from the ASHRAE Standard is 1.3% higher than DOE AFUE from the label, a statistically significant difference. This test does not rely on replicating field conditions in the lab. There are several potential reasons for this finding, including changes to the standards over time, sampling differences, bias in the test, or emissivity changes from oxidation of the heat exchangers. The ASHRAE Standard is revised every 4 years and the DOE standard also undergoes periodic revision, so it is possible that the older equipment was measured under a different standard.

5. Testing a linear fit of efficiency with time was not significant for either the slope or intercept values. The implications are that there is a non-zero increase in measured AFUE from the DOE label, but it is not time dependent, indicating that the change happens in the first 15 years of field use. It is also possible that there is some bias in the lab test compared to the DOE standard, as mentioned earlier. At minimum, these data can be used to conclude that there is no degradation in efficiency over time for the natural gas furnaces in this sample when compared with their DOE label AFUE. The degradation predicted by Equation 1 is not supported in this research.

The research questions are addressed below:

Q1: What is the degradation in furnace efficiency for typical field installation compared to the rated performance?

A1: Furnace steady-state efficiency calculated from field data is 6.4% below that measured in the laboratory under Standard conditions, a statistically significant difference.

Q2: How should AFUE be modified in models (such as BEopt) to account for differences between the field and the laboratory, especially for retrofit situations?

A2: BEopt and other models do not need to adjust for differences between rating conditions and the field environment for furnaces that are installed properly.

Q3: How do rated and measured AFUE compare for vintage furnaces?

A3: Older furnaces show no degradation of performance in AFUE over an average lifetime of 19 years, in fact a slight increase was measured. This 1.3% increase is small but significantly different from zero. From the data, time is not a significant variable in the regression, so there may be an initial increase or a slight bias caused by differences in test standards.

6 Conclusions and Recommendations

The conclusions of this research are that the DOE AFUE measurements done by the manufacturer are a good measure of the performance of natural gas furnaces in the field where the installation instructions are followed. Field conditions are difficult to replicate in the laboratory, so lab testing that replicates the field environment requires more study. AFUE comparisons between the label and the ASHRAE Standard test in the lab show no degradation after an average lifetime of 19 years, in fact a slight increase was measured. AFUE does not show a significant time dependency.

PARR recommends that BEopt and other models use the DOE labeled AFUE as the actual efficiency of natural gas furnaces installed in the field without adjustment for installation practices or degradation with time. This dataset supports those recommendations. Field measurements of efficiency, static pressure, and airflow (using a flow plate) were inconsistent in this study when compared to laboratory measurements. It is recommended that field measurements be used only as a general indicator of performance when tuning a furnace or adjusting airflow, not as an absolute indication of performance for modeling or energy savings analysis.

PARR conducted this investigation to determine which deficiencies in the field, if any, hold the largest energy saving potential. Setting the furnace on rate, and tuning the fan to manufacturers recommended rise range (temperature rise across the furnace) are the two most significant factors in achieving good performance, as recommended by the manufacturer. If the fan speed cannot be adjusted properly, changes to the distribution system need to be made. If the qualified installer follows the manufacturer's installation instructions regarding these settings and others, the furnace should perform as rated.

Future natural gas furnace testing is recommended to add data to the cases where a relationship could not be determined in this project: replicating field conditions in the lab and establishing efficiency change with time. It may also be valuable to determine if a furnace installed poorly would operate significantly below the AFUE rating. Examples would be furnaces working outside the rise range (very high or very low), and furnaces cycling off the high limit controller for a significant part of the time.

References

ASHRAE. (1982). Standard "Method of Testing for Heating Seasonal Efficiency of Central Furnaces and Boilers." ANSI/ASHRAE Standard 103-1982, Approved by the ASHRAE Board of Directors on October 1, 1982.

ASHRAE. (2007). Standard "Method of Testing for Annual Fuel Utilization Efficiency of Residential Central Furnaces and Boilers." ANSI/ASHRAE Standard 103-2007, Approved by the ASHRAE Board of Directors on June 27, 2007.

Brand, L.; Rose, W. (2012). *Measure Guideline: High Efficiency Natural Gas Furnaces*. Gas Technology Institute, Des Plaines IL, DOE/GO – 102012-3684.

Brand, L., (2012) "Expert Meeting Report: Achieving the Best Installed Performance from High-Efficiency Residential Gas Furnaces," Gas Technology Institute, Des Plaines IL, 2012

Burdick, A. (2011). *Strategy Guideline: Accurate Heating and Cooling Load Calculations*. Golden, CO: National Renewable Energy Laboratory. NREL/SR-5500-51603.

Hendron, R., Engebrecht, C. (2010), *Building America House Simulation Protocols*." Golden, CO: National Renewable Energy Laboratory. NREL/TP-550-49426.

Polly, B.; Kruis, N.; Roberts, D (2011). *Assessing and Improving the Accuracy of Energy Analysis for Residential Buildings*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5500-50865.

Yee, S., Baker, L., Brand, L., and Wells, J. (2013) "Energy Savings from System Efficiency Improvements in Iowa's HVAC SAVE Program." Chicago, IL: Midwest Energy Efficiency Alliance.

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

DOE/GO-102013-4112 ▪ August 2013

Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 10% post-consumer waste.