COLD CLIMATE HOUSING RESEARCH CENTER
CCHRC

AFUE

Annual Fuel Utilization Efficiency

A Review for Cold Climate Applicability

by Cold Climate Housing Research Center
2013

Contents

Acknowledgments

CCHRC would like to thank the following individuals for providing information regarding AFUE and their own research for this report:

Thomas Butcher, Brookhaven National Laboratory

Jim Romersberger, Quintessence Corporation

John Siegenthaler, Appropriate Designs

The authors would also like to thank Alan Mitchell of Analysis North for reviewing the report.

Finally, thanks to Alaska Housing Finance Corporation for providing funding for this report.

List of Acronyms

AFUE	Annual Fuel Utilization Efficiency
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.
BTU	British Thermal Unit
CAE	Combined Annual Efficiency
DHW	Domestic Hot Water
DOE	Department of Energy
F	Fahrenheit
HDD	Heating Degree Days
Hg	Mercury
PSI	Pounds per Square Inch

Motivation

Residential-sized furnaces and boilers are rated according to their Annual Fuel Utilization Efficiency (AFUE). It is a widely-used, standardized metric, but it is not specific to heating appliances in cold climates. Also, the AFUE is not always achieved in real-world heating appliance installations; see (Brand, 2012) and (Pigg & Parkhurst, 2007). This goal of this AFUE review is to determine whether a modification of the AFUE calculation or test methodology would provide a more accurate reflection of seasonal efficiency in a cold climate setting. The primary area of focus is on the assumptions and variables that would be different if AFUE were formulated specifically for a cold climate region such as Alaska. Other variables that affect heating system efficiency in all locations but are not necessarily considered in AFUE, such as heat distribution, oversize factor, and control system, are also examined .

What is AFUE?

The Annual Fuel Utilization Efficiency (AFUE) is defined as the ratio of annual output energy of a boiler or furnace to the annual input energy. It is a widely-referenced metric for specifying the seasonal energy usage of electric, gas, and oil-fired boilers and furnaces. Its intent is to provide a standard basis of comparison between these heating appliances for residential and light-commercial buildings. It is used by the Department of Energy to establish minimum-allowed seasonal efficiencies for appliances sold in the United States. For example, the current minimum AFUE for a non-condensing, fossil-fueled furnace is 78% and the minimum AFUEs for hot water boilers are 82% for a gas-fired boiler and 84% for an oil-fired boiler (U.S. Department of Energy, 2012).

AFUE is just one of many efficiency metrics that are used to describe boilers and furnaces. Some of the more common ones are defined below (Siegenthaler, 2004). Each describes heating appliance efficiency in a unique way.

Steady-state efficiency: A heating appliance operates in steady-state efficiency when it is fired continuously under non-varying conditions. The steady state efficiency is the ratio of the heat output rate to the energy input rate while conditions are constant.

Combustion efficiency: The combustion efficiency refers to how effective an appliance is in converting the chemical energy in fuel to heat. It can be measured in the field by measuring the temperature and CO_2 content of the exhaust gas while the appliance is operating under steady-state conditions. The combustion efficiency can then be calculated (or looked up in a table) based on the fuel used. Basically it is calculated assuming that output energy equals input energy minus the stack losses, or *(input – stack loss)/input* (Durkin, 2006).

Cycle efficiency: Cycle efficiency is the ratio of the heat output rate to the energy input over a defined period of time. It will always be less than steady state efficiency because of heat losses that occur when the appliances is switched off. The cycle efficiency is dependent on the run fraction of the appliance, or the percentage of time the appliance is on. The cycle efficiency is higher for devices that have higher run fractions and lower idle losses.

AFUE: AFUE is a seasonal efficiency. It is meant to account for the part-load operation of a heating appliance over the course of the heating season and is used to compare the predicted fuel usage of appliances over the course of a year.

AFUE was first established in 1978. The standard for the testing of a heating appliance to determine the AFUE rating is currently given by ANSI/ASHRAE Standard 103-2007: *The Method of Testing Annual Fuel Utilization Efficiency of Residential Central Furnaces and Boilers*. It includes a specific test method for determining cyclic and part-load performance, methods for interpolating and extrapolating test data, and calculation procedures for establishing the seasonal performance of the heating appliance. It also includes standards for the testing equipment.

The current standard was approved by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE) Standards Committee in 2007 and by the American National Standards Institute (ANSI) in 2008. ASHRAE is the technical organization that creates the standard, and ANSI provides the framework and guidelines for standards development. It is currently up for review and revision by ASHRAE, which typically happens on a 5-year cycle. The committee for reviewing standard 103 was formed in June 2012, the first step in a year-long process for review.

Scope of AFUE

The AFUE methodology applies to residential and light commercial boilers and furnaces with an input of gas, oil, or electricity. The output of the appliance is heated air, water, or steam. The heating appliance must also meet the following capacity requirements:

- Central furnaces with inputs less than 225,000 BTU/hr
- Central boilers with inputs less than 300,000 BTU/hr
- Can also apply to furnaces in the same cabinet as air conditioners with rated cooling capacity of 65,000 BTU/hr or less

Test Procedure

ASHRAE/ANSI Standard 103 specifies the collection of experimental test data as inputs for the calculation of AFUE. The tests are performed on complete space heating appliances that are installed, according to manufacturer instruction, in a test room. Standard 103 contains specifications for setting up the heating appliance. For instance, guidelines in the standard address the size and location of pipes or ducts attached to the heating device. Additionally, diagrams for various testing scenarios are included; for instance, one figure shows the arrangement for ducts and plenums on a gravity central furnace. Details are also given for the sensors that are used in testing procedure. Table 1 contains some of the error ratings given in Standard 103 for a selection of the instruments used in the AFUE test procedure. The diagrams in the standard also contain information about where sensors should be placed on the appliance and its corresponding piping and ductwork.

Table 1: Some of the standard 103 specifications for sensor error

Instrument	Allowable error for AFUE test
Thermometer	± 1°F
Thermocouple	± 2°F
Gas pressure	± 0.2 inches of water
Oil pressure	± 0.5 psi
Air pressure	± 0.01 inches of water
Steam pressure	± 0.2 inches of mercury
CO2 in stack and flue gas	± 0.1 percentage points
Time	± 0.5 second per hour
Weight	± 0.5% of the measured quantity

Requirements are also given for the fuel used by the heating appliance. There are three fuel types covered in the AFUE Standard: electricity, fuel oil, and natural gas. Electrical input must be maintained at a supply within 1% of the nameplate voltage. Fuel oil must meet requirements on flash point, pour point, water and sediment percent by volume, carbon, distillation temperature, viscosity, gravity, and sulfur content. Natural gas must meet requirements for specific gravity and heating value, and the supply has to be maintained within a specified pressure range.

Section 8 in Standard 103 contains the testing conditions necessary to collect the data to determine AFUE. A selection of these conditions for different types of appliances is in Table 2. While several conditions are specified by the standard, some are for the appliance setting to match the manufacturer recommendation, for example: the burner on an oil boiler should be tuned to give a CO_2 reading recommended by the appliance manufacturer.

Table 2: Selection of testing conditions from Standard 103

Testing Conditions	
Gas burner input rate	60°F and 30 in. of Hg
Hot water supply temperature to boilers	Between 120° and 124°F
Combustion air temperature	Within 5°F of room temperature
Room temperature	Between 65° and 100°F
Steady state temperature rise in furnace airflow	No greater than 130°F
Steady state temperature rise in boiler water flow	Between 19° and 24°F

Boilers and furnaces undergo the following procedures after being set up according to the standard specifications. The test collects data on on-cycle, steady state, and off-cycle performance.

1. Determine the draft factor: The standard has a table of heating appliance characteristics that allow testers to look up a draft factor for the appliance. The draft factor is the ratio of gas mass flow rate through the flue during off-cycle to the gas mass flow rate through the flue during on-cycle at the same temperature. The draft factor can also be measured experimentally using a tracer gas test.

2. Determine the off-cycle loss factor: The off-cycle loss factor is the ratio of off-cycle sensible heat loss tested with the flue damper closed to the off-cycle sensible heat loss with the flue damper open in atmospheric systems with a draft diverter or draft hood. To obtain the loss factor, the stack gas mass flow rate and the stack gas temperature are measured during two cool-down periods. These measurements serve as inputs to calculations that are included in the standard.
3. Steady-state performance test: The appliance is operated under steady state conditions while the fuel input rate, the flue gas temperature, the flue gas carbon dioxide content, and the ambient room temperature are measured and recorded. For condensing units, the condensate is collected during the steady state test to be measured after the collection period. For units with step modulating or two-step controls, the test must be performed at each fuel input rate.
4. Cool-down test: In this test, the burner is turned off and the flue temperature is measured using procedures described in the standard. This test is not required for electric appliances.
5. Heat-up test: After the cool-down test is performed and the appliance has come to equilibrium, the appliance is started again for the heat-up test. The appliance is allowed to heat up to steady state. During this test, flue gas temperatures are measured at specified intervals. This test is not required for electric appliances.
6. Condensing furnaces and boilers also will undergo an additional test to measure the condensate heat loss under cyclic conditions. The condensate is collected and its mass and temperature are measured. The temperature is used to calculate the sensible heat that is lost through the condensate.
7. There is an optional jacket loss measurement procedure for units that will be installed in an unheated location. The jacket loss can also be assigned the value of 1%.

Losses

AFUE accounts for a number of different losses on heating appliances, including both on- and off-cycle losses in addition to the losses sustained during steady-state operation. The losses are determined in the calculations portion of AFUE, and are listed below:

1. Sensible heat loss at steady state operation
2. Sensible heat loss during burner on-cycle
3. Sensible heat loss during burner off-cycle
4. Latent heat loss due during steady-state and part-load operation
5. Infiltration heat loss during burner on-cycle
6. Infiltration heat loss during burner off-cycle
7. Steady-state and part-load heat loss due to hot condensate going down the drain in condensing appliances

Sensible heat losses represent the heat that is lost up the flue because flue gases are hotter than the combustion air, but do not contribute to space heating. The latent heat loss is due to the water vapor discharged in the flue gas. Infiltration losses happen when outside air is drawn into conditioned space by air moving through the heating appliance. Infiltration losses can also include indoor heated air that is used for combustion or drawn into the appliance and lost through the flue.

Also, there are losses which AFUE does not account for:

1. Jacket loss is considered useful heat by default, because the appliance is assumed to be indoors. However, the standard does account for jacket loss if the appliance is located in an unheated space. There is a procedure for measuring the jacket loss experimentally, or the option exists to assume that jacket loss is 1%, where jacket loss is defined as the hourly heat loss through the jacket divided by the hourly input. In the calculations section, formulas are provided to account for jacket loss should it be a nonzero quantity. There is no option for the situation where the appliance is located indoors, but not all jacket loss is useful. For instance, in a situation where the appliance is located in a heated space but the jacket loss causes the ambient temperature to rise above the set point temperature during the shoulder seasons, there is no calculation provided to differentiate between which portion of jacket loss is useful which portion is not. Also, there is not an option for assuming that jacket loss maybe be useful for part of the year, and wasted heat during another part of the year. An example of this situation would be a combination appliance, which remains in use during the summer in order to provide domestic hot water.
2. Electrical energy, other than as the primary fuel in electric furnaces and boilers, is not accounted for in the calculations for AFUE. This means that the electricity used for auxiliary equipment such as controls, blowers, and pumps is not considered input energy to the device in the context of AFUE. However, Standard 103 contains a procedure for including this energy in the calculation for a seasonal efficiency known as the Energy Factor. The calculations for the Energy Factor are located in Appendix B of Standard 103.

Calculations

After data has been collected on the performance of the heating appliance, the AFUE is determined by following the calculations in Standard 103. Calculation procedures are given for the following types of appliances:

1. Electric furnaces and boilers: For electric furnaces and boilers, the AFUE is 100% unless the unit is installed in an unheated location, in which case jacket loss must be accounted for.
2. Non-condensing and non-modulating combustion appliances: To find the AFUE for non-condensing, non-modulating combustion appliances, the calculations first step the user through determining the steady-state efficiency and the heating seasonal efficiency using the data gathered during the testing phase.
3. Condensing combustion appliances: This section contains modifications to the calculation procedure to account for latent heat gain and heat loss due to hot condensate going down the drain.
4. Non-condensing, modulating combustion appliances: For modulating appliances, some calculations must be carried out at both maximum and reduced input rates.
5. Condensing and modulating appliances: This section contains modifications to the modulating calculations necessary to account for condensing units.

Assumptions

A number of assumptions are used in calculating AFUE from the test data. Many of them are listed below.

1. An oversize factor of 0.7 is assumed to be the national average oversize factor. This means that the heating appliance is rated to produce 70% more heat than the peak load of the residence. This is used in the final calculation to find AFUE.
2. Average outdoor temperature of 42°F. This is used in calculations for appliances that use outdoor air for combustion instead of room temperature air, and in heat loss calculations.
3. Multiplication factor for jacket losses, should they exist, is assumed to be 1.7 for appliances with isolated combustion systems and 4.7 for appliances located outdoors. The multiplication factor adjusts the jacket loss measured in the laboratory to that which would be measured under outdoor design temperatures.
4. Average burner cycle on-time and off-time are assumed for single-stage furnaces and boilers and calculated for two-stage and modulating appliances. For single-stage furnaces, on-time is 3.87 minutes and off-time is 13.3 minutes. For single-stage boilers, on-time is 9.68 minutes and off-time is 33.26 minutes.
5. Average indoor temperature of 70°F, which is used in calculations for flue and stack temperature changes in appliances that use ambient air for combustion.
6. Average outdoor temperature at which an appliance begins to operate of 65°F and an outdoor design temperature of 5°F. These numbers are used to find the balance-point temperature for modulating appliances, or the temperature used to apportion the annual heating load between the reduced cycling mode and the modulation or maximum cycle load.
7. Average annual heating degree-days of 5200. This is used in the final calculation to find AFUE.
8. Average non-heating-season hours per year of 4600. This is used in the final calculation to find AFUE.

Cold Climate Considerations

A number of the assumptions used in the AFUE calculations are for warmer climates than Alaska. These assumptions come from national averages. Using an average temperature rather than a more detailed summation method saves calculation time and can produce a nearly identical result. For instance, in (Chi & Kelly, 1978) the authors showed that using the average outside temperature in seasonal efficiency calculations can produce the same results as using a small number of weather bins (which average to the average outside temperature) in a summation analysis.

However, much of the average weather data does not match Alaska's climate. For instance, the average annual temperature used in the AFUE formula is 42°F, and the average heating degree days (HDD) are listed at 5200. The average annual temperature and HDD for some Alaskan locations are listed below (Alaska Climate Research Center, 2012):

Table 3: Weather data for selected Alaskan locations

Location	Average annual temperature (F)	HDD at 65°F
Anchorage	36.2	10470
Barrow	10.4	19674
Bethel	29.9	12769
Fairbanks	26.7	13980
Juneau	41.5	8574
Wasilla	36.8	10254

Of this list, only Juneau, with a climate representative of Southeast Alaska, has an annual temperature near 42°F, and it also has considerably more heating degree days (over 3000 more) than assumed in the AFUE calculation. Lower ambient temperatures act to decrease the AFUE because of the greater heat load for the building attributable to the infiltrating air drawn from the heating appliance. A larger number of HDD means that a location will likely have a higher ratio of indoor temperature to design temperature. This will act to increase the AFUE by increasing the fraction of time that the boiler operates under steady-state efficiency. Also, for modulating appliances, the assumed design temperature of 5°F in the AFUE calculations is higher than the design temperature in most of Alaska. The design temperature affects the balance point of the modulating system, or the temperature at which the modulating system used to apportion the annual heating load between the reduced cycling mode and the modulation or maximum cycle load. A lower design temperature will lower this balance point for Alaska appliances.

Unfortunately, weather data are used in both supporting calculations and the final formula for AFUE. There is no one multiplication factor that could be found to translate an existing AFUE to apply at a colder climate.

Other Variables Not Considered in AFUE

There are several other variables that AFUE does not account for in its testing and calculation procedure that can affect appliance efficiency. These can affect seasonal efficiency in any climate. Some examples are listed below.

Appliance Tuning

Standard 103 specifies how to tune the appliance, including parameters such as the CO_2 and operating temperatures. Installed appliances may not be tuned to the same specifications. For example, supply and return temperatures can affect the efficiency of an appliance. Figures 1 and 2 provide an illustration of the effects of water temperatures on condensing boiler efficiency. Return water temperature has a larger effect on the efficiency of condensing systems than on non-condensing systems, so a deviation from the AFUE value will make a difference in AFUE and installed efficiency for a condensing system. Standard 103 does contain calculations for boilers used with low-temperature applications, such as radiant floors, in an appendix. However, the inlet and outlet temperatures are still specified (inlet water temperature of 90-94°F and temperature rise of 19.5 - 20.5°F at steady-state operation) in the appendix, so this still does not encompass all operating temperatures.

Additionally, while appliance check-ups are recommended on an annual basis, not all homeowners maintain their appliance on a timely schedule. The yearly maintenance check-up is important because the heating contractor tunes the appliance for optimal efficiency.

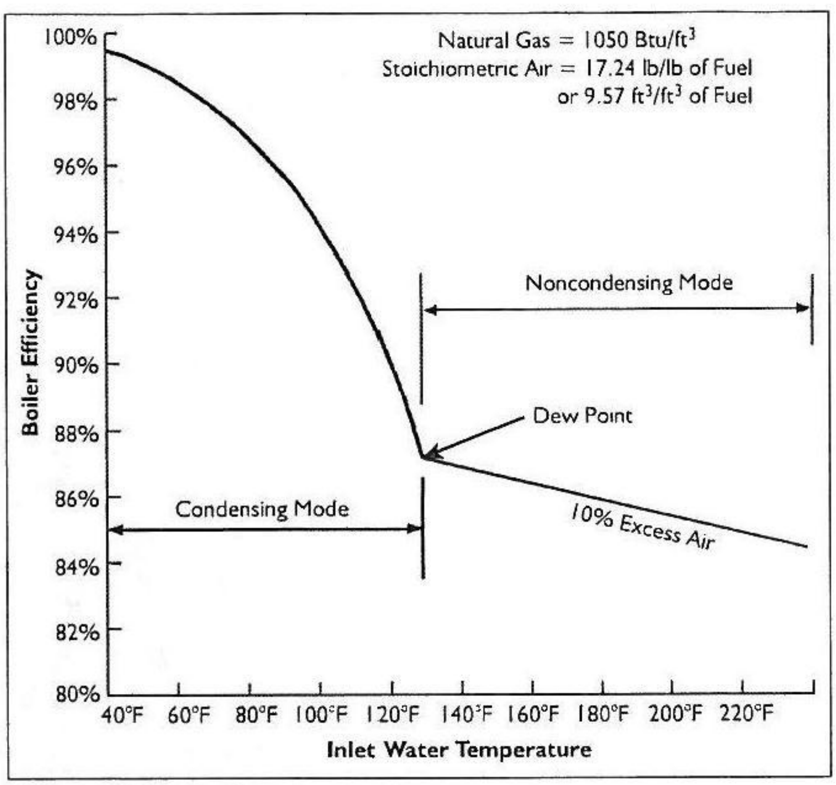

Figure 1: Effect of inlet water temperature on condensing boiler efficiency. Figure courtesy of (Durkin, 2006).

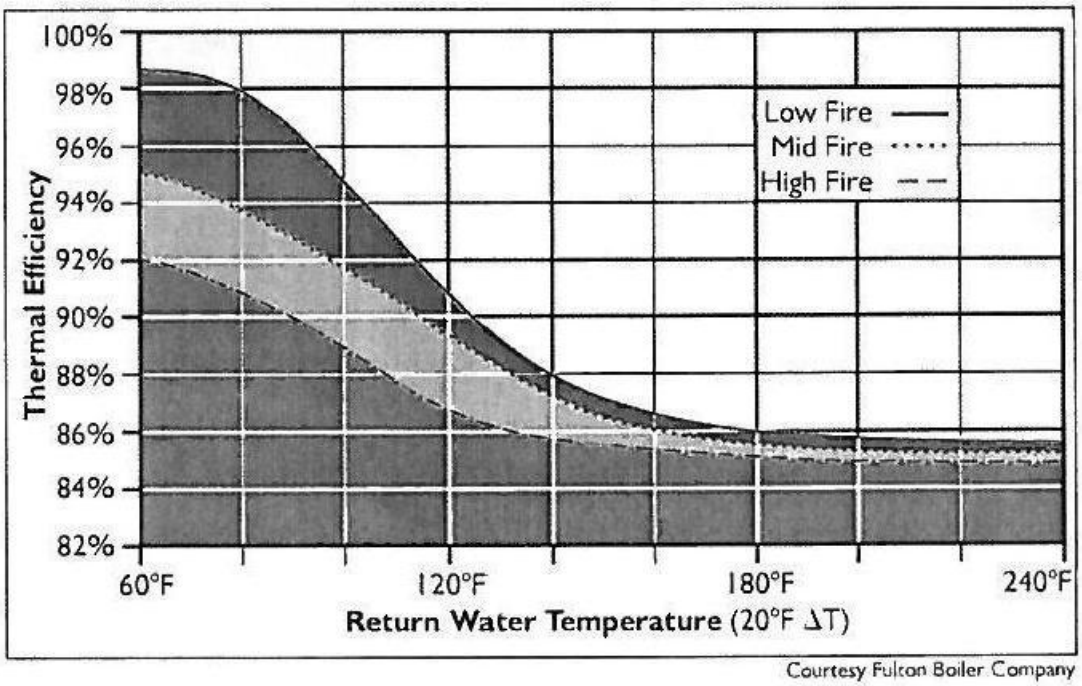

Figure 2: Effect of return water temperature on condensing boiler efficiency. Figure courtesy of (Durkin, 2006).

Fuel characteristics

Standard 103 specifies the characteristics of the natural gas or fuel oil to be used in the AFUE test for combustion appliances. Residential installations may not have access to the same quality of fuel. The fuel determines constants used in the AFUE calculation, such as the coefficients used to determine latent heat loss due to uncondensed water vapor in the flue gas. Using a different quality of fuel will cause deviation from the AFUE results.

Distribution system

The distribution system for the AFUE test is specified by the standard. Distribution systems with fewer or more leaks and different layouts will affect system efficiency. They can also affect the appliance efficiency. For instance, dirty filters and poor duct configuration can cause furnace blowers to move heat away from the appliance less efficiently than properly maintained and configured ducting.

Control system

AFUE specifies cycle times in its calculations and does not include provisions for alternate control systems. Many alternate control systems, such as outdoor reset controls and programmable thermostats, are used in cold climates, where the long heating season rewards any increase in heating system efficiency. These devices can be found in all climates as well. For instance, outdoor reset controls on boilers can taper supply water temperatures on boilers when the outdoor temperature is far above the design temperature, such as during the shoulder season. Programmable thermostats also are used to lower room temperature below 70°F when occupants are not home, decreasing the load on the heating appliance. Lastly, combination appliances may have a control system option to “go cold” in the summer when the appliance is only supplying domestic hot water and not space heating.

Oversize factor

AFUE uses an oversize factor of 70%, based on a national average. However, recent developments in software and sizing techniques have allowed installers to size appliances more in line with the Air Conditioners Contractors of America guidelines. A recent meeting of experts in residential furnaces recommended that an oversize factor of 40% would be more reflective of current installations (Brand, 2012). The oversize factor recommended for residential installation by the 2009 Alaska Building Energy Efficiency Standards (BEES) is 25% greater than the heating load, considerably less than 70%.

Combined heating and hot water

Some centralized appliances provide both space heating and domestic hot water (DHW). These appliances are typically a boiler with a “tankless” heat exchanger coil or an indirect DHW tank that is treated by the boiler as another zone. Currently, these appliances are only labeled with the space heating seasonal efficiency, or the AFUE. However, the AFUE is not indicative of the actual annual performance of the appliance when serving a combined space and domestic hot water function (Butcher, 2011). Unfortunately, there is not a federal labeling procedure for these types of appliance, in spite of a separate ASHRAE standard 124-2007, which contains a procedure for finding an annual efficiency for combined appliances.

Findings

It is important to remember the intent of AFUE, which is to compare the energy consumption of furnaces and boilers on a standardized basis. It isn't intended to be used as a predictive measure of performance for any single installation. In a residence, many factors unique to the installation affect the efficiency of the heating system, including the distribution system, the supply and return temperatures for the appliance, the control system, and the amount of maintenance the appliance receives. AFUE allows appliances to be compared under specific testing conditions, and installation particulars and appliance characteristics must be considered in addition to AFUE when choosing an appliance for a residence.

Unfortunately there is no simple modification to AFUE ratings that can be made to appliances already rated to account for different climates and installations. The calculations in Standard 103 involve multiple steps, with many steps building on previous ones. Also, data from testing AFUE of an individual appliance is not readily available. In order to recalculate the AFUE with changed average seasonal temperature, for instance, the testing data for the appliance would be necessary to finish the calculations.

Alternative methods to rating seasonal efficiency do exist, two of which are briefly discussed below. The first method, outlined in (Butcher, 2007) and (Butcher, 2011), is to take a set of direct input and output measurements for the appliance under different loads: full, partial, idle, space heating only, domestic hot water only, and combination. This set of measurements is then used to make a performance curve (input vs. output) for the device, as shown in Figure 3.

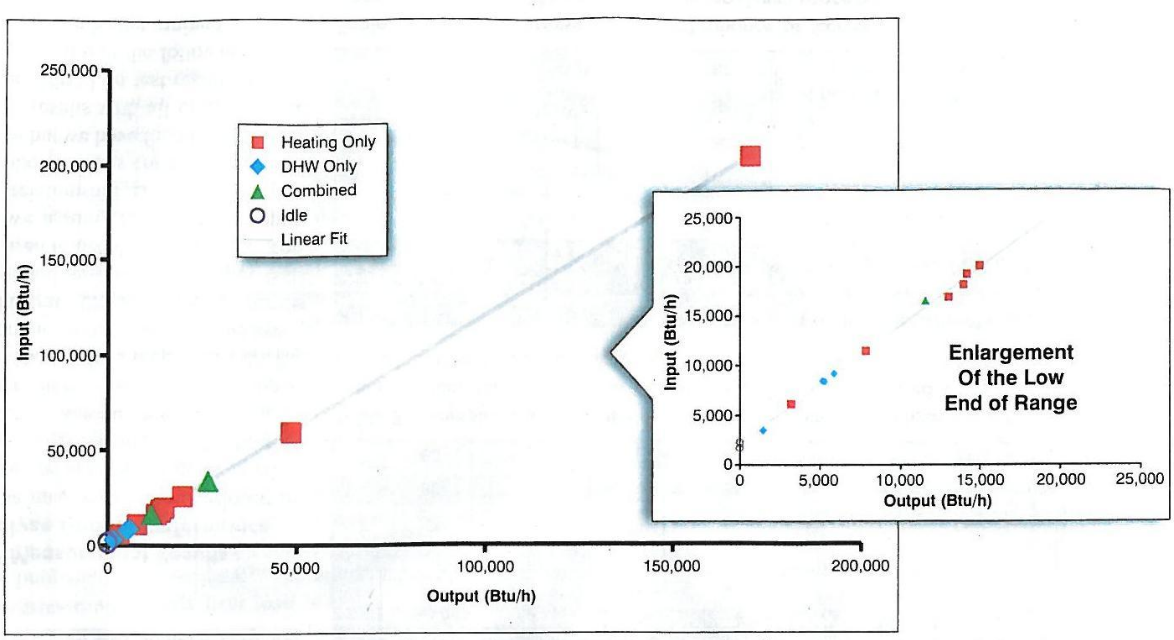

Figure 3: Input/output curve for a combination boiler with a tankless coil. Figure from (Butcher, 2011).

Annual performance can then be calculated for a specific system by a bin calculation using weather data or by using an hourly load calculation for a specific building. In many cases, the performance curve is nearly linear, meaning the system can be characterized by its steady state efficiency (or its input and output at full load) and the idle loss of the appliance. This approach works for space heating appliances, domestic hot water appliances, and combination appliances. Also, different curves can be made for different situations (control settings, oversize, and location). Ideally, a software tool could be developed to allow comparison of options for a given location. Such a tool could have the performance curves for several appliances, and options for installers to customize the seasonal efficiency to a specific installation.

John Siegenthaler, a hydronic heating engineer at Appropriate Designs in New York, has also recommended another approach to seasonal efficiency. He is currently studying the use of an analytical model of cycle efficiency as a function of duty cycle as a way to characterize an appliance. In the model, simulations are run with load and bin weather data to “sum” the effect of boiler efficiency variations over a heating season. The drivers for simulation are bin air temperature, load, control settings, and cycle efficiency (Siegenthaler, personal communication, July 26, 2012). Again, this method would involve a software tool that possibly could be made available to installers to customize seasonal efficiency to a particular installation.

Future Research

This section contains possible directions with which to pursue further research. Additional research should continue the investigation into making appliance ratings more applicable to different climate zones and specific installations.

1. According to Appendix A of Standard 103, there is a public domain computer program to aid in calculations available from the National Institute of Standards Technology (NIST). Researchers did not obtain this report as part of the current project. CCHRC could obtain this computer program to learn about it and explore the possibility of customizing it for individual installations and/or cold climates. For instance, the program may allow the user to modify some of the assumptions that are used when calculating AFUE.
2. Current research is focusing on seasonal efficiency testing methods that differ from AFUE. Two alternatives, one from Brookhaven National Lab and one from Appropriate Designs, are discussed in the previous section of this report. CCHRC could identify an alternative methodology and work in collaboration with the method's authors to produce a calculator that allows customization for combination appliances, climate, installation variables, supply and return temperature, and controls with the purpose of making the calculator available to residents of cold climates.
3. Should an alternative seasonal efficiency calculator be created (for instance, using the AFUE computer program or by collaborating with other researchers), CCHRC could work with heating appliance manufacturers to obtain testing data from the procedure in Standard 103. This data could be used as input to an alternative methodology to obtain a new seasonal efficiency. Alternatively, CCHRC could work with the energy rating program in Alaska, AkWarm, to research a method to use AkWarm to calculate a more accurate installed seasonal efficiency using inputs specific to the appliance location and building.
4. CCHRC could implement a monitoring program to measure seasonal efficiency in the field and compare the results with AFUE ratings and seasonal efficiencies calculated from alternative methods.
5. The AFUE standard comes under review every 5 years. CCHRC could send a representative to technical meetings as part of this review, and participate in the review phase by sharing relevant research or concerns.

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Brand, L. (2012). *Expert Meeting Report: Achieving the Best Installed Performance from High Efficiency Residential Gas Furnaces*. Des Plaines, IL: Partnership for Advanced Residential Retrofit

These notes from an expert meeting of industry experts, researchers, manufacturers, installers, and policy-makers cover the key points of each presentation. The goals of the meeting were to identify the best installation practices for high efficiency, explain how AFUE and field efficiency can differ, and investigate the impact of installation practices on the efficiency and durability of the appliance.

Butcher, T. (2007). *Performance of Integrated Hydronic Heating Systems*. Upton, NY: Brookhaven National Laboratory.

This report describes a project done by the Brookhaven National Lab. The project aimed to provide decision tools to consumers of space heating and DHW appliances by testing several types of systems. Researchers developed performance curves for the appliances and used the curves to predict energy use.

Butcher, T. (2011). Performance of Combination Hydronic Systems. *ASHRAE Journal*, *53*, 36-41.

The journal article provides a summary of a study done on the efficiency of combination hydronic systems. The author discusses the different methods of heating space and domestic hot water and the efficiency tests which are used to indicate system performance. The performance of combination systems is then estimated by first establishing an input/output curve for each appliance through testing. There is also a discussion on the parameters that affect the performance of the appliance, including the idle loss, and steady state efficiency.

Caron, R. & Wilson, R. (1983). Water heating efficiency of integrated systems designed for space and water heating (paper number AC-83-01). *ASHRAE Transactions, 89*, 18-29.

In this article, researchers present the test method and results of a field test on the water-heating performance of combination systems. Combination systems, conventional water heaters, and energy-conserving conventional water heaters were tested in residences. The water-heating efficiency of the combined appliances was found to be in the range of 49-54%.

Chi, J. & Kelly, G. (1978). A method for estimating the seasonal performance of residential gas and oil-fired heating systems (paper number AT-78-1). *ASHRAE Transactions*, *84*, 405-421.

In this article that predates the AFUE standard, the authors discuss a test procedure for estimating the seasonal efficiency of a gas- or oil-fired furnace. The procedure involves obtaining test data during warm-up, steady state operation, and cool-down and then performing calculations to use this data to obtain a seasonal efficiency. The article includes example calculations.

Durkin, T. (2006). Boiler System Efficiency. *ASHRAE Journal*, *48*, 51-57.

This article examines boiler efficiency ratings in light of rising fuel prices. It explains the difference in the various ratings, factors that affect boiler efficiency, and the economics of improving industry heating standards.

Kweller, E. (1992). Derivation of the combined annual efficiency of space/water heaters in ASHRAE Standard 124-1991 (paper number AN-92-2-2). *ASHRAE Transactions*, *98*(1), 665-675.

This paper presents an overview of ASHRAE Standard 124-1991 (note that this standard is currently 124-2007). The standard provides the procedure and calculations for measuring the annual efficiency of residential combined space and water heaters. It reviews the history of the standard, the efficiency test, and the factors that affect the combined efficiency. It also includes a sample calculation.

Pigg, S. & Parkhurst, R. (2007). *Investigation of High Efficiency Furnace SSE Measurement versus AFUE*. Madison: Wisconsin Division of Administration and Wisconsin Division of Energy Services

This research paper is a summary of an investigation of the measured SSE of gas furnaces that were installed as part of the Wisconsin Weatherization program. The investigation tested 9 furnaces which had previously had a SSE test where the SSE was below the rated AFUE. The findings are discussed in the report (many involve inaccuracies in the field SSE test) and the authors suggest improvements that can be made to the field SSE test to make it more accurate.

Subherwal, B.R. (1986). Combination Water-Heating/Space-Heating Appliance Performance (paper number PO-86-09). *ASHRAE Transactions, 92*, 415-432.

This paper documents a study on the efficiency of combination space and water heating appliances. The study consisted of laboratory tests and field tests at six residential sites during the heating and non-heating seasons. The researchers concluded that in all field tests, the heating appliance provided adequate hot water for space-heating and water-heating needs. Also, the water heating efficiency was higher for each appliance during the heating season, due to the higher use of hot water during that time.

Walker, I. (2008). Comparing residential furnace blowers for rating and installed performance (paper number NY-08-025). *ASHRAE Transactions*, *114*, 187-195.

This paper describes a study to assess the performance of residential furnace blowers for heating, cooling, and air distribution. The researchers also compare rated vs. actual performance.

Wise, R. & Kweller, E. (1986). Part-load, seasonal efficiency test procedure evaluation of furnace cycle controllers (paper number PO-86-13). *ASHRAE Transactions, 92*, 674-684.

This paper documents a test method developed to test the efficiency of furnaces under various cycling conditions, including furnaces with cycle controllers. The authors describe the cycle controllers, describe the efficiency test procedure and analysis, and discuss the results. They conclude that using the test method is not a viable alternative to AFUE because the test method is more difficult to perform and replicate, changing methods would necessitate retesting of all furnaces, and because changes in efficiency due to cycle controllers were too small to justify such a change.