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Measure Guideline: High Efficiency Natural Gas Furnaces

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Partnership for Advanced Residential Retrofit

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Definitions

ACCA	Air Conditioning Contractors of America
AFUE	Annual Fuel Utilization Efficiency
ANSI	American National Standards Institute
DOE	Department of Energy
ECM	Electronically Commutated Permanent Magnet
EIA	Energy Information Administration
ESP	External Static Pressure
HVAC	Heating, Ventilation and Air Conditioning
MERV	Minimum Efficiency Reporting Value
NATE	North American Technician Excellence
NEC	National Electrical Code
NFPA	National Fire Protection Association
PSC	Permanent Split Capacitance

Executive Summary

The single largest consumer of energy in most homes is the heating and cooling system; in colder climates, energy consumption for space heating is predominant. A home energy audit is a good way to evaluate the performance of the thermal envelope and heating and cooling system, and identify the improvements that can be made to reduce energy costs. Common recommended energy-efficiency measures include sealing air leaks, adding insulation to the attic, and upgrading the heating and cooling system to higher efficiency equipment. For homes with gas-fired warm air furnaces, this could mean replacing an existing 70% to 80% Annual Fuel Utilization Efficiency (AFUE) furnace with a high efficiency furnace in the 90% to 98% AFUE range. A home energy auditor will calculate the energy savings and the payback period for investing in this upgrade, but it is often cost justified, especially when utility rebates or tax incentives are offered. In new construction, a similar energy savings and payback analysis is performed by the builder, and the new home buyer is offered several upgrade packages for consideration.

This Measure Guideline covers installation of high efficiency gas furnaces. Topics include: when to install a high efficiency gas furnace as a retrofit measure; how to identify and address risks; and the steps to be used in the selection and installation process. The guideline is written for Building America practitioners and HVAC contractors and installers. It includes a compilation of information provided by manufacturers, researchers, and the U.S. Department of Energy (DOE), as well as recent research results from the Partnership for Advanced Residential Retrofit (PARR) Building America team. Content that can be shared with homeowners is written in a way that can be understood by that audience.

Proper installation of a high efficiency gas furnace requires attention to many details and interconnecting systems: heating capacity (sizing), consideration for duct distribution systems, gas piping, vent systems, provision for combustion air, flue gas condensate disposal, electrical connection requirements, provision for forced-air cooling (as required), air filtering equipment, and humidification requirements. These factors and others are discussed in this guideline.

Key recommendations supported by the research include: use of direct vent systems (outdoor air for combustion); proper sizing of duct distribution systems to avoid high static pressure that causes high fan power usage and a drop-in installed AFUE in some cases; and proper furnace sizing to reduce cycling and improve comfort in the space. The advantages and disadvantages of the three standard types of high efficiency furnaces are also addressed.

Further detail on specific topics is available in the manufacturer’s installation instructions. Installation should only be performed by a trained professional and in accordance with manufacturer’s installation instructions and local codes.

1 Home Inspection

Installing a high efficiency gas furnace in a home is a straightforward process in both new construction, where provision has been made for required services, and in an existing home as a replacement. Always inspect the home before installing the equipment to identify and mitigate risks from poor construction practice, identify necessary changes in other equipment associated with the existing furnace, verify correct vent terminal clearances to doors, windows, and outside air intakes per code and manufacturer requirements, and inspect for deterioration of existing systems. If left uncorrected, these risks may impact proper operation of the equipment or create an unsafe environment for the occupant. If the installation of the high efficiency furnace is part of a whole home energy upgrade, homeowners should use a RESNET or BPI-certified auditor to conduct the initial home inspection. If the installation is not part of a whole home audit, the homeowner should use a reputable HVAC contractor with accredited HVAC technicians (NATE, for example) for the installation.

The home inspection for natural gas high efficiency furnaces should focus on health, safety, and durability of the installation. In the general case, gas furnaces require installation with proper clearance to combustibles, an unconfined space in some cases, provision for combustion air and flue gas vent systems, and clearance to neighboring buildings if sidewall venting is used. Special retrofit situations may require relining of masonry chimneys if the furnace is removed from a common vent system with another atmospheric appliance. Refer to Section 3, Field Inspection, for more information.

Installation should be performed by a trained and qualified contractor. Local construction codes, national building codes, and the manufacturer's installation instructions should be consulted as a part of the home inspection process. Table 1 provides common risks and mitigation strategies to consider for the home inspection.

Table 1. Common Risks and Mitigation Strategies

If this risk is present	Then take this action	To improve
Failure of existing vent system, blocked masonry chimney, CO alarm sounding	Shut down the affected equipment, ventilate the house, and contact a service technician immediately	Health and Safety
Existing equipment overheats the home while the burner is operating or cycles on and off excessively (more frequently than 6-10 times per hour)	Consider a lower capacity replacement system. Consult a sizing tool such as ACCA Manual J or equivalent.	Durability and Performance
Existing system to be replaced is common-vented with another appliance through a masonry chimney	Consult an accredited HVAC technician or review the masonry chimney relining guidelines in the International Fuel Gas Code	Safety and Durability

If this risk is present	Then take this action	To improve
Leaky and undersized ductwork	Seal the existing ductwork if leaky or analyze using ACCA Manual D or equivalent and replace.	Comfort and Performance
Ducts outside the conditioned space	Insulate ducts outside the conditioned space (ventilated attics or crawl spaces and garages), seal connections with mastic, and relocate the ducts inside the conditioned space.	Performance, Safety, and Indoor Air Quality

2 Tradeoffs

2.1 Measure Selection Criteria

Space heating in residential buildings can be accomplished by several hardware options, including: natural or propane gas furnaces, hydronic heating systems (steam and hot water boilers), electric heat pumps, combination heating and hot water systems, and electric baseboard heating systems. The alternatives to the high efficiency natural gas furnace are other devices that use the same ducted air distribution systems such as electric heat pumps and combination heating and hot water systems where lower capacity is an acceptable option. Energy prices and heating loads can vary significantly by climate, so a detailed load analysis and energy calculation should be performed by an auditor to determine the cost-effectiveness of alternate systems. The U.S. Department of Energy (DOE) Energy Information Administration (DOE EIA) provides a calculator to use when comparing energy costs across fuels and equipment types and climates. A link to the DOE EIA Energy Cost Calculator is included in the references.

Within the natural gas furnace family, there are two types of equipment to choose from. mid-efficiency furnaces have an Annual Fuel Utilization Efficiency (AFUE) of 80%-83%, and high efficiency furnaces have an AFUE of 90%-98%. The tradeoff between these two options is provided in section 2.2 below, Cost and Performance. The National Appliance Energy Conservation Act limits the minimum efficiency of natural gas furnaces to 80% AFUE when tested according to the DOE standard (Title 10, Code of Federal Regulations).

High efficiency gas furnaces may provide benefits beyond energy cost savings to the homeowner when compared to other equipment that use ducted air distribution systems such as electric heat pumps or combination heating and hot water systems (combo systems). When compared to electric heat pumps, these benefits may include higher delivered air temperature, insensitivity to outdoor weather conditions, and higher capacities to match the load in older homes. Gas furnaces are typically sized to provide a 50°F rise in air temperature from return to supply, or 120°F supply air temperature under all outdoor conditions. Electric heat pumps may require supplemental resistance heat to provide the same level of comfort, especially in cold climates, although new electric heat pumps are under development that may provide the same delivered air temperature. When compared to combo systems, these benefits may include the availability of higher capacity equipment and constant heating capacity when there is coincident water heating demand. Combination heating and hot water systems may offer the same level of comfort, but the control systems generally support the domestic water heating load when there is coincident demand. Cost and performance tradeoffs within the measure are provided in section 2.2, below.

High efficiency gas furnaces have limited interaction with the thermal envelope but significant interaction with central space cooling (air conditioning) equipment, humidifiers, air cleaners, and the air distribution system (ductwork). Selecting the right furnace capacity for the application, properly designing the distribution systems, and selecting the correct fan speed settings on the furnace blower will provide seamless interaction between the furnace and the other systems.

Furnace interaction with the thermal envelope typically takes the form of increasing infiltration (if the direct vent option is not supported), heat losses through the enclosure and interactions with the distribution system that can lead to duct leakage outside the conditioned space. High efficiency furnaces use about 10 cubic ft. of air for every cubic ft. of gas burned, or about 13 cfm of air for the typical 80,000 Btu/hr furnace. The increase in heating load associated with the increase in infiltration, if outdoor air for combustion is not used, is on the order of 1% in cold climates, or about 800 Btu/hr in this example. In addition, furnaces that use indoor air for combustion may be competing with draft-hood equipped appliances, dryers, range hoods, fireplaces, and ventilation systems for air, resulting in nuisance heat outages. For this reason, direct vent systems are strongly recommended in this Measure Guideline for furnaces installed within the conditioned space.

In the case of distribution system interactions, the furnace circulating air blower speed (for PSC motors) is selected according to the manufacturer's installation instructions to match the equipment heating and cooling capacity. Separate wiring connections on the control board are used for heating and cooling fan speeds. For heating fan speed selection, consult the manufacturer's installation instruction—fan speeds are selected according to the capacity of the furnace. For cooling, manufacturers will recommend a cooling fan speed according to the capacity of the cooling system. Furnace fans are designed to work against an external static pressure (ESP) at rated flow in the distribution system. This pressure is typically 0.5 to 1.0 inches of water column (125 to 250 Pa), though some practitioners design for significantly lower numbers (Chitwood and Harriman, 2010).

Other distribution systems interactions related to the tightness of ducts and location of ducts within the conditioned space are addressed elsewhere in *Building America Best Practices Series 10 - Retrofit Techniques and Technologies, Air Sealing*, and in other Measure Guidelines. Good design practice is duct leakage of no more than 50 cfm at 25 Pascals (0.1 inches of water column) test pressure (Chitwood and Harriman, 2010).

2.2 Cost and Performance

High efficiency gas furnaces, sometimes referred to as condensing furnaces, condense the water vapor from the flue gases and return the latent heat of vaporization to the circulating air in the form of sensible heat. There are several basic options within the high efficiency gas furnace family that offer cost and performance tradeoffs to the homeowner. The principal option is the selection of the furnace AFUE in a range between 90% and 98%. There are three common product categories, differentiated by efficiency and circulating air blower control (AFUE ranges approximate):

1. Single-stage furnace with blower motor operating at a single speed, generally 90% to 92% AFUE
2. Two-stage furnace with blower motor operating at multiple speeds, can range from 92% to 96% AFUE
3. Step modulating furnace with variable-speed (electronically commutated permanent magnet (ECM) or multitap permanent split capacitance) blower motor, can range from 96% to 98% AFUE.

The higher efficiency products command a higher market price as they offer improved comfort features as well as energy cost savings. High efficiency furnaces with step modulating and multispeed blowers modulate the furnace capacity and circulating air volume to match the heating load of the home under varying weather conditions.

Figure 1 shows that electronically commutated permanent magnet motors (also known as brushless DC motors) are twice as efficient at moving air as the standard permanent split capacitance motors. Induction motors are not commonly used in warm-air furnaces.

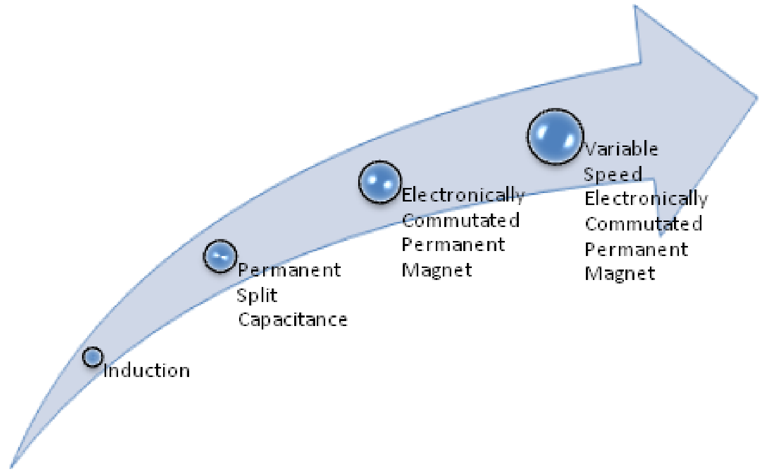

Figure 1. Electric motor options by increasing efficiency

Furnaces are typically sized to meet the maximum heating load of the home, using a multiplier from 1.4 (ACCA Manual S) to 1.7 (ASHRAE 103) to provide for recovery from setback at design conditions. For example, a house with a calculated heating load of 62,000 Btu/hr at design conditions in Minneapolis (-11°F) may be sized for 80,000 Btu/hr with a multiplier of 1.3. The key advantage of step modulating burners and variable speed blowers is realized during periods where the required capacity is less than the design condition, i.e., the outdoor temperature is greater than -11°F in the Minneapolis example. The modulating furnace will vary its capacity to 30% to 40% of maximum input and reduce the fan speed accordingly to avoid rapidly overheating the space. A secondary advantage to modulating systems is that furnace fans will operate longer in each cycle and provide more even air temperatures in the home.

The installed cost for high efficiency furnaces can vary significantly, depending on the complexity of the installation: presence of existing cooling system, central humidifier, electronic air cleaner, pleated filter box, distance to vent termination, and condensate disposal location. Table 2, below, provides average installed cost information for residential furnaces and the incremental cost for upgrading the efficiency (National Residential Efficiency Measures Database, 2010). Installed cost and incremental cost are calculated using a typical 80,000 Btu/hr furnace:

Table 2. Average Furnace Replacement Cost

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

For a home with a $1000 annual heating cost, the standard payback for upgrading from 78% AFUE to 90% AFUE is approximately 9 years. With a $500 utility rebate and federal tax credit of 25%, for example, the payback can be reduced to 5 years. The actual payback will depend on the heating load, energy costs, rebates available, current tax incentives, and local market conditions. Table 3, below provides annual energy cost savings for various furnace efficiency upgrades (DOE EERE).

Table 3. Annual Estimated Savings for Increasing Efficiency (Source: DOE EERE)

Annual Estimated Savings for Every $100 of Fuel Costs by Increasing Your Heating Equipment Efficiency									
Existing System AFUE	**New/Upgraded System AFUE**								
	55%	**60%**	**65%**	**70%**	**75%**	**80%**	**85%**	**90%**	**95%**
50%	$9.09	$16.76	$23.07	$28.57	$33.33	$37.50	$41.24	$44.24	$47.36
55%	----	$8.33	$15.38	$21.42	$26.66	$31.20	$35.29	$38.88	$42.10
60%	----	----	$7.69	$14.28	$20.00	$25.00	$29.41	$33.33	$37.80
65%	----	----	----	$7.14	$13.33	$18.75	$23.52	$27.77	$31.57
70%	----	----	----	----	$6.66	$12.50	$17.64	$22.22	$26.32
75%	----	----	----	----	----	$6.50	$11.76	$16.66	$21.10
80%	----	----	----	----	----	----	$5.88	$11.11	$15.80
85%	----	----	----	----	----	----	----	$5.55	$10.50
90%	----	----	----	----	----	----	----	----	$5.30

2.3 Summary of Research

PARR conducted laboratory-based research on the AFUE of high efficiency furnaces that were significantly oversized or with high external static pressure (undersized ducts, high pressure drop coils, dirty or high efficiency filters) to determine if those factors would influence installed performance. The research results are summarized below and in Appendix D.

The research suggests that high efficiency furnace AFUE is insensitive to oversizing based on lab testing in the 70% to 120% oversizing range and that AFUE is slightly reduced with high external static pressure (above 0.5 inches of water column) for single-stage furnaces with PSC motors. The power to operate the circulating air blower increases slightly for step modulating furnaces installed in high external static situations, but decreases slightly for furnaces with PSC motors under those circumstances.

Implications for furnace replacements are that furnaces should be sized as small as possible to match the duct size or the ducts should be replaced if a higher furnace capacity is required. Some practitioners recommend replacing the ducts if the furnace capacity is significantly reduced to increase air velocity and improve comfort in the space (Chitwood and Harriman, 2010).

Modulating furnace and two-stage furnace AFUE are less sensitive to undersized ducts and are therefore a better choice than single-stage high efficiency furnaces in those situations.

3 Measure Implementation Details

3.1 Field Inspection

A thorough field inspection before installation will produce a better result than making adjustments for problems found during the installation. Since the duct system is an integral part of a furnace installation, in addition to the steps outlined below, ducts should be sized to meet the air flow requirements of the system (using ACCA Manual D or equivalent) and sealed to reduce leakage.

There are seven steps to furnace field inspection:

1. Safety first
2. Determine that sufficient combustion air is available (ANSI z223.1, 2012) or use a direct vent system
3. Determine that the vent terminal (exhaust) can be located according to manufacturers' installation instructions
4. Determine that a suitable condensate disposal drain is available
5. Determine that there is proper clearance to combustibles
6. Inspect for a common vented appliances that will require a change in its vent system
7. Exercise caution installing furnaces in ventilated attics where freezing can occur.

Step 1 – Safety first

In the case of a retrofit, check the existing furnace to determine if the vent system is performing as designed. Missing vent pipes, visible deterioration of the vent system, or flue gas discharge into the home, are safety issues that should be addressed immediately. In the case of common vented systems, the draft hood of each appliance should be tested with a smoke pen to determine if excessive spillage is occurring. Generally, this is spillage that occurs for more than 60 seconds after ignition. If this occurs, shut off the power to the furnace and contact a qualified service technician or take the appropriate action. Once safety is addressed, then proceed to Step 2.

Step 2 – Determine that sufficient combustion air is available (ANSI z223.1, 2012) or use a direct vent system

Not all manufacturers require piping outdoor air for combustion into the furnace in the installation instructions; however, it is considered a best practice by the Building America program, which recommends that high efficiency furnaces are installed with this technique. A suitable location for the supply terminal must be found on the exterior of the building that will not draw in combustion air from the flue gas stream. Some local codes also restrict vent terminals on the sides of buildings. Manufacturers require furnaces installed in garages to have outdoor air for combustion to avoid a possible heat exchanger failure due to accelerated corrosion from paint and solvents. Furnaces installed in ventilated attics (see Step 7) may not require additional combustion air piping to the outdoors. The installer should determine if a suitable location is available for drawing combustion air. If combustion air from the space is used (other-than-direct-vent method), provisions in the code (ANSI z223.1, 2012) related to confined spaces and number and size of ventilation openings must be consulted.

Step 3 – Determine that the vent terminal (exhaust) can be located according to manufacturers' installation instructions

Vent terminals may not be located near windows and doors or near the combustion air intake opening according to the manufacturer's installation instructions. Sidewall vents are prohibited in some jurisdictions for aesthetic reasons and the possibility of venting into an opening in an adjacent building. In some colder regions, sidewall venting is prohibited by local code to avoid ice formation on adjacent buildings if the separation between buildings is too narrow. Using the largest diameter vent pipe allowed by the manufacturer reduces this effect. Local codes should be consulted before the inspection. At the end of this step, the inspector should have identified a suitable vent terminal location.

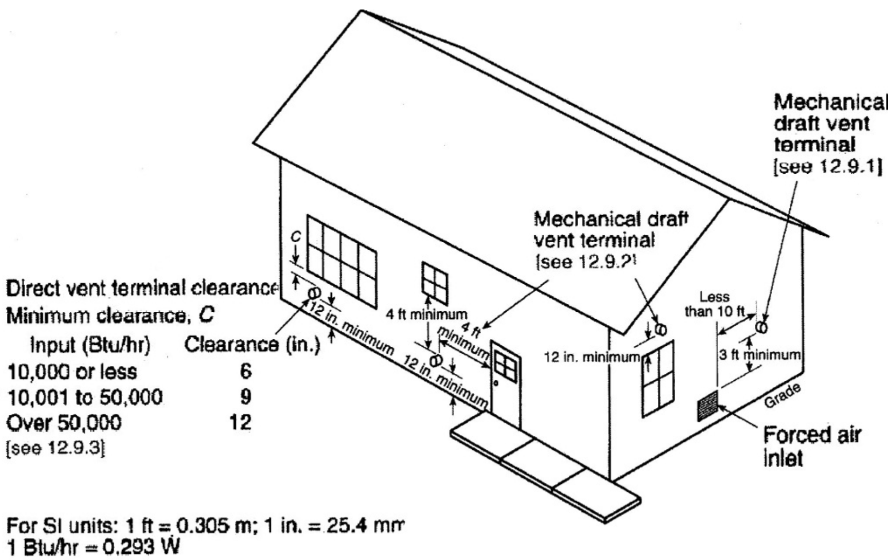

Figure 2. Combustion air and vent terminal locations (Source: 2012 National Fuel Gas Code, Copyright American Gas Association. Used with Permission.)

Step 4 – Determine that a suitable condensate disposal drain is available

High efficiency furnaces produce condensate from condensing water from the flue gases as the temperature drops below the dew point. Several other minor constituents are present in the condensate, but there are no restrictions from draining flue gas condensate into residential drains. The inspector should look for the availability of a gravity drain below the level of the condensate trap in the furnace. If a humidifier or air conditioning system is also installed, this drain can be used for all three purposes. If a gravity drain is not available, a condensate pump can be used to pump condensate to a higher drain. In cold climates, flue gas condensate should only be drained into the house sanitary drain system, never outdoors. Other local codes may restrict how flue gas condensate systems can be drained. For furnaces installed in attics in cold climates, see Step 7.

At the end of this step, the inspector should be sure that a suitable condensate disposal drain is available.

Step 5 – Determine that there is proper clearance to combustibles

Manufacturers' installation instructions require proper clearance to combustibles for both the furnace and the first few feet of the duct distribution system. The manufacturer's installation instructions or ANSI z223.1 should be consulted. At the end of this step, the inspector should confirm that there is proper clearance to combustibles.

Step 6 – Inspect for common vented appliances that will require a change in the vent system

In replacement situations, there may be another appliance sharing the same vertical vent as the furnace to be replaced; see Figure 3. When the furnace is removed, the vent system (vent connector and vertical vent) for the remaining appliance must be reviewed according to the venting tables in ANSI z223.1. In general, Type B Gas Vent systems will not require significant modifications with draft-hood equipped appliances, but exterior masonry chimneys will require relining, as shown in Figure 4. Failure to consider the existing vent system modifications will underestimate the cost of the replacement, or cause deterioration and failure of the existing Type B Gas Vent system or masonry chimney. At the end of this step, the inspector should determine if the vent system for remaining appliances requires modification.

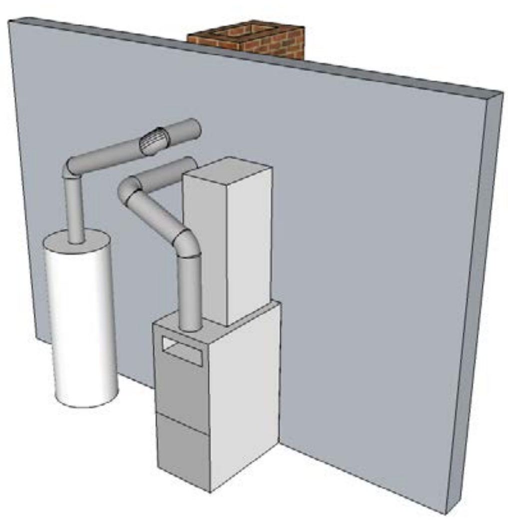

Figure 3. Before replacement

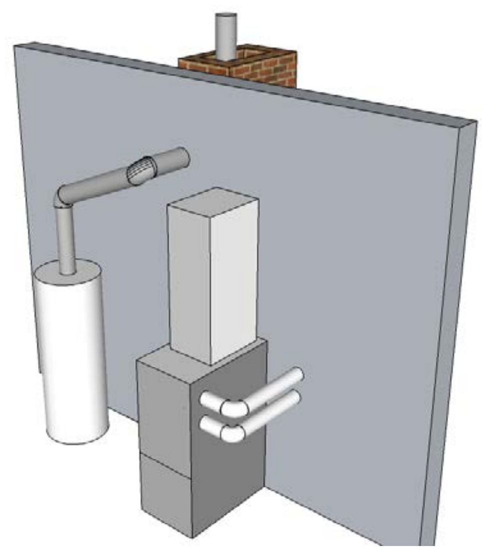

Figure 4. After replacement; note the chimney liner

Step 7 - Exercise caution installing furnaces in ventilated attics where freezing can occur

Installing gas furnaces in attics is a common practice in many areas of the country where climates are mild, and slab-on-grade construction is used. The mid-efficiency furnaces typically installed in those homes are now being replaced by high efficiency furnaces both in new construction and replacement. In ventilated attics, manufacturers recommend that condensate drainage systems should be weatherized where temperatures in the attic can drop below 32°F. Weatherization includes the use of heat tape and insulation on condensate traps and drain lines. In addition, drain lines should be as short as possible in the attic, may be run under the insulation, and should terminate in the conditioned space. Failure to follow these recommendations could result in leakage of condensate into the space below from frozen and burst pipes, and a service call to restart the furnace, especially where power outages occur in cold weather. The inspector should look for the availability of a heat tape power outlet in the attic and provision for a condensate drain as close as possible to the furnace in the living space.

Figure 5. Heat tape on a condensate trap

Here are a few other considerations and options for installing furnaces in attics in cold climates. Central humidifier water supply and drain lines and air conditioning condensate lines can also freeze in unventilated attics in cold climates, especially if there is a power outage. Weatherization of those lines should also be considered. Better yet, build a well-insulated heated space in the attic for the furnace, humidifier, and drainage systems to eliminate the heat tape electric energy load, and avoid the potential for damage to the living space below.

3.2 Installation Procedure

High efficiency furnaces are available in several configurations: upflow, downflow, horizontal left, and horizontal right. Some units can only be installed in one orientation, and some (multipoise) furnaces can be installed in two or more orientations. Select the correct model for the job.

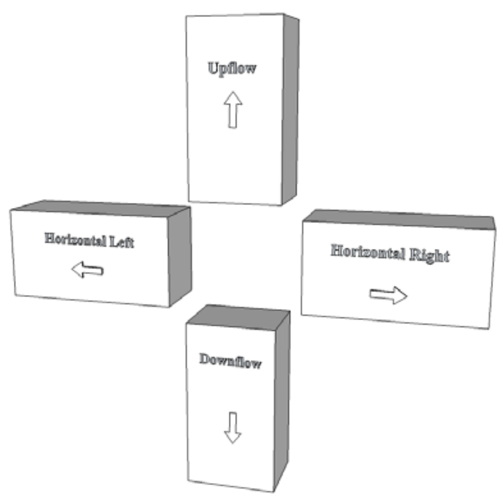

Figure 6. Furnace orientation

The duct distribution system should already be in place. Replacing an existing furnace commonly requires modifications to the distribution system for the new furnace height and depth. New transition pieces should be fabricated based on the new furnace dimensions and the size of the openings. Consideration should be made for the existing cooling coil in a replacement if the cooling coil is not going to be replaced. The existing humidifier or electronic air cleaner should also be considered when new duct transition pieces are built.

This guideline addresses only the furnace replacement steps. Refer to the cooling system or humidifier manufacturers' installation instructions to replace those devices.

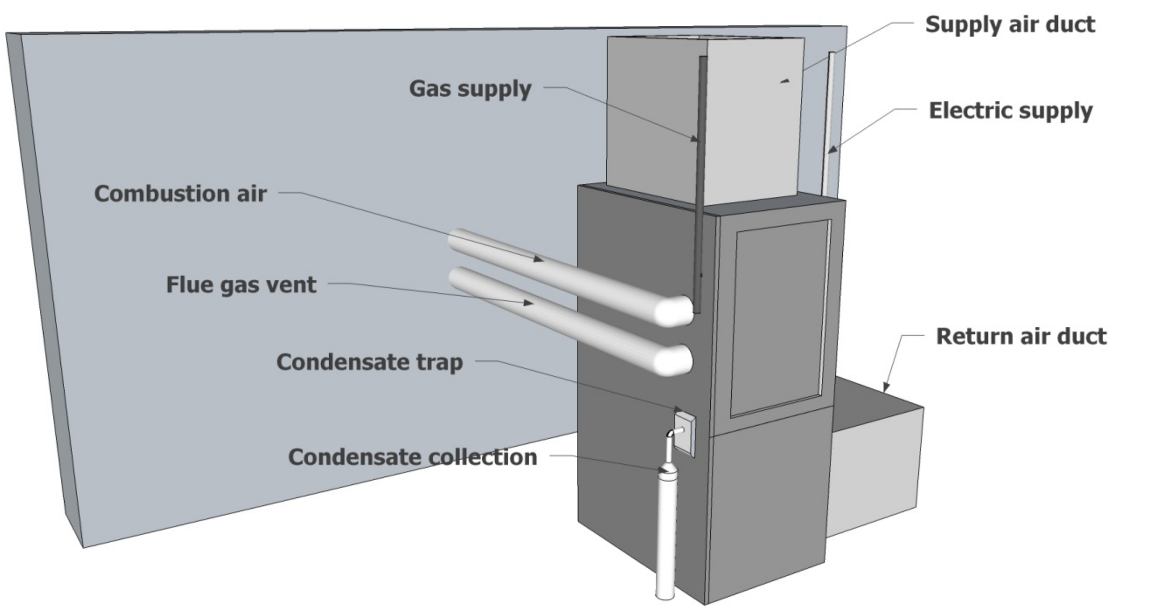

Figure 7. High efficiency furnace components

The basic installation steps are as follows:

1. Remove the existing furnace
2. Cut the left or right side return air opening in the furnace or remove the cover from the bottom opening
3. Prepare a platform and drain pan for furnaces installed in attics
4. Install the furnace
5. Attach ducts
6. Connect the furnace wiring to the proper fan speed settings on the control board
7. Connect the gas piping
8. Connect the condensate trap to the drain (include air conditioning condensate system and humidifier condensate system as appropriate)
9. Make electrical connections

10. Connect the combustion air and vent piping for remaining appliances where common vent was disconnected
11. Connect the thermostat
12. Complete testing per manufacturer's instructions. Verify the safe operation of existing natural draft equipment when existing vent system has been modified.

Additional detail follows:

Step 1 - Remove the existing furnace

Disconnect the existing furnace from the power source, gas supply, vent system and ductwork and remove it. If an existing air conditioning evaporator coil is going to be removed, the refrigerant should be recovered first. The existing furnace may have a flexible chimney liner that may be needed for a common-vented water heater.

Figure 8. The existing furnace may have a flexible chimney liner

Step 2 - Cut the left or right side return air opening in the furnace or remove the cover from the bottom opening

Most furnaces are shipped with a removable bottom pan for return air from below. If the installation includes a left or right side return, the bottom pan will be left in place and a return air opening will be cut in the left or right of the blower compartment to match the size of the ductwork or filter cabinet dimensions.

Figure 9. Attic installations are typically horizontal left or right

Step 3 - Prepare a platform and drain pan for furnaces installed in attics

For furnaces installed in attics, a plywood working platform should be built. Most manufacturers recommend a drain pan to protect the home from condensate or humidifier leaks. The furnace can be installed in an upflow, horizontal right, or horizontal left orientation. For horizontal installations, allow space for the condensate trap and drain line to be installed below the furnace. When replacing a mid-efficiency furnace or in new construction, a suitable drain inside the building should be identified and provision for running the pipe below the insulation should be made. For cold climates, a suitable power supply for heat tape should also be identified. See Field Inspection, Step 7.

Step 4 - Install the furnace

Set the furnace in place and check for suitable clearances, duct connector sizes, gas supply, vent system routing, space for the filter housing, condensate drain, and power supply.

Figure 10. All services may be connected on the same side of the furnace

Step 5 - Attach ducts

Replace the air conditioner evaporator and attach ducts to the furnace following manufacturer's instructions. Supply and return ducts should be sealed tightly to the furnace cabinet.

Step 6 - Connect the furnace wiring to the proper fan speed settings on the control board

Select the proper heating and cooling fan speed using the manufacturer's installation instructions and change the location of the connectors on the control board to match the fan selection.

Step 7 - Connect the gas piping

Connect the gas piping and test the connection with a soap and water solution or commercial leak testing product to make sure there are no leaks.

Step 8 - Connect the condensate trap to the drain (include air conditioning condensate system and humidifier condensate system as appropriate)

Move the condensate trap to the proper location depending on the orientation of the furnace. Tubes connecting the condensate trap to the inducer fan housing inside the furnace may need to be relocated. In some furnaces, tubing may need to be capped and other tubes will be connected. Check the manufacturer's installation instructions for details.

Figure 11. Condensate traps are gravity fed, the inlets must always be on the top

Connect the condensate trap outlet to a suitable open drain.

Wrap heat tape around the trap and condensate lines if the furnace is installed outside the conditioned space in a cold climate. A heat tape controller that deactivates the heat tape above 40°F ambient temperature is recommended.

Some furnaces are designed with multiple internal and external locations for the condensate trap and tubing, depending on the furnace orientation (see Figure 6 on page 11). Those furnaces may have holes in the plate separating the draft inducer section of the furnace from the circulating air blower section. Seal those holes carefully to avoid creating a negative pressure near the combustion air blower and reducing the AFUE.

Step 9 - Make electrical connections

Install power to the furnace control board. Some local codes require a switch between the furnace and power source. Most furnaces require a separate 110V to 24V AC transformer as a part of the thermostat circuit. Electrical connections should be made in accordance with the National Electrical Code, NFPA 70.

Step 10 - Connect the combustion air and vent piping (including vent system) for remaining appliances where common vent was disconnected

Although manufacturers permit the use of indoor air for combustion, outdoor air reduces infiltration, reduces the load on the heating and cooling system, and reduces energy costs. In this step, only outdoor air is addressed. For indoor air (non-direct-vent) connections, refer to the manufacturer's installation instructions.

The length and diameter of the outdoor air and vent system piping and the types of materials to be used are determined by the manufacturer. Generally PVC, CPVC, and ABS plastics are approved for use in this case. The maximum length of tubing and the number of elbows are based on the capacity of the combustion air fan (also known as the draft inducer).

Table 4, below shows how the maximum vent pipe length varies with altitude, capacity, pipe diameter, and number of elbows (example only – consult the manufacturer's installation instructions). In general, larger pipe diameters increase the maximum vent pipe length. Vent system piping should be installed to slope back to the furnace (and the condensate drain) ¼ inch per foot.

Table 4. Maximum Length of Vent Pipe (Table Abbreviated)

Altitude, ft. (m)	Capacity KBtu/hr (kW)	Termination Type	Pipe Diameter inches (cm)	Maximum Pipe Length for Given No. of 90º Elbows, ft. (m)		
				1	2	3
0 to 2000 (0 to 610)	40 (12)	2 pipe or concentric	1 ½ (3.8)	50 (15.2)	45 (13.7)	40 (12.2)
			2 (5.1)	70 (21.3)	70 (21.3)	70 (21.3)
0 to 2000 (0 to 610)	60 (18)	2 pipe or concentric	1 ½ (3.8)	50 (15.2)	45 (13.7)	40 (12.2)
			2 (5.1)	70 (21.3)	70 (21.3)	70 (21.3)
0 to 2000 (0 to 610)	80 (23)	2 pipe or concentric	1 ½ (3.8)	30 (9.1)	25 (7.6)	20 (6.1)
			2 (5.1)	70 (21.3)	70 (21.3)	70 (21.3)
0 to 2000 (0 to 610)	100 (29)	2 pipe or concentric	2 (5.1)	45 (13.7)	40 (12.2)	35 (10.7)
			2 ½ (6.4)	70 (21.3)	70 (21.3)	70 (21.3)

Avoid areas where dirt or debris can be drawn into the combustion system as it can foul the trap and cause the furnace to shut down for a service call.

Combustion air inlets on the outside of the building should not be located above vent exhaust to avoid recirculation of the flue gasses and nuisance outages of the furnace. Vent exhaust should be located a safe distance from windows and doors. To avoid flue gas recirculation, use a commercial concentric vent system or direct the flue gases away from the building and bring in combustion air from near the building using suitable pipe fittings. Follow the manufacturer's installation instructions for combustion air inlets and sidewall vent locations.

Where the pipes enter the furnace cabinet, the area between the pipes and the furnace cabinet should be filled with weather-stripping or caulked with a suitable RTV-type sealant.

Several cautions are in order for cold climates, snowy climates, and areas where sidewall venting is used between closely spaced buildings.

In cold climates, the length of pipe exposed to the outdoor conditions is limited to avoid freeze-up. Insulation can be added to the outside of the vent pipe if there are no restrictions and as aesthetics allow. Sloping the vent pipe back toward the furnace is very important in cold climates to minimize ice formation on pipes and exterior surfaces.

In snowy climates, the vent terminal should be located one foot above the maximum snow level for that climate. In most cases that elevation will be three feet above the ground. This technique is called snorkeling.

Figure 12. Vent termination above the snow line

For sidewall venting with closely spaced buildings, consult the local code. In most areas, sidewall venting requires a minimum of ten feet of space between buildings. In cold climates, that distance may be greater to avoid ice formation on adjacent structures. Increasing the diameter of the vent pipe and raising the vent exhaust to the highest elevation above the ground will reduce ice formation on adjacent buildings.

Step 11 - Connect the thermostat

Connect the thermostat to the furnace. In some cases a separate 110 V to 24 V AC transformer will be required.

Step 12 - Complete testing per manufacturer's instructions. Verify the safe operation of existing natural draft equipment when existing vent system has been modified.

In some cases, the condensate trap may need to be filled prior to operating the furnace in order to satisfy one of the pressure safety switches. Fill the condensate trap and return the tubes to their original connections.

Turn on the power to the furnace and adjust the thermostat to call for heat. Address any trouble codes on the control board and inspect the drain tubing, vent system, and condensate drain system for leaks. Check that the furnace temperature rise and gas input rate are consistent with the manufacturer's installation instructions. Verify that atmospheric appliances disconnected from the furnace common vent are venting correctly.

The AFUE test procedure specifies fan speed adjustments to maintain the temperature rise across the furnace within a specified range. Those adjustments influence the outcome of the test. If the adjustments are not done in the field, the field performance will be degraded.

3.3 Verification Procedures and Tests

Here are the steps to verify the installation and test the operation of the furnace:

1. Check gas lines and vent system for leaks
2. Prime condensate trap with water, if necessary. Determine that the trap is working properly.
3. Adjust gas pressure at gas valve to proper range for higher elevations
4. Check performance of high limit switch and pressure safety switches
5. Clean all debris and leave homeowner guide

Figure 13. Seal unused vent openings

Step 1 - Check gas lines and vent system for leaks

Using a soapy water solution or a commercial product, wet the new gas pipe joints, unions, and fittings and look for bubbles. If there are any leaks, shut off the gas supply upstream of the leaks and repair.

Inspect the vent pipes while the furnace is operating for visible condensate on the exterior of the pipes. If there is no visible condensate, use the soapy water solution to check for leaks. Repair all leaks found.

Verify that old vent openings have been sealed and that any common-vented appliances are being vented according to the NFPA 54 Code.

Step 2 - Prime condensate trap with water, if necessary. Determine that the trap is working properly.

In some furnaces, the condensate trap must be primed before the furnace is started. With the furnace off, pour water into the draft inducer housing or into the trap directly through one of the tubes. Start the furnace and observe that it is cycling normally. Remove the drain tube from the drain and observe that the condensate is flowing normally.

Step 3 - Adjust gas pressure at gas valve to proper range for higher elevations

Furnaces are generally shipped with the combustion system adjusted correctly for sea level operation—the appliance operates at the rated name plate capacity with good combustion. For higher elevations, some adjustment needs to be made to the gas valve. Consult the manufacturers' installation instructions for guidance.

Figure 14. Verify that the condensate trap is working properly

Step 4 - Check performance of high limit switch and pressure safety switches

There are many types of safety tests that manufacturers recommend post-installation. Two common ones are to block the return air flow to test the high temperature safety switch and to disconnect one of the tubes from the pressure sensor to test the performance of the safety system with a blocked vent condition. Detailed safety testing instructions are included in the manufacturers' installation instructions.

Step 5 - Clean up debris and leave homeowner guide

All debris should be removed from the job site and the homeowner guide should be left with the homeowner.

How to get the most out of a high efficiency furnace:

1. Install the smallest capacity that will meet the load – the furnace should recover from setback in an hour on the design day. The goal should be to have the longest on-time per cycle to avoid cycling losses.

2. Match the ducts to the furnace. Fan power goes as the cube of the pressure rises, so size the duct system to provide the required air flow at minimum external static pressure.

3. Attach the supply and return duct system to the furnace with no leaks. Review the manufacturer's instructions for the permitted techniques.

4. Avoid installing high efficiency furnaces in ventilated attics in cold climates or where the outdoor temperature drops below 32^{o}F and there may be power outages. Heat tape can consume 40-100W of power 24/7 - 365 days of the year.

5. Use outdoor air for combustion to reduce additional load from infiltration by approximately 1%.

6. Install the vent terminal and intake pipe with proper spacing or using a concentric fitting so flue gasses are not pulled in with combustion air. Poor combustion causes nuisance outages and reduces efficiency.

Summary

A common result of a home energy audit is a recommendation to replace the existing gas furnace with a high efficiency model. The steps outlined in this Measure Guideline include: when to install a high efficiency gas furnace as a retrofit measure; how to identify and address risks; and the methods to be used in the selection and installation process. Proper installation of a high efficiency gas furnace requires attention to many details and interconnecting systems: heating capacity (sizing), consideration for duct distribution systems, gas piping, vent systems, provision for combustion air, flue gas condensate disposal, electrical connection requirements, provision for forced-air cooling (as required), air filtering equipment, and humidification requirements. These factors and others are discussed in this guideline.

Key recommendations supported by recent PARR research are use of direct vent systems (outdoor air for combustion), proper sizing of duct distributions systems to avoid high static pressure that causes high fan power usage and a drop in installed AFUE, and proper furnace sizing to reduce cycling and improve comfort in the space. Those recommendations are explored in detail in this Measure Guideline.

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Appendices

Appendix A: Prescriptive Measure Checklist

☑	Item	Used for
	Heating load calculation _________________________	Basis for furnace capacity – model selection
	Cooling load calculation _________________________	Basis for cooling system sizing and furnace model selection
	Furnace type and model number	Combine all information on sizing above and include oversize factor for recovery from setback _________________________________
	Check ductwork for leaks or undersizing and repair or replace	Good practice for significant energy savings
	Chose combustion air from indoors or outdoors (circle)	Basis for installation decisions, and determination of confined space and ventilation requirements
	Measure distance to vent termination ____________________ft.	Basis for size of vent piping and allowable number of elbows Pipe diameter____in. Length______ft. Elbows______
	Heat tape and pipe insulation ____________________ft.	Furnaces installed in attics where outdoor temperature will drop below 32°F
	Condensate trap and tubing appropriate for furnace orientation	Condensate trap is gravity fed – trap and tubing change locations with furnace orientation
	Condensate drain sloped away from furnace	Required for proper drainage and to avoid frozen lines in cold climates
	Vent and condensate lines leak-tight	Avoid water damage from leaks and venting of flue gasses into conditioned space
	Gas lines leak-tight	Safety
	Set gas input	To obtain rated capacity
	Set temperature rise	To obtain rated performance
	Set fan speeds	To obtain rated performance
	Test safety devices—over-temperature and ignition system safety	Avoid unsafe conditions

☑	**Item**	**Used for**
	Set thermostat anticipator	For optimum comfort and where used
Other systems		
	Check vent system for formerly common-vented appliances	Safety check—may need to replace B-vent or reline masonry chimney
	Check ductwork for leaks or undersizing and repair or replace	Good practice for significant energy savings

Appendix B: Sample Calculations

Equipment sizing

Load calculation (under design conditions) = L

Oversizing factor for recovery from setback (decimal value) = O

Furnace Efficiency, (AFUE) = E

Furnace capacity = L*(1.0+O)/E

Payback

Payback is the number of years to repay the cost of replacing a furnace with energy savings.

Current Annual Energy Cost =AC

Estimated Annual Energy Savings for new high efficiency furnace (from table) = ASH

Installed Cost of new high efficiency furnace = ICH

Payback = ICH/(AC-ASH)

If the furnace is at the end of its useful life, payback is the number of years to repay the cost of upgrading from a minimum efficiency option to a high efficiency option.

Estimated annual energy savings for replacing mid-efficiency furnace with high efficiency furnace (from table) = ASM

Installed Cost of new mid efficiency furnace = ICM

Payback (upgrade) = (ICH-ICM)/ASM

Appendix C: Material Specifications

Vent system materials for Category IV furnaces:

PVC – schedule 40 PVC is generally recommended

PVC – DWV

CPVC

ABS – DWV

Appendix D: Research on Installed Performance

Recent research by the PARR Building America team, shown in Figure 15 and Figure 16, sheds some light on the effect of oversizing and high external static pressure on the measured AFUE of high efficiency gas furnaces. Three furnaces were tested in the lab using the standard ASHRAE 103 AFUE test procedure (ASHRAE, 2007) with varying levels of oversizing and external static pressure. A single-stage, a two-stage, and a step-modulating high efficiency furnace were tested with three levels of oversizing and three levels of external static pressure applied. A Minimum Efficiency Reporting Value (MERV) 8 filter was also tested and results were consistent with the 0.12 inches of water column increase in external static pressure that was added to the system.

PARR chose the ASHRAE 103 standard for testing rather than the DOE method because the ASHRAE standard serves as the consensus standard in the engineering community. The major differences between the two standards are: adjustable fan control timing differences, insulation of the draft inducer, and use of igniter and inducer blower power in the calculation. In this study, the test cases are compared to each other rather than the rated value, so the choice of standard does not impact the results.

Figure 15. PARR AFUE lab testing

Figure 16. Furnace AFUE test showing jacket loss detail

Table 5, below, provides information on the furnaces tested and the types of tests conducted.

Table 5. PARR Furnace Testing

Furnace Type	Description	DOE AFUE ICS Rating	Capacity	Oversize Tests	External Static Pressure Tests
Single-stage	Single-stage gas valve with PSC inducer (combustion) and circulating air blower motor	93.1% AFUE	80,000 Btu/hr	70% oversize (standard level for ASHRAE test), 100%, 120%	0.2 inches water column (standard level for ASHRAE test), 0.5 inches, and 0.8 inches
Two-stage	Two stage gas valve with two-stage PSC inducer (combustion air) and blower motors	93.0% AFUE	80,000 Btu/hr	70% oversize (standard level for ASHRAE test), 100%, 120%	0.2 inches water column (standard level for ASHRAE test), 0.5 inches, and 0.8 inches
Step-modulating	Three stage gas valve with ECM inducer (combustion air) and blower motors	97.0% AFUE	80,000 Btu/hr	70% oversize (standard level for ASHRAE test), 100%, 120%	0.2 inches water column (standard level for ASHRAE test), 0.5 inches, and 0.8 inches

Oversizing

The results of the research show that high efficiency furnace AFUEs are insensitive to oversizing in the range tested when evaluated according to the ASHRAE standard. As seen in Figure 17, no furnace varied by more than 0.5% AFUE when tested between 70% and 120% oversizing using the ASHRAE standard. This result is consistent with work done by others (Brand, 2012). A difference of 0.5% AFUE is within the measured accuracy of the PARR lab test set up. All furnaces tested at less than the DOE AFUE value in Table 5, due to variations in the sample or differences between the DOE and ASHRAE test procedures, as discussed above.

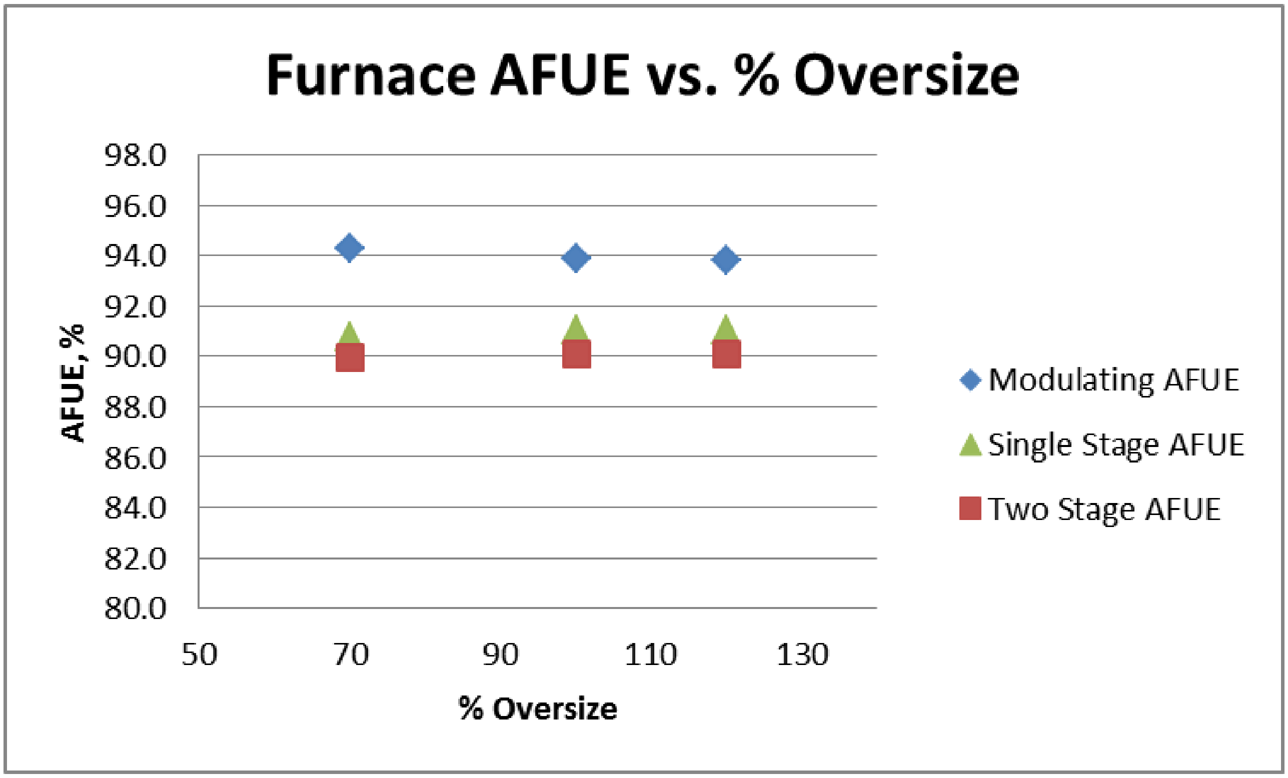

Figure 17. Furnace AFUE with oversizing

High efficiency furnaces have very little off-cycle air flow through the heat exchanger, so cycling losses and off-cycle losses are kept to a minimum, supporting this finding. However, anecdotal information from the field contradicts this result. Possible reasons for this discrepancy are:

1. Field data includes atmospheric or mid-efficiency furnaces

2. Field data includes some furnaces with improper installation issues (firing rate not adjusted, improper fan speed selected, poor sizing)

3. Heating of ductwork in unconditioned spaces. Greater oversizing is believed to cause rapid heating of ductwork and loss of this heat to unconditioned spaces during long off periods. Further research in this area is being conducted by PARR.

High External Static Pressure

For tight ducts with high external static pressure, the research does show an impact on both fan energy use and AFUE, depending on the case. Figure 18 shows the AFUE impact from high external static pressure. Figure 19 on page **Error! Bookmark not defined.** shows the impact of fan energy on AFUE.

The ASHRAE standard measures AFUE at 0.2 inches of water column external static pressure (pressure drop in the ductwork external to the furnace) without the use of a filter. In this study, high external static pressure is considered to be above 0.5 inches of water column.

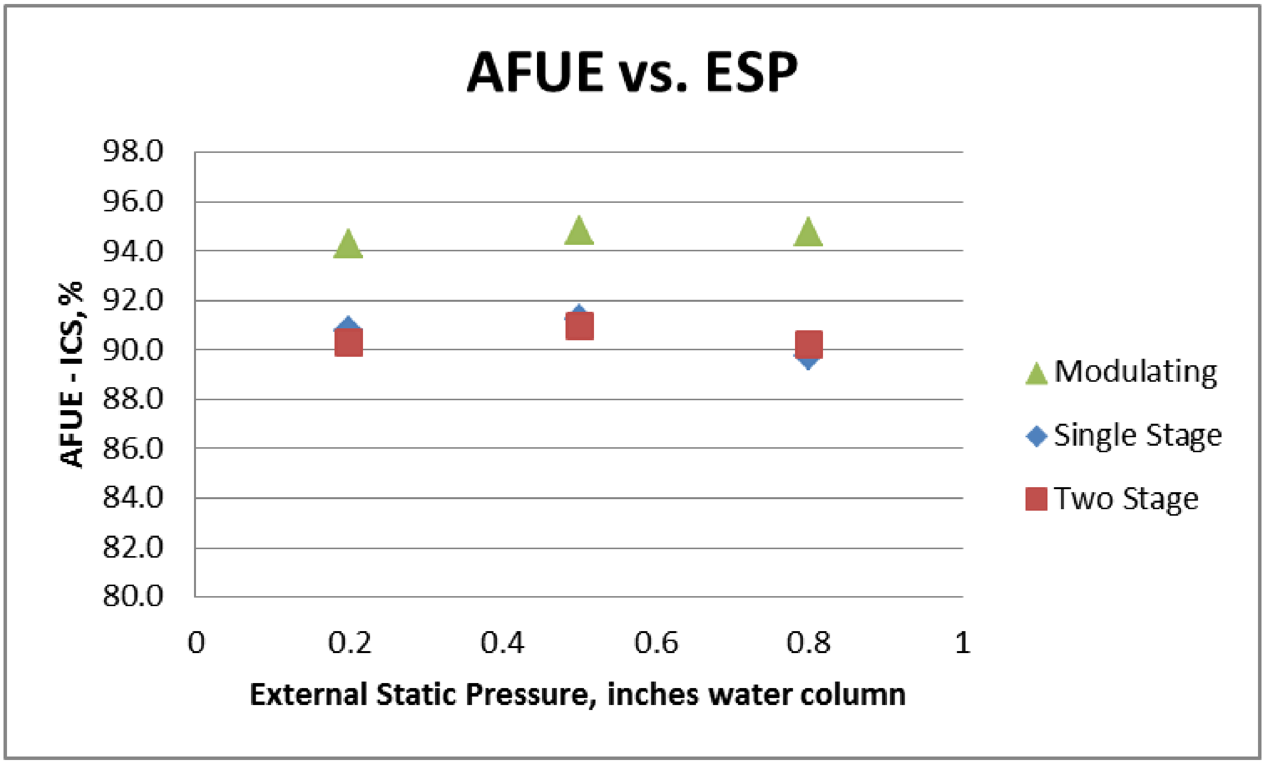

Figure 18. AFUE with varying external static pressure

Figure 18 shows that AFUE decreases with increasing external static pressure for the single-stage and two-stage furnaces at the 0.8 inches of water column test point, while the modulating furnaces is insensitive to the higher external static pressure (within the 0.5% error band of the test). The reason for this effect is that the PSC blower begins to stall at higher external static pressure and moves less air. Figure 19 shows that the blower power is reduced for the PSC when the fan begins to stall. When less air is moving, the furnace produces a higher delivered air temperature, which reduces the efficiency slightly—about 1% in the single-stage furnace case. The two-stage furnace, however, is less sensitive to this phenomenon since it generally operates at the lower fan speed in the AFUE test.

The modulating furnace uses an electronically commutated permanent magnet motor, which is controlled to increase the fan speed to make up for the increase in static pressure, following the fan curve. Figure 18 shows that there is no degradation in AFUE with the modulating furnace and Figure 19 shows the corresponding increase in blower power.

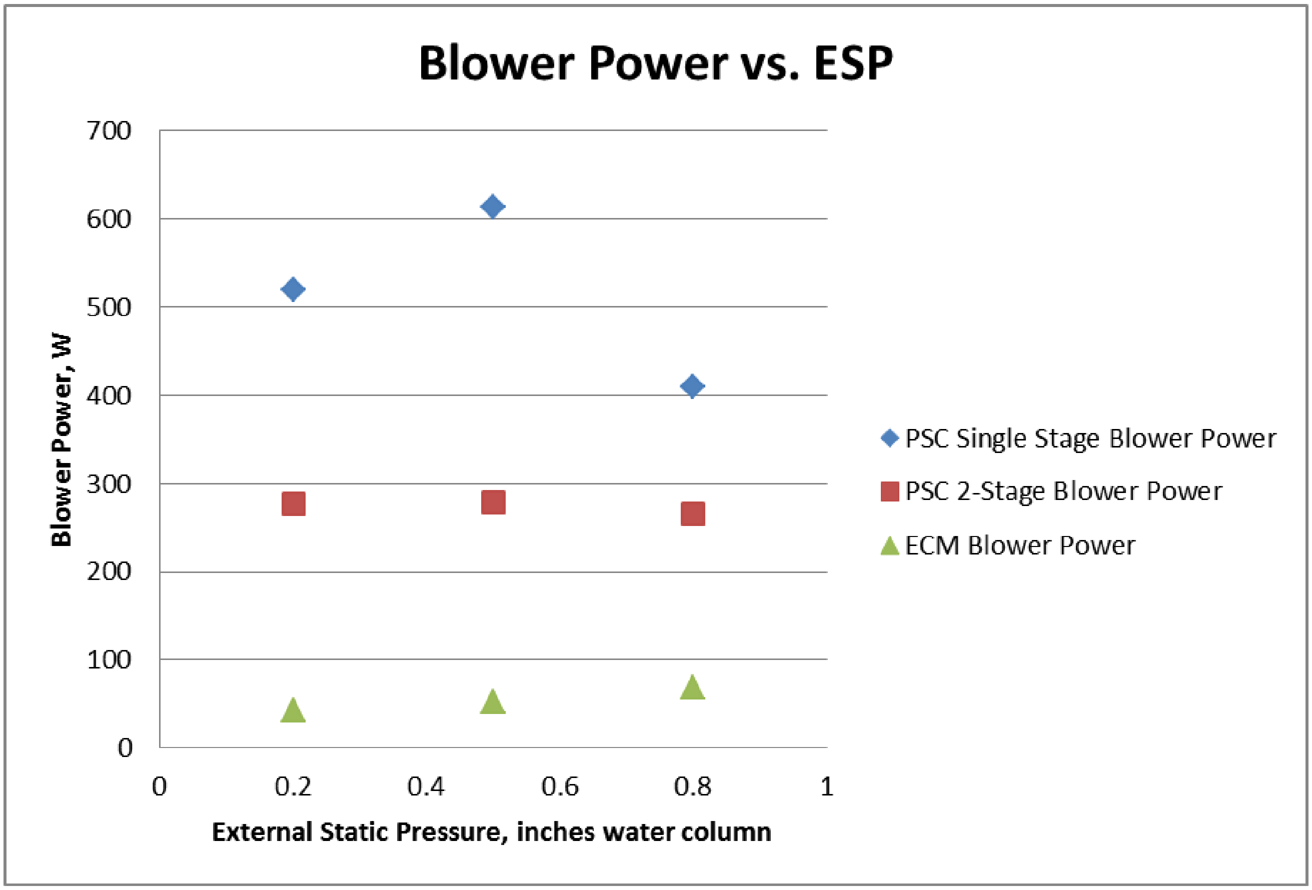

Figure 19: Blower power with varying external static pressure

Summary of Research

The research suggests that high efficiency furnace AFUE is insensitive to oversizing based on lab testing in the 70% to 120% oversizing range and that AFUE is slightly reduced with high external static pressure above 0.5 inches of water column for single-stage furnaces with PSC motors. The power to operate the circulating air blower increases slightly for step modulating furnaces installed in high external static situations, but decreases slightly for furnaces with PSC motors under those circumstances.

Implications for furnace replacements are that furnaces should be sized as small as possible to match the duct size or the ducts should be replaced if a higher furnace capacity is required. Some practitioners recommend replacing the ducts if the furnace capacity is significantly reduced (Chitwood and Harriman, 2010). Modulating furnaces and two-stage furnace AFUE are less sensitive to undersized ducts and are therefore a better choice than single-stage high efficiency furnaces in those situations.

A few important notes:

1. The AFUE test procedure specifies fan speed adjustments to maintain the temperature rise across the furnace within a specified range. Those adjustments influence the outcome of the test. If the adjustments are not done in the field, the field performance will be degraded.

2. AFUE is highly correlated to CO_2 level. If a furnace is designed for a 5% CO_2 level at low fire and operates at 4%, the AFUE is reduced about 1% to 1.5%. To achieve the best CO_2 level, the furnace should first be adjusted to the proper rate, and then the minimum diameter of combustion air pipe and vent pipe should be used for the length needed (as specified in the manufacturer's installation instructions). Unlike conventional furnaces, there is no adjustment for CO_2 level in high efficiency furnaces.

3. Some furnaces are designed with multiple internal and external locations for the condensate trap and tubing, depending on the furnace orientation (see Figure 6 on page 11). Those furnaces may have holes in the plate separating the draft inducer section of the furnace from the circulating air blower section. Seal those holes carefully to avoid creating a negative pressure near the combustion air blower and reducing the AFUE.

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