DOCKETED

Docket Number:	17-BSTD-02
Project Title:	2019 Title 24, Part 6, Building Energy Efficiency Standards Rulemaking
TN #:	222296
Document Title:	Residential Furnace Blower Performance Testing
Description:	Document relied upon.
Filer:	Adrian Ownby
Organization:	Proctor Engineering Group
Submitter Role:	Public
Submission Date:	1/22/2018 11:07:13 AM
Docketed Date:	1/22/2018

Residential Furnace Blower Performance Testing

Prepared by

Proctor Engineering Group

for

California Energy Commission

November 2017

1 Introduction

The California Title 24 Building Energy Efficiency Standards (2016) currently require central forced air systems in residential new construction to be designed such that the fan is capable of moving at least 350 cfm per ton of nominal cooling capacity with fan efficacy less than or equal to 0.58 W/cfm when the system is operated at maximum cooling capacity. These requirements were developed through research conducted in 2006 to determine the capability of HVAC equipment available at the time.

In July, 2019 new Federal regulations take effect that establish minimum efficiency requirements for furnace fans. The new regulations will require furnace fans to provide minimum efficiency equivalent to the constant torque brushless permanent magnet (BPM) type motors used in multi staged furnaces (reference 1). This means that in 2019 the minimum efficiency furnace fan will become more efficient than the 2006 standard furnace fan, for which permanent split capacitor (PSC) type fan motors were typical.

To account for the change in minimum furnace fan efficiency, it was proposed that the California Title 24 fan efficacy requirement should be modified to 0.45 W/cfm. Laboratory testing was conducted to evaluate the reasonableness of the proposed fan efficacy requirement.

The purpose of this test was to determine whether BPM blower motors in a representative sample of non-weatherized furnaces are capable of delivering at least 350 cfm/ton of air using 0.45 W/cfm or less. This was accomplished by testing each fan's performance at different speed settings and outlet static pressures, in order to create performance curves for each fan.

Performance relative to the proposed Title 24 requirements was evaluated at the typical rated cooling speed static pressure for residential furnaces, which is 0.5 inches water column (IWC). Figure 1 shows an example of a manufacturer published furnace specification. California Mechanical code section E 607.2 specifies that "Duct systems shall be sized in accordance with ACCA Manual D, ASHRAE handbooks, or other equivalent methods." Thus, it is reasonable to expect that duct systems in residential new construction be designed to the typical rated static pressure for residential furnaces using ACCA Manual D or equivalent methods. As an additional reference point, performance was also evaluated on the system curve specified in the DOE test procedure for the 2019 furnace fan standards.

Because the 2019 Federal furnace fan standards are not yet in effect, it was not possible to verify that the furnaces selected for testing were compliant and could legally be produced in 2019. It was decided that if any tested fans were unable to meet the proposed Title 24 requirements, additional testing would be performed to evaluate performance relative to the maximum Fan Efficiency Ratio (FER) of

$$FER = 0.044 \times Q_{max} + 182$$

for non-weatherized, non-condensing furnaces mandated in the 2019 Federal standards.

Heating Capacity and Efficiency			040-10	040-12	060-12	060-14	080-16	080-20	100-20	120-22
Input	High Heat	(BTUH)	40,000	40,000	60,000	60,000	80,000	80,000	100,000	120,000
	Low Heat	(BTUH)	26,000	26,000	39,000	39,000	52,000	52,000	65,000	78,000
Output	High Heat	(BTUH)	39,000	39,000	58,000	58,000	78,000	78,000	97,000	117,000
	Low Heat	(BTUH)	25,000	25,000	38,000	38,000	50,000	51,000	63,000	76,000
Certified Temperature Rise Range °F (°C)		High Heat	40 - 70 (22 - 39)	40 - 70 (22 - 39)	40 - 70 (22 - 39)	40 - 70 (22 - 39)	40 - 70 (22 - 39)	40 - 70 (22 - 39)	40 - 70 (22 - 39)	40 - 70 (22 - 39)
		Low Heat	30 - 60 (17 - 33)	30 - 60 (17 - 33)	30 - 60 (17 - 33)	30 - 60 (17 - 33)	30 - 60 (17 - 33)	30 - 60 (17 - 33)	30 - 60 (17 - 33)	30 - 60 (17 - 33)
Airflow Capacity and Blower Data			**040-10**	**040-12**	**060-12**	**060-14**	**080-16**	**080-20**	**100-20**	**120-22**
Rated External Static Pressure (in. w.c.)		Heating	0.10	0.10	0.12	0.12	0.15	0.15	0.20	0.20
		Cooling	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Airflow Delivery @ Rated ESP (CFM)		High Heat	815	860	1120	1135	1505	1555	1865	2375
		Low Heat	660	660	910	860	1160	1200	1435	1675
		Cooling	905	1065	1065	1475	1610	2005	2005	2115

Figure 1: Rated cooling speed external static pressure for a residential furnace product line

2 Tested Equipment

Ten furnaces with BPM blower motors were selected for testing, as listed in Table 1. The furnaces were specified by Proctor Engineering Group (PEG), and were chosen to represent the lower price range of furnaces with BPM motors that can be purchased today. For most manufacturers, the furnaces selected for testing are a step or two up in price from their least expensive models with PSC motors.

Table 1: List of Tested Furnaces

Furnace #	Motor HP	Speeds	ECM Descriptor	Heating Stages	AFUE	Heating Capacity, Btuh	Cooling Capacity, tons
1	3/4	variable	variable speed	2	80	61000	4.0
2	1	5	constant torque	1	92	82000	4.5
3	3/4	variable	variable speed	2	96	58000	3.5
4	1/3	5	control logic	1	80	36000	2.5
5	1	variable	variable speed	2	80	70000	4.5
6	1/2	5	constant torque	1	95	28000	2.0
7	1/2	4	constant torque	1	95	38000	2.5
8	1	4	constant torque	1	80	79000	5.0
9	1/2	5	multi speed	2	80	48000	3.5
10	1	5	multi speed	2	96	96000	5.0

The tested furnaces come from five different manufacturers, range between 40,000 to 100,000 Btuh in heating capacity, and are designed to be combined with cooling coils ranging from 2 to 5 tons of cooling capacity. They have Annual Fuel Utilization Efficiency (AFUE) ratings between 80 and 96. All of these furnaces have BPM blower motors, with sizes of ⅓ HP, ½ HP, ¾ HP or 1 HP.

Two of the blower motors can be set to four different speeds, five have five operating speeds, and three are variable speed motors. The BPM motor controls are described as “constant torque”, “multi speed”, “variable speed”, or as having the manufacturer’s particular control logic. The cooling capacity was calculated from each furnace’s specified maximum cooling airflow at 0.5 IWC, where:

Cooling capacity, tons = Integer (maximum cooling airflow @ 0.5 IWC / 200 + 0.5) / 2

3 Test Setup

The test plan was developed through collaboration between Proctor Engineering Group (PEG) and Pacific Gas and Electric Company (PG&E) staff at the Applied Technology Services (ATS) laboratory in San Ramon, California.

Testing was performed by PG&E staff at the ATS laboratory in San Ramon, California. The tests measured the fan airflow and power use of all ten residential furnaces across a variety of fan speeds and at different levels of external static pressure. Testing progress and resulting data were reviewed by PEG to ensure test plan objectives were met, and that results were in line with expectations based on the manufacturer’s published performance data.

The test furnaces were placed in the lab’s “Outdoor Room” with their discharge ducted to the “Indoor Room” airflow measurement apparatus, as shown in Figure 2.

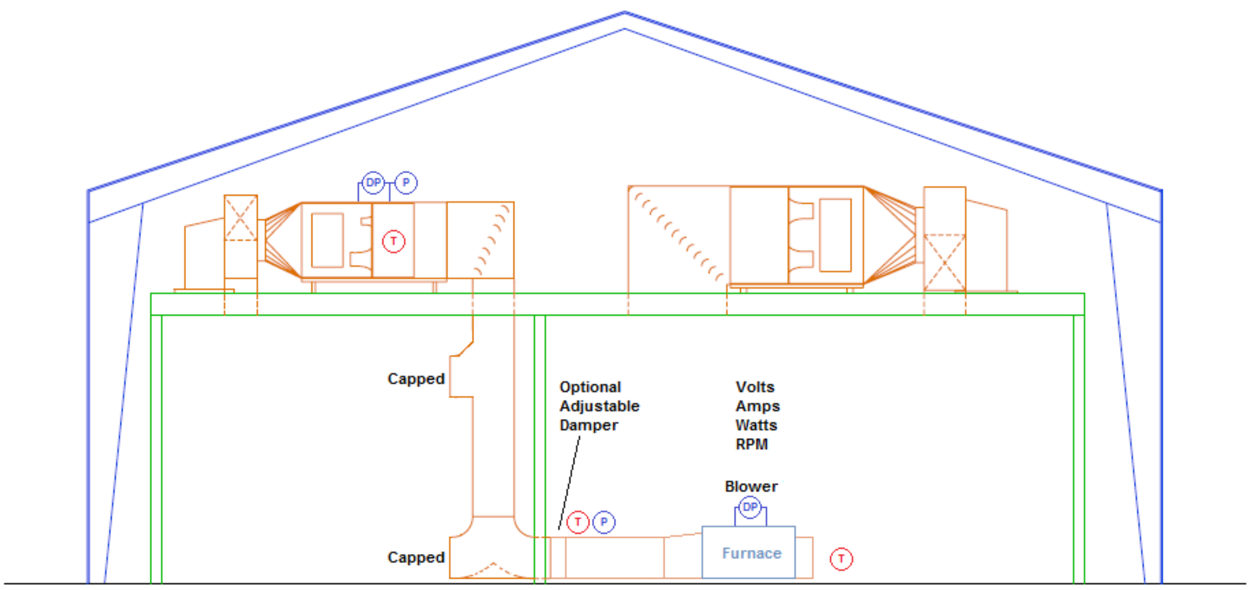


Figure 2: HVAC Lab Setup for Furnace Tests

All testing was performed in accordance with the AMCA 210/ASHRAE 51-1999 Standard, Laboratory Methods for Testing Fans for Aerodynamic Performance Rating, ASHRAE Standard 37-2009, Methods of Testing for Rating Electrically Driven Unitary Air-Conditioning and Heat Pump Equipment, and ANSI/ASHRAE Standard 103-1993 Method of Testing for Annual Fuel Utilization Efficiency of Residential Central Furnaces and Boilers, listed as references 2, 3 and 4 at the end of this report.

All furnaces were tested in the upflow position for ease of access to the motor speed controls. No filters were in place for any testing because total external static pressure, which includes pressure drop across the air filter, was controlled by the laboratory equipment to meet the values specified in the test plan. The furnace burner was not fired during any performance curve testing.

To measure fan performance, measurements of fan speed, airflow, and power were made at outlet static pressures from 0.0 IWC to 1.0 IWC, in 0.1 IWC increments. Static pressure at the furnace discharge was adjusted through a combination of changing the number of open nozzles in the airflow apparatus and changing the speed of a booster blower downstream of the apparatus. Each fan's performance was measured at a variety of speeds, including their maximum and minimum speeds, and at least two speeds in between. All speeds were tested for fans with four or five speeds, and at least five speeds were measured for variable speed fans.

In addition to the general fan performance testing, the worst performing unit underwent additional testing to enable estimation of the FER rating to determine whether it is likely meet 2019 federal guidelines.

The FER is based on measurement of the fan power along an operating curve defined by a static pressure of 0.65 IWC at the maximum flow rate. Three points are evaluated: 1) Emax at the unit's maximum cooling flow, Qmax, 2) Eheat at the unit's lowest stage of heating, adjusted to the highest available airflow setting at this stage, and 3) Ecirc in the default continuous fan operation mode. Based on these values, FER is calculated as follows:

$$FER = \frac{(CH \times E_{Max}) + (HH \times E_{Heat}) + (CCH \times E_{Circ})}{(CH + 830 + CCH) \times Q_{Max}} \times 1000$$

More information about the FER test and calculation procedures can be found in the test plan of reference 6. The value of Eheat is usually measured with the furnace burner fired. Due to the short timeline to accomplish this testing, and the difficulty of hooking up a gas line and flue to the furnace, Eheat for this testing was measured at room temperature conditions. Since in regular FER testing this value is normalized to room temperature conditions, this has a small effect on our estimation of FER.

Further details about the test setup, instrumentation, and methodology is included in the project laboratory test plan, listed as reference 6 and embedded at the end of this report.

4 Test Results

Furnace fan performance data is presented in two sets of graphs. The first set of graphs, presented in Figures 4.1.1 through 4.1.10, show performance plots of each fan's measured airflow in CFM per ton and fan efficacy in watts per cfm versus external static pressure in IWC for the four or five different fan speeds tested on each fan. This graph also displays two lines to visually illustrate pertinent operating conditions:

1) The green "constant 0.5" ESP" vertical line represents the fan performance at an external static pressure of 0.5 IWC at any fan speed. 0.5 IWG is the typical rated cooling speed static pressure for residential furnaces.

2) The red "max 0.65 ESP" curve represents the system curve defined in the 2019 furnace fan standard, which specifies 0.65 IWG static pressure at maximum fan speed for units designed to be installed with an evaporator coil, but tested without a coil in place.

TABLE III.1—REQUIRED REFERENCE SYSTEM CRITERIA (I.E., ESP AT MAXIMUM AIRFLOW) BY FURNACE FAN INSTALLATION TYPE

Installation type	ESP at maximum airflow (in. wc)
Units with an internal evaporator coil	0.50
Units designed to be paired with an evaporator coil	0.65
Units designed to be installed in a mobile home [12]	0.30

Figure 4.1: DOE Specified External Static Pressure at Maximum Fan Speed (Reference 5)

The DOE furnace fan test procedure specifies that the furnace be set to the maximum airflow control setting. With the furnace operating at the maximum fan speed, duct resistance to airflow is then adjusted to 0.65 IWG. Subsequent testing is then conducted with the duct outlet restrictor in the same position to simulate fan performance in a duct system of constant physical characteristics. According to fan laws, as the airflow decreases at lower fan speeds, static pressure drops in proportion to the square of the airflow, a relationship known as a system curve. The "max 0.65 ESP" curve shows the cfm/ton vs. external static pressure relationship corresponding to the reference system curve specified in the DOE test procedure. The intersections of the "max 0.65 ESP" curve with the fan performance curves represent the operating point of each fan speed when the furnace is evaluated on the reference system curve specified by the DOE test procedure.

The second set of graphs plots watts per CFM versus CFM per nominal ton of cooling are presented for all tested furnaces in Figures 4.2.1 through 4.2.10. These graphs are delineated into four quadrants by lines at 0.45 W/cfm and 350 cfm/ton. Operating points in the lower right quadrant meet the proposed new fan efficiency limit of 0.45 W/cfm, while providing at least 350 cfm/ton of airflow. The green "constant 0.5 ESP" line and red "max 0.65" ESP" system curve are also shown.

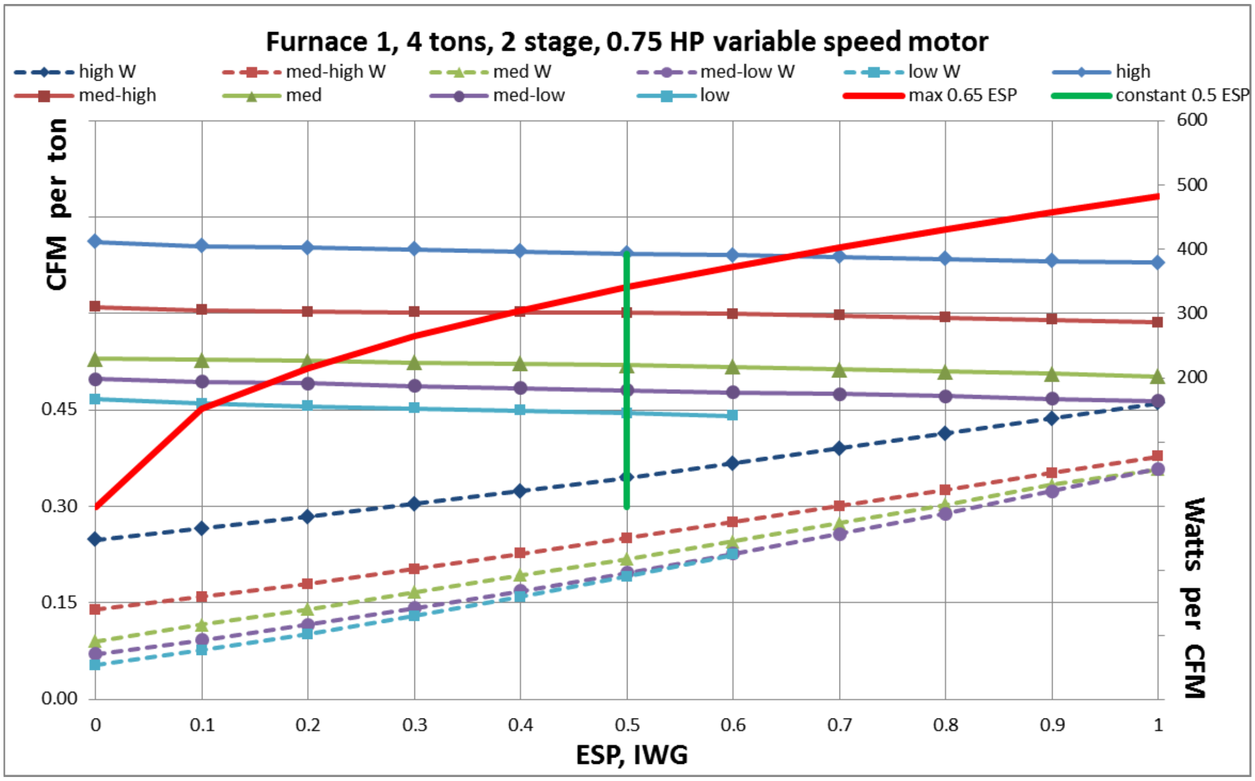


Figure 4.1.1 Furnace 1 normalized airflow and power use versus static pressure at five fan speeds

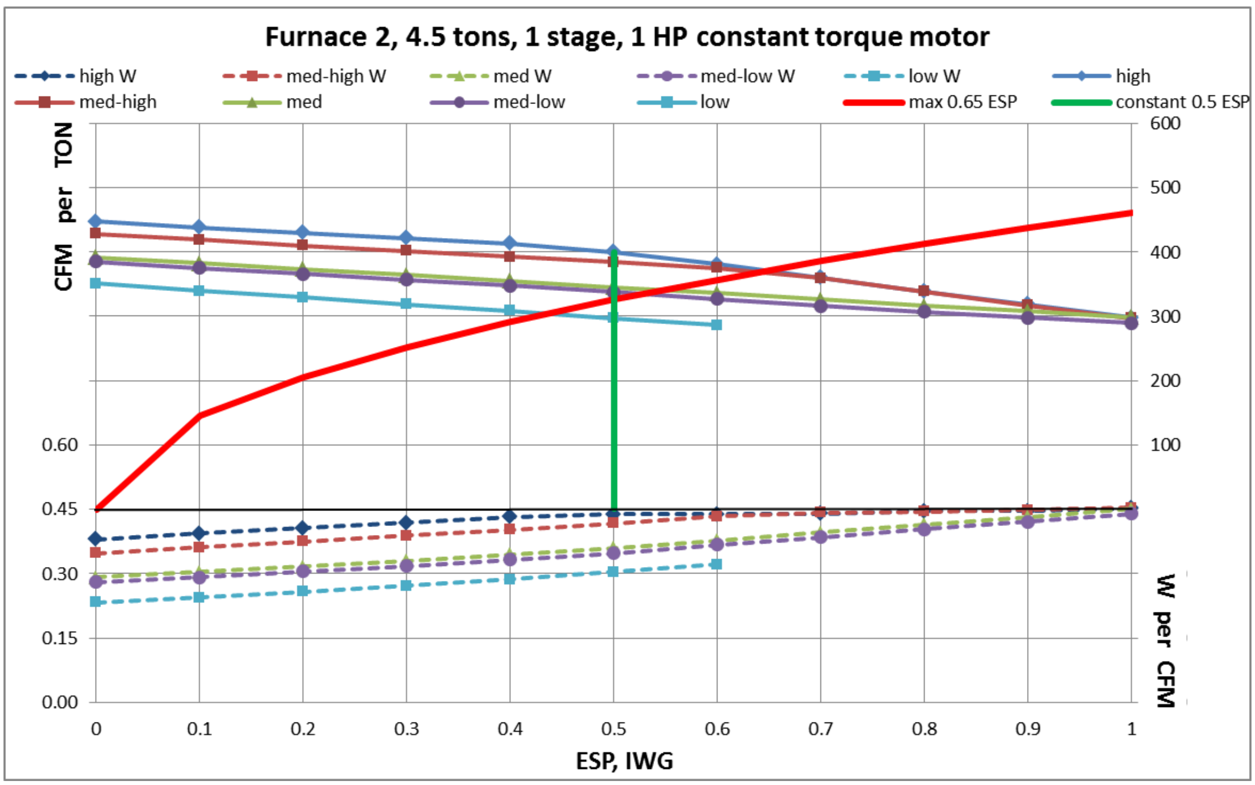


Figure 4.1.2 Furnace 2 normalized airflow and power use versus static pressure at five fan speeds

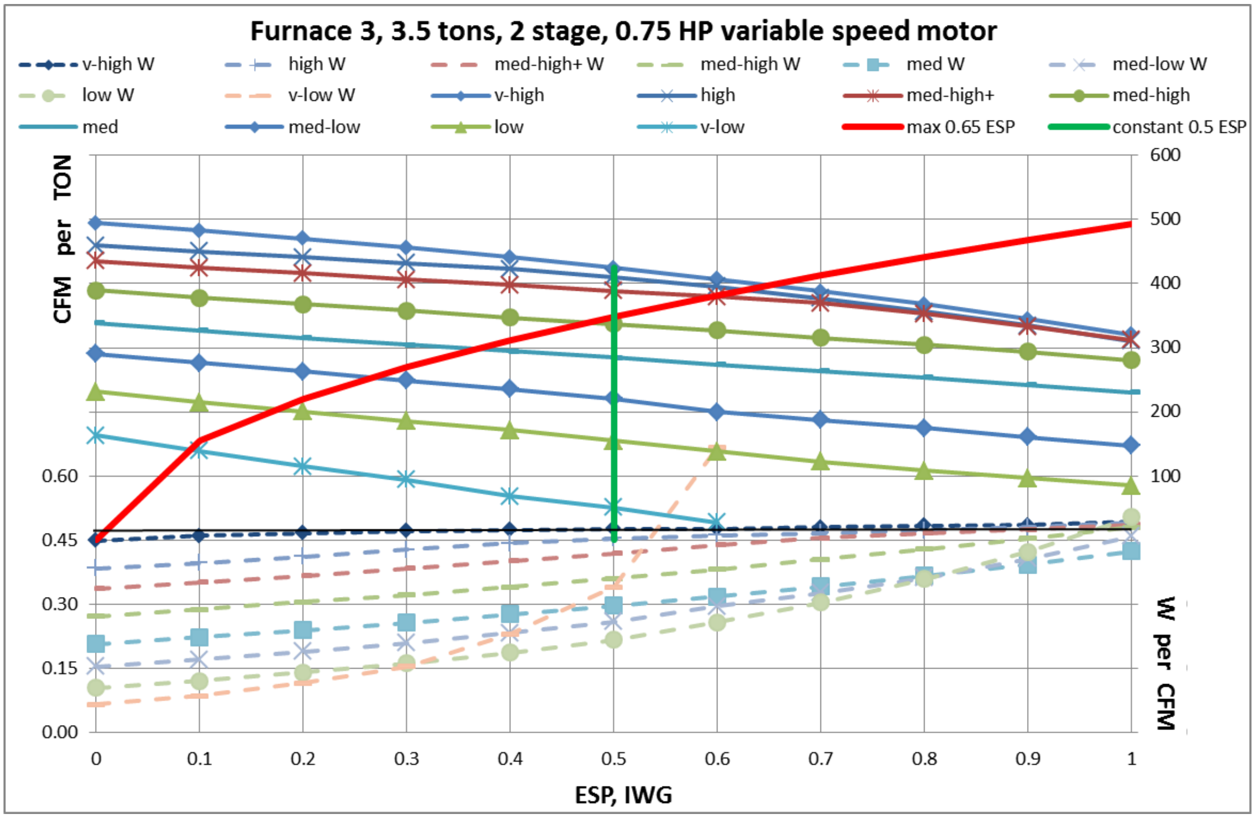


Figure 4.1.3 Furnace 3 normalized airflow and power use versus static pressure at eight fan speeds

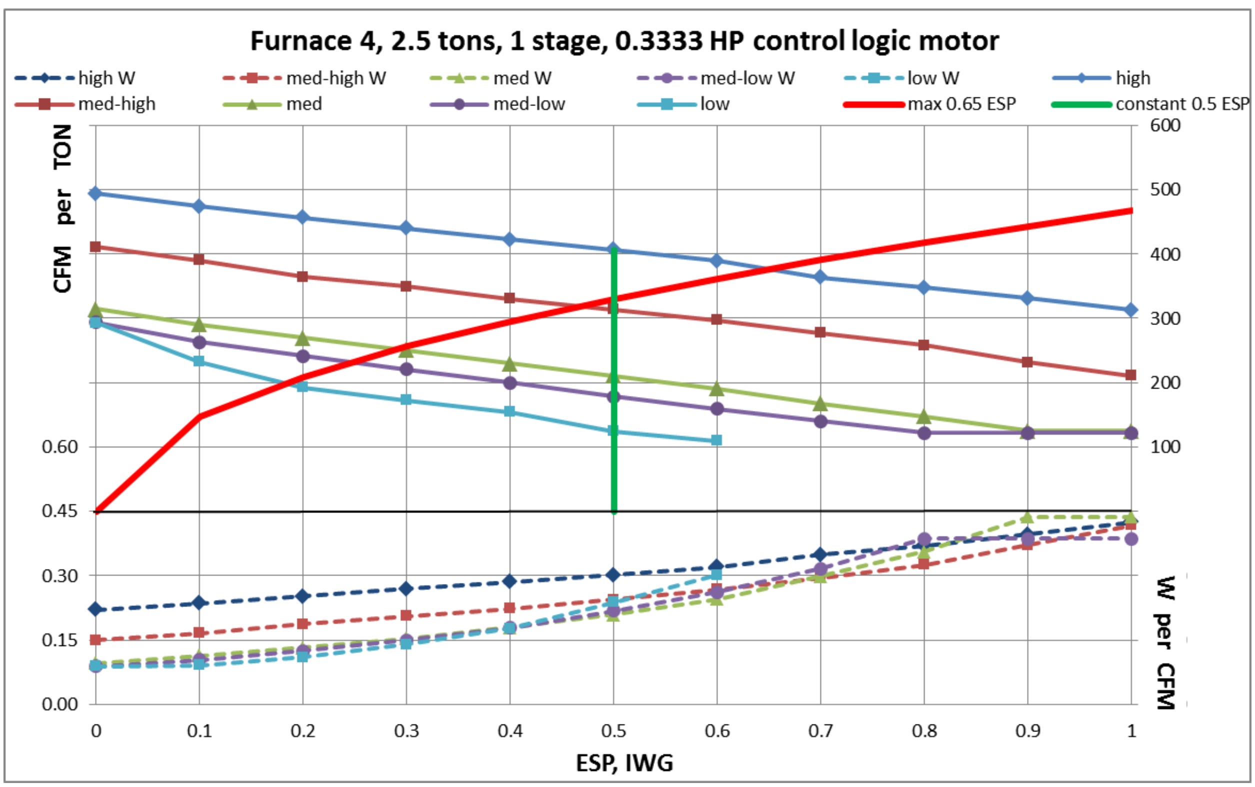


Figure 4.1.4 Furnace 4 normalized airflow and power use versus static pressure at five fan speeds

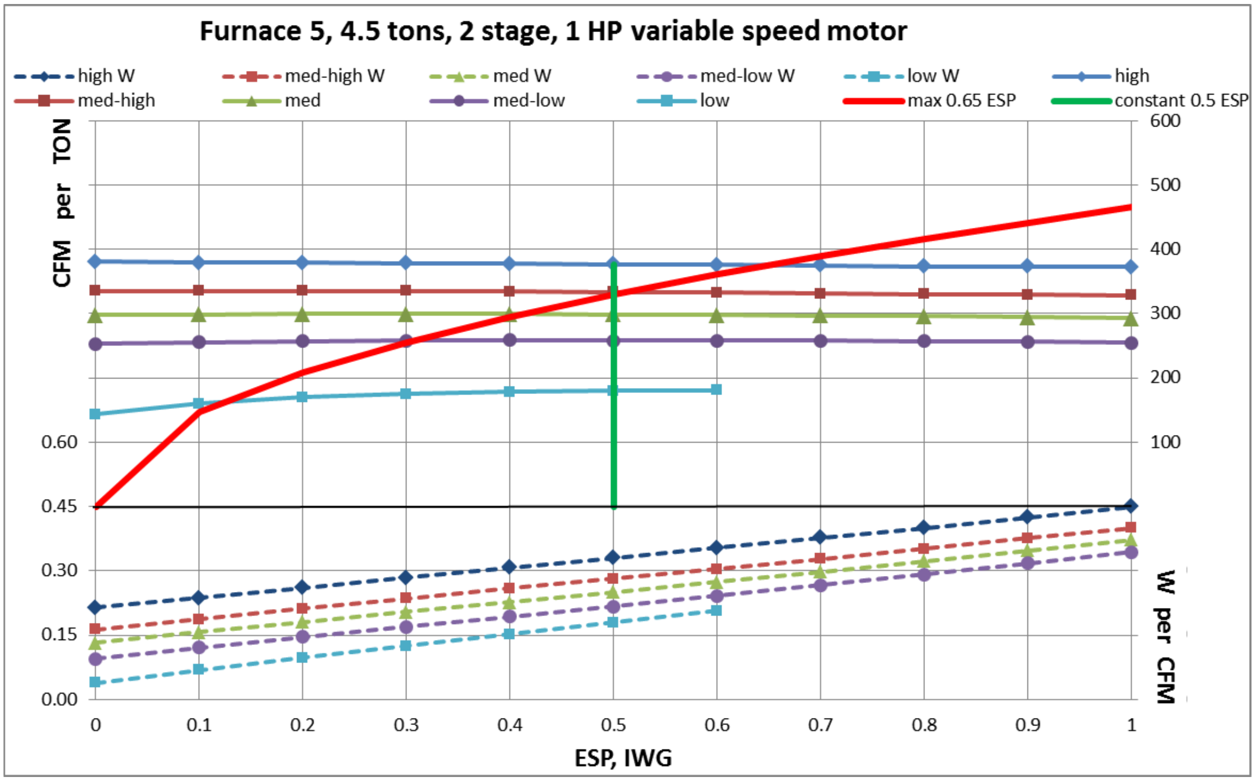


Figure 4.1.5 Furnace 5 normalized airflow and power use versus static pressure at five fan speeds

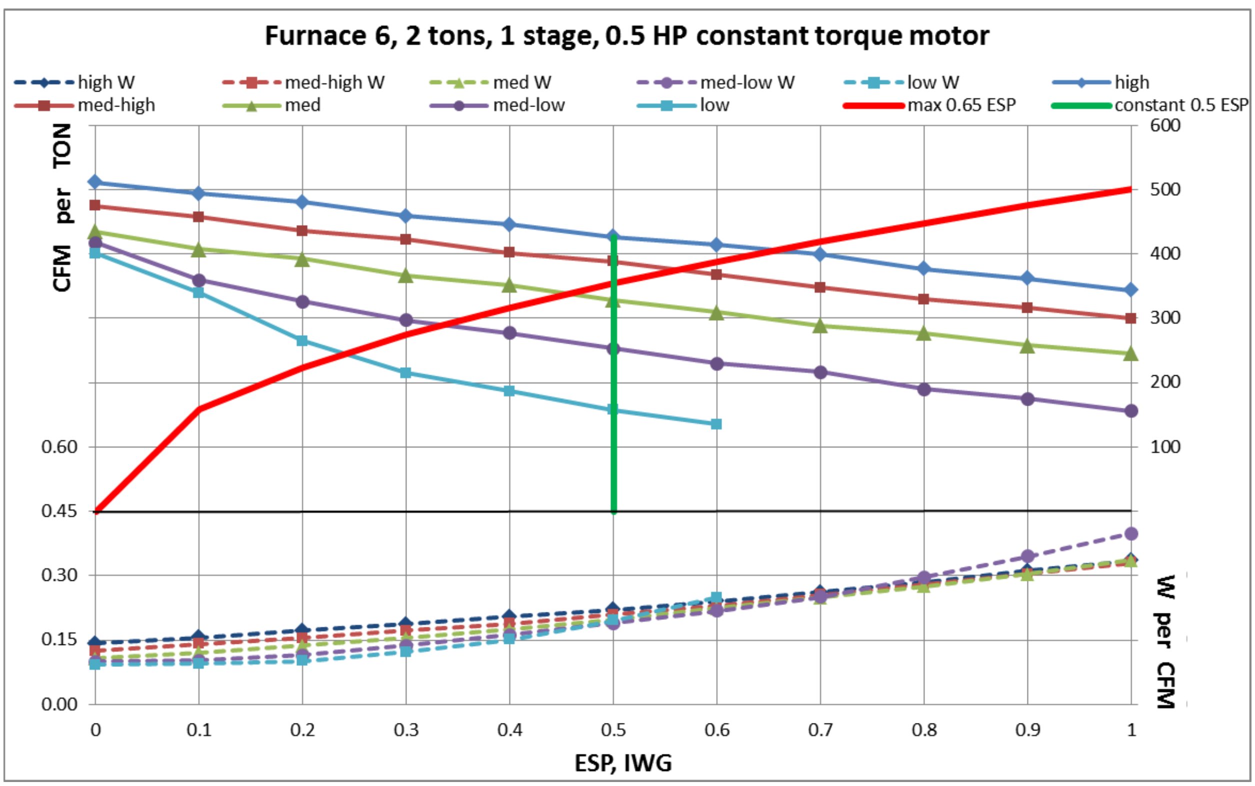


Figure 4.1.6 Furnace 6 normalized airflow and power use versus static pressure at five fan speeds

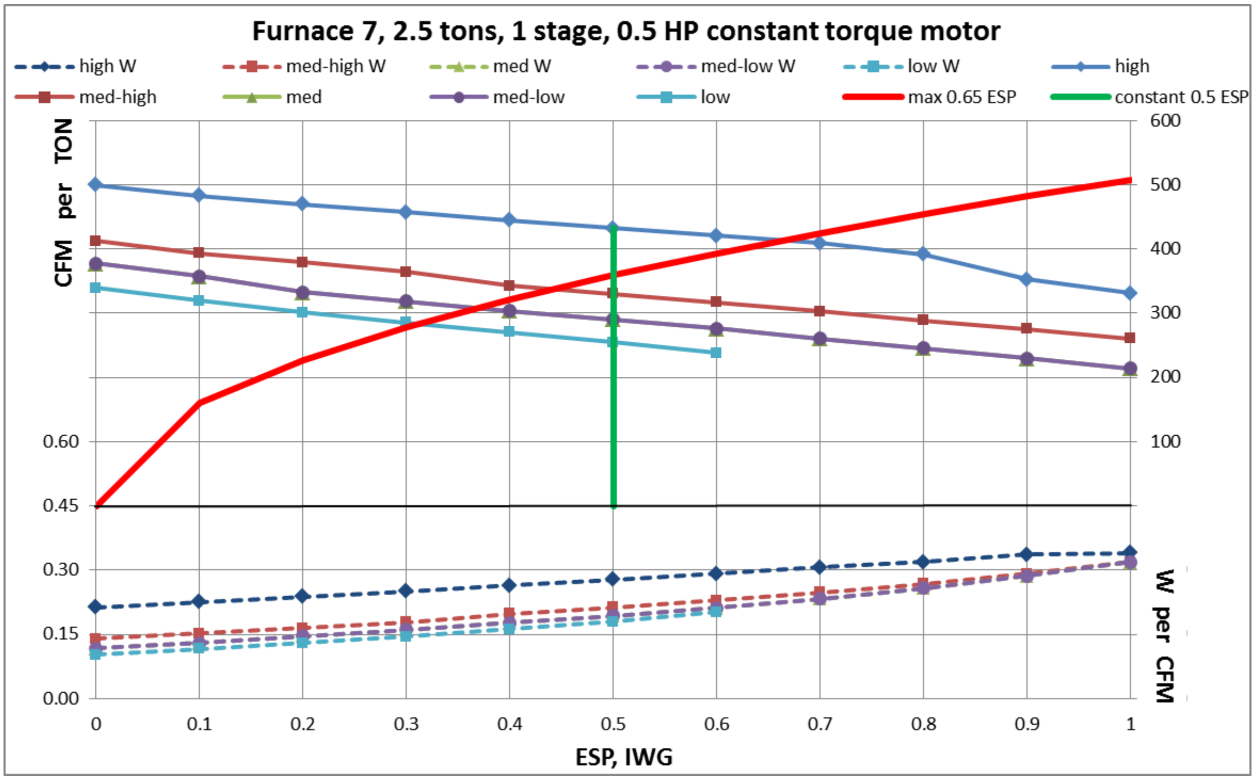


Figure 4.1.7 Furnace 7 normalized airflow and power use versus static pressure at four fan speeds

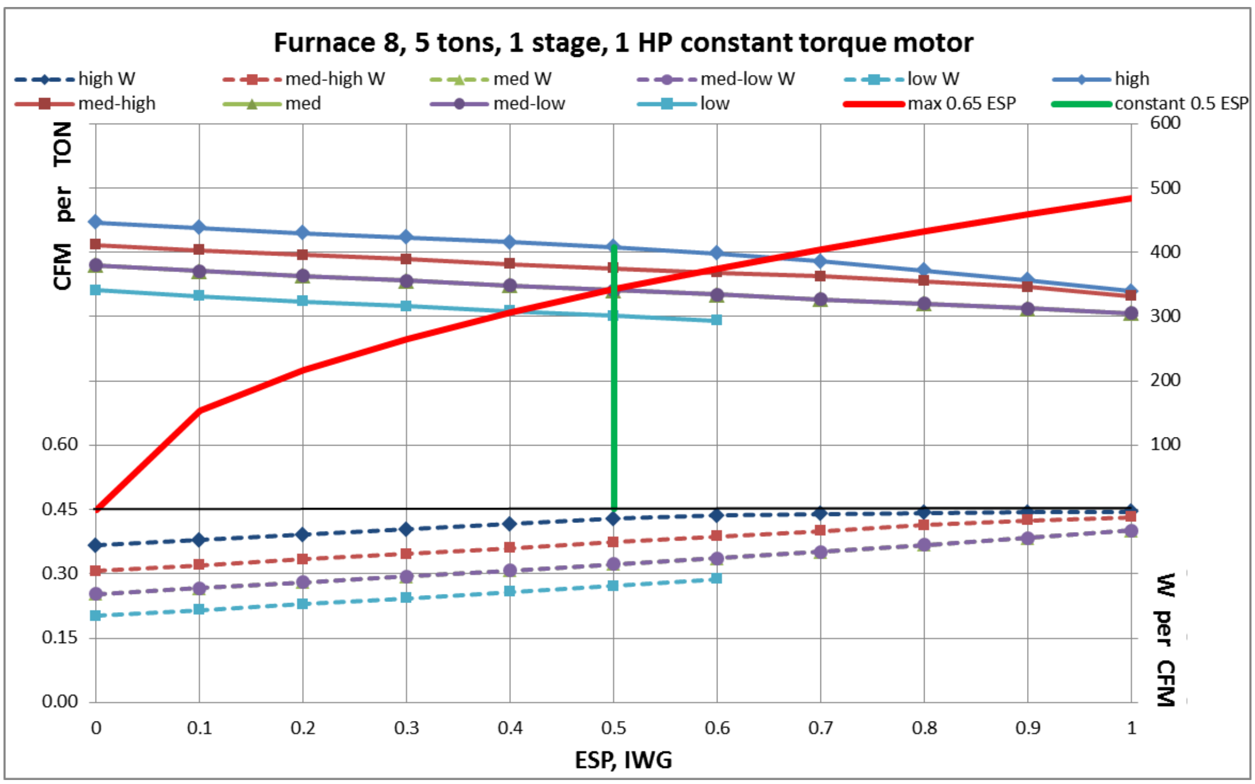


Figure 4.1.8 Furnace 8 normalized airflow and power use versus static pressure at four fan speeds

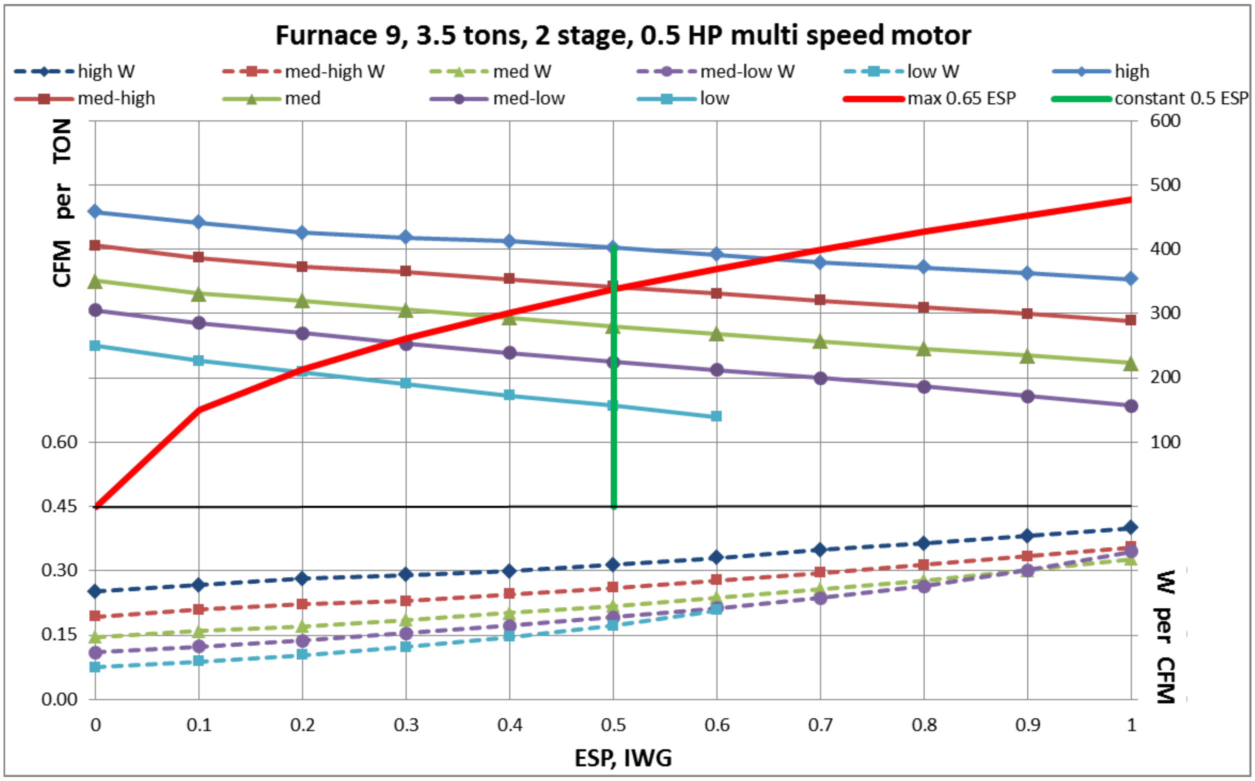


Figure 4.1.9 Furnace 9 normalized airflow and power use versus static pressure at five fan speeds

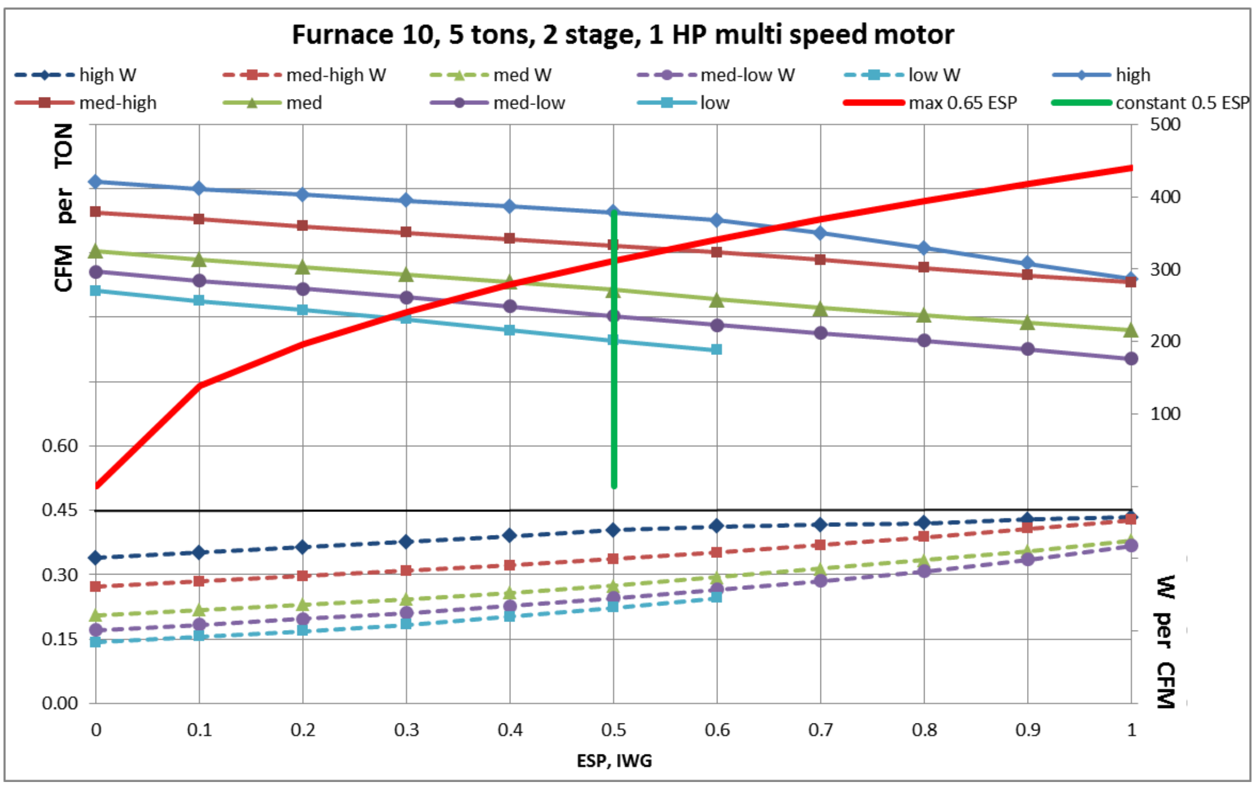


Figure 4.1.10 Furnace 10 normalized airflow and power use versus static pressure at five fan speeds

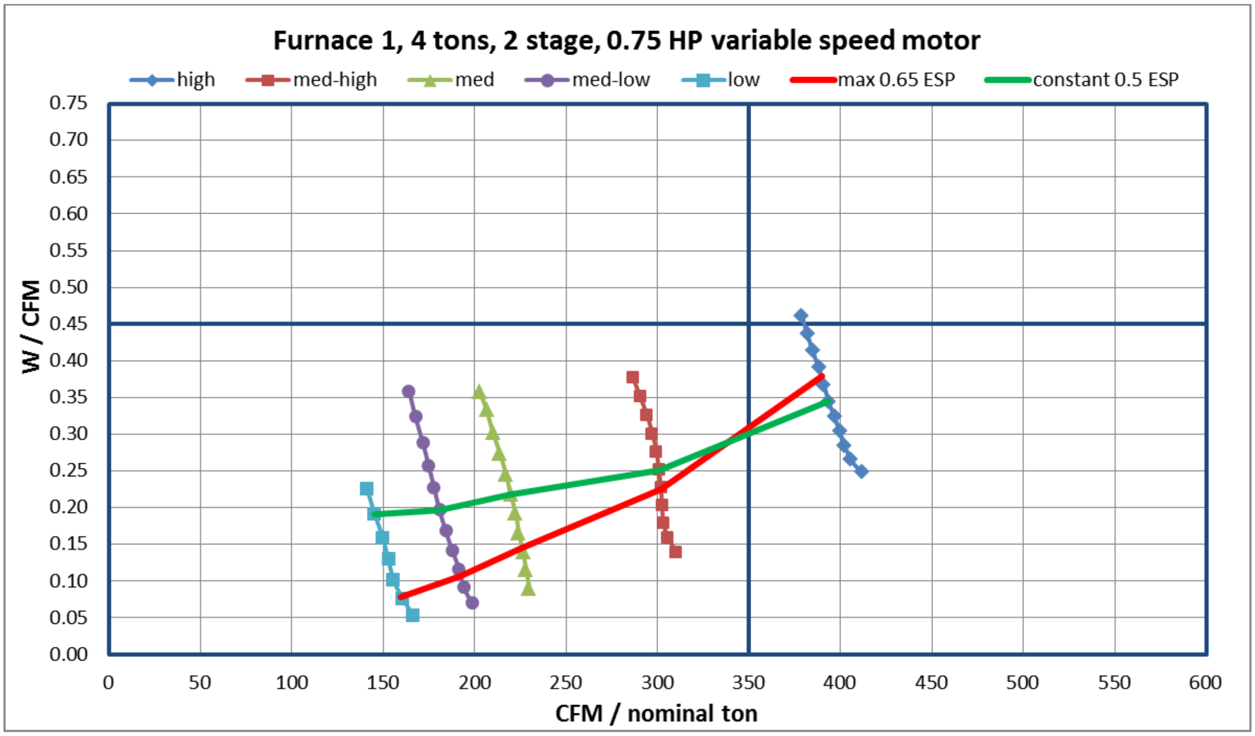


Figure 4.2.1 Furnace 1 normalized operation, W/cfm versus cfm/nominal ton

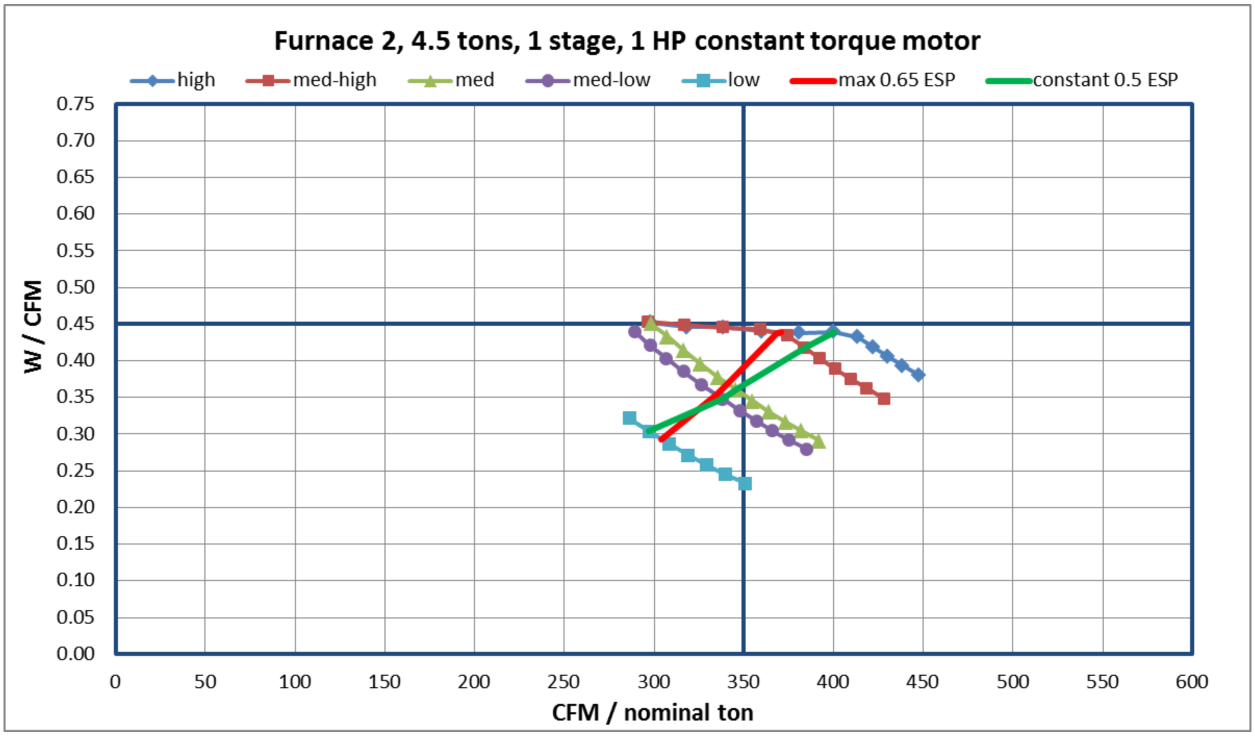


Figure 4.2.2 Furnace 2 normalized operation, W/cfm versus cfm/nominal ton

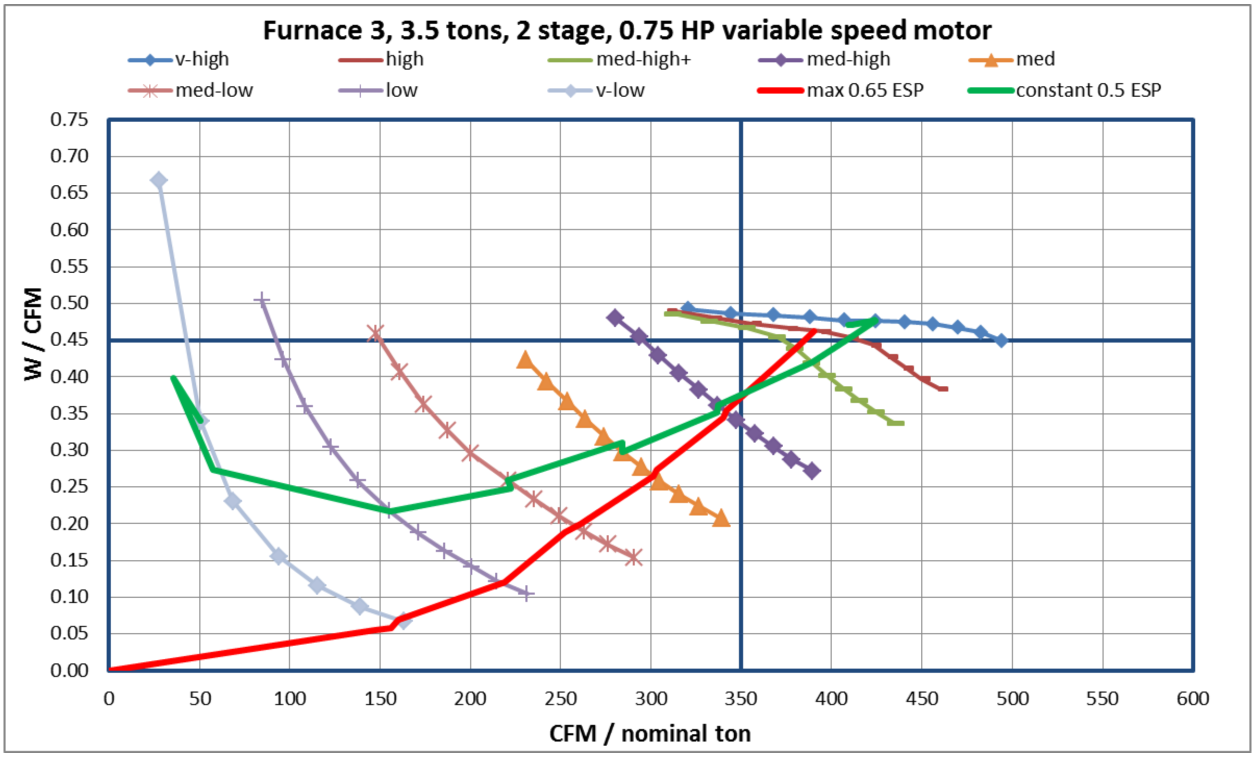


Figure 4.2.3 Furnace 3 normalized operation, W/cfm versus cfm/nominal ton

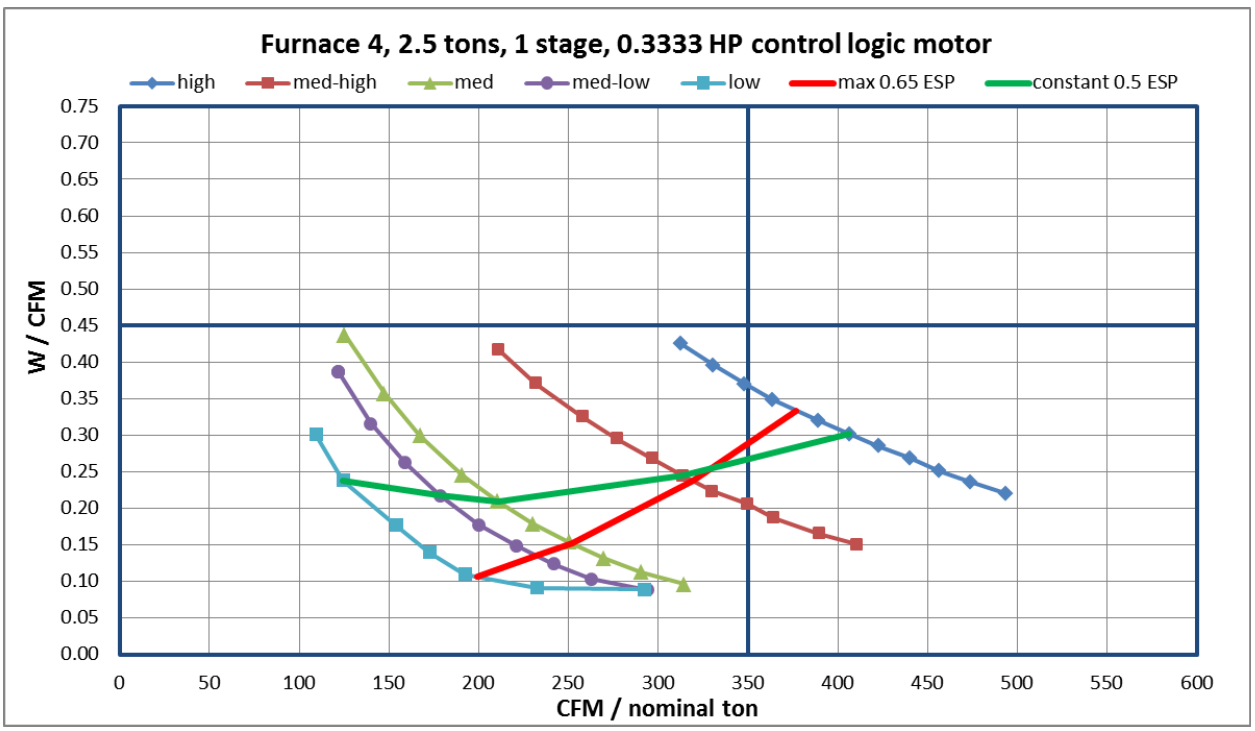


Figure 4.2.4 Furnace 4 normalized operation, W/cfm versus cfm/nominal ton

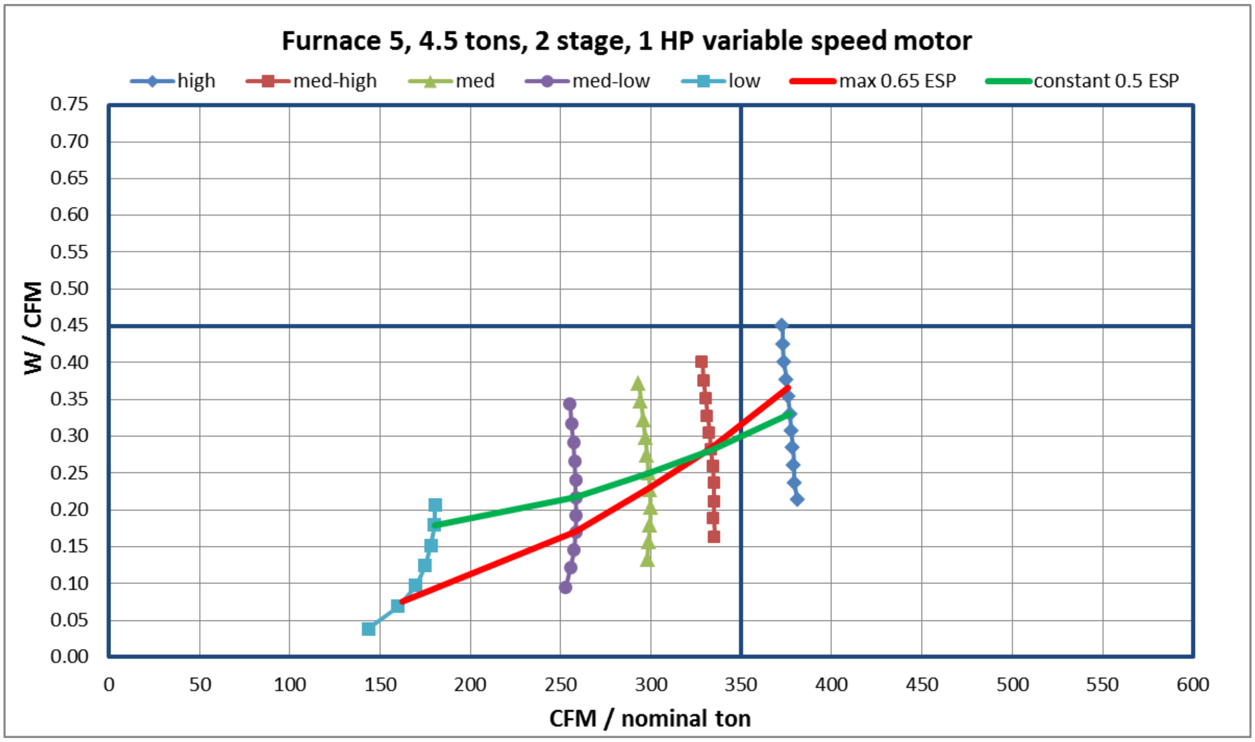


Figure 4.2.5 Furnace 5 normalized operation, W/cfm versus cfm/nominal ton

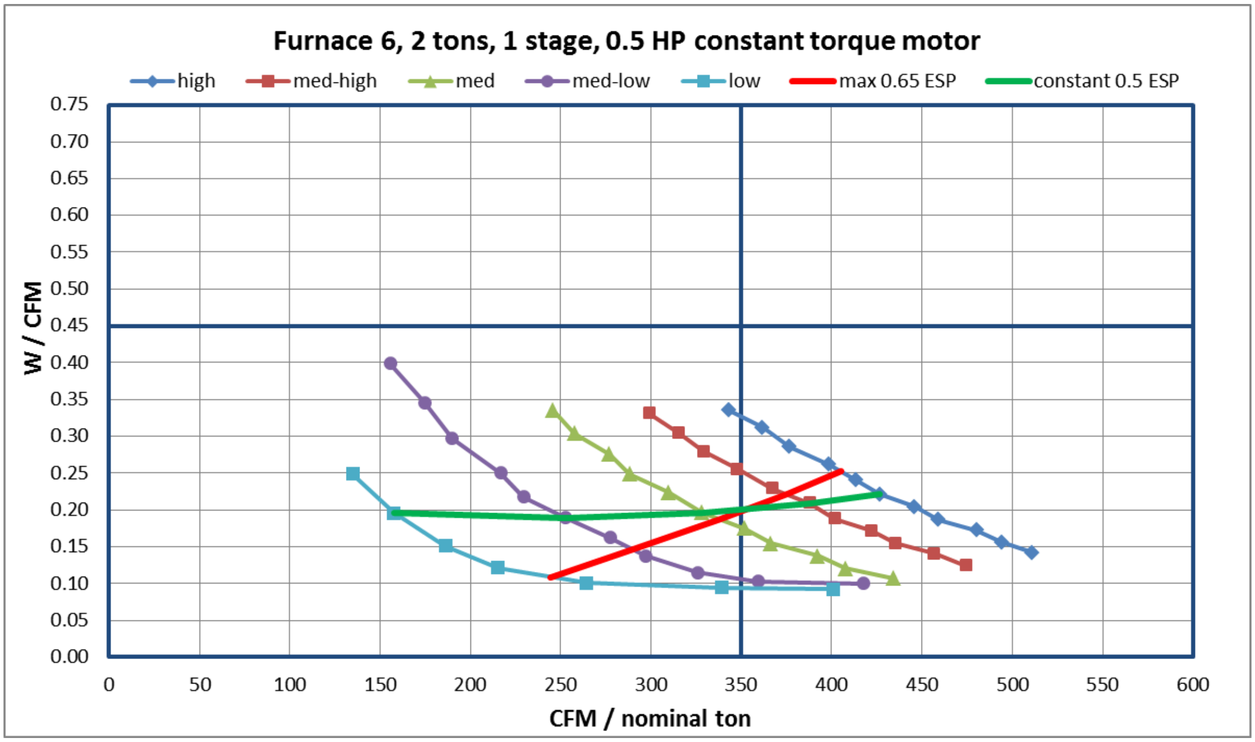


Figure 4.2.6 Furnace 6 normalized operation, W/cfm versus cfm/nominal ton

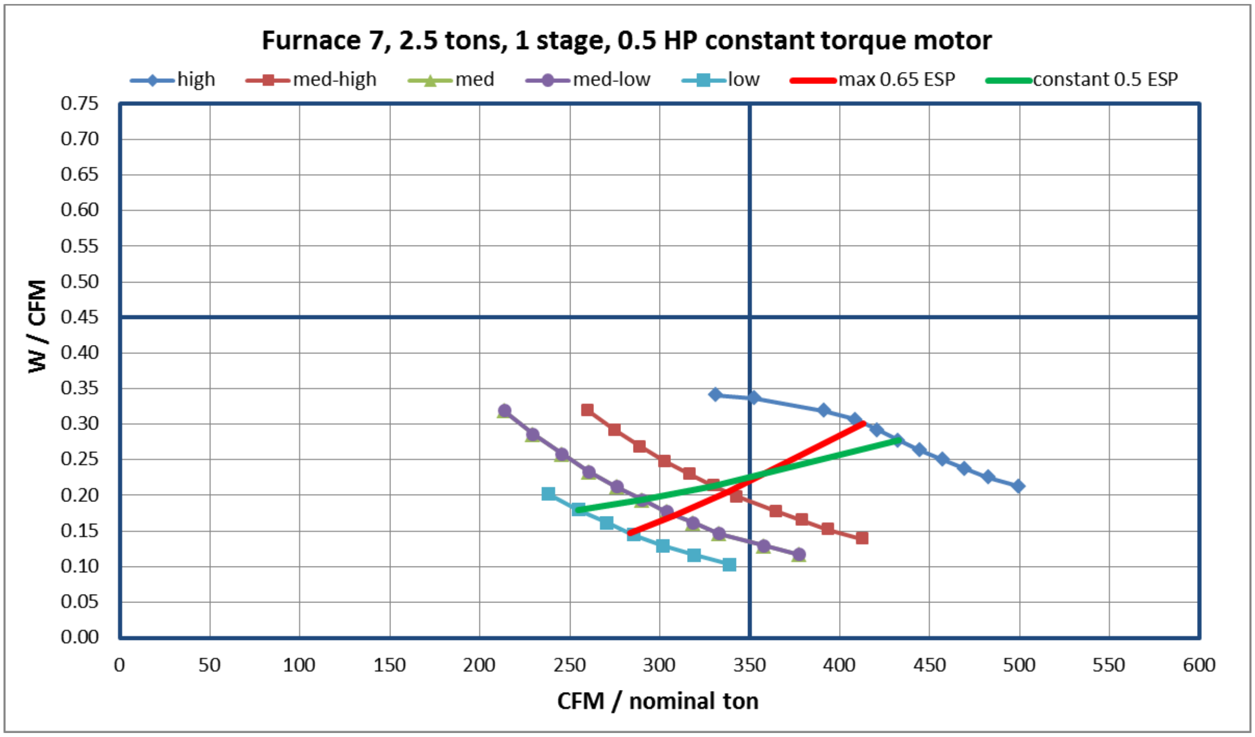


Figure 4.2.7 Furnace 7 normalized operation, W/cfm versus cfm/nominal ton

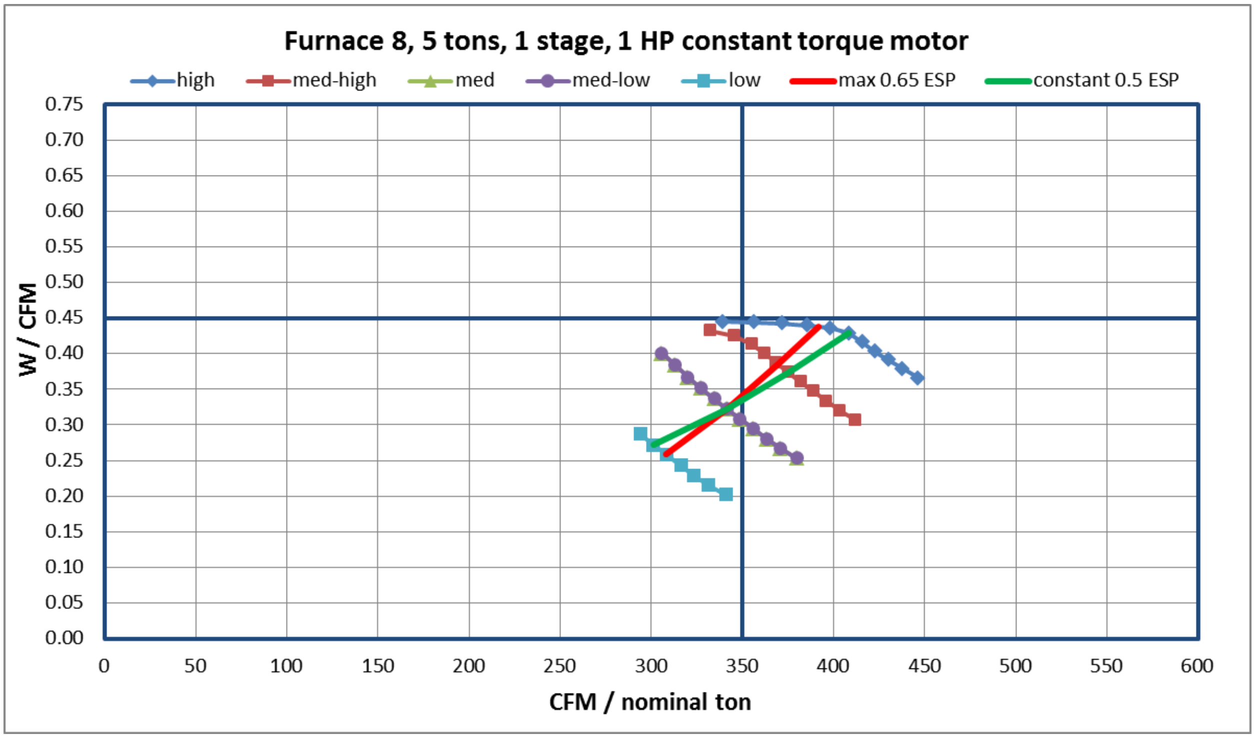


Figure 4.2.8 Furnace 8 normalized operation, W/cfm versus cfm/nominal ton

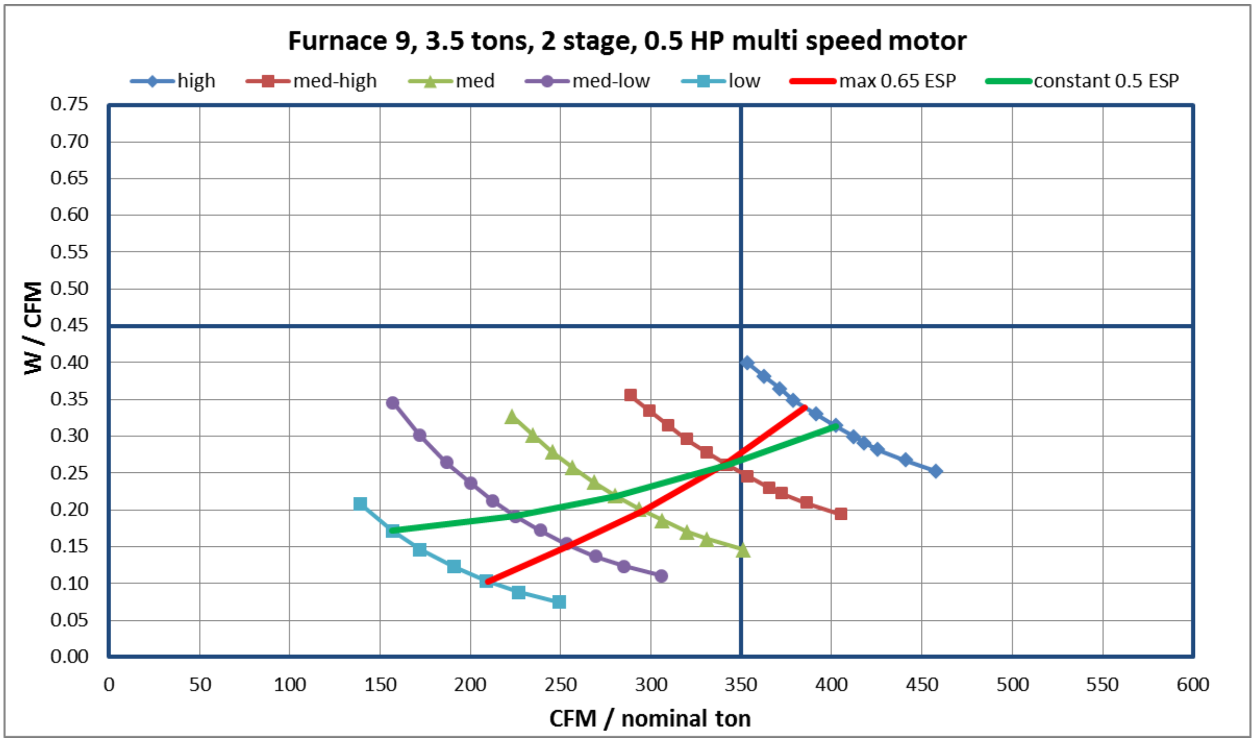


Figure 4.2.9 Furnace 9 normalized operation, W/cfm versus cfm/nominal ton

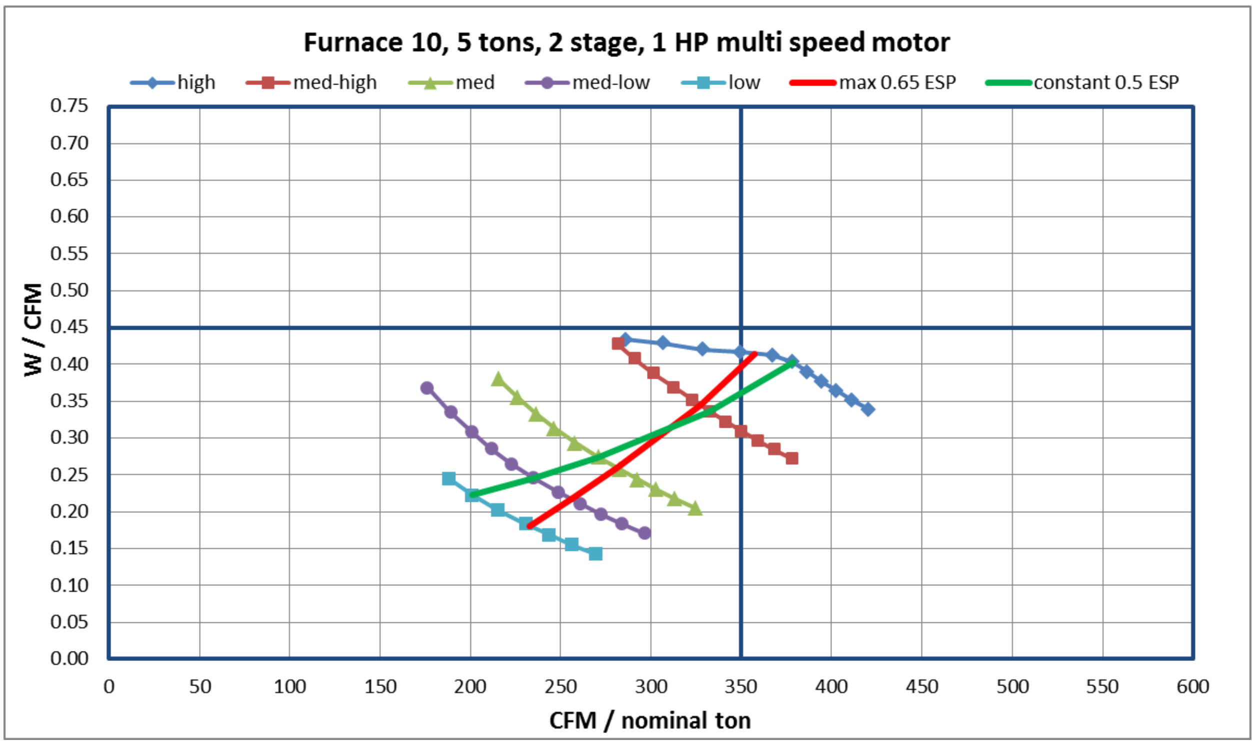


Figure 4.2.10 Furnace 10 normalized operation, W/cfm versus cfm/nominal ton

Table 4.1 displays the ability of each furnace to meet the proposed Title 24 requirements of airflow of at least 350 W/cfm, and energy use of 0.45 W/cfm or less. All furnaces tested are capable of meeting the proposed requirements both at the rated static pressure of 0.5 IWC, and on the 0.65 IWC system curve specified in the 2019 Federal standards for furnace fan testing (reference 5).

Table 4.1 Ability of tested furnace fans to deliver at least 350 W/cfm at 0.45 W/cfm or less

Furnace #	Cooling Capacity, tons	Heating Stages	Motor HP	Motor Control	Meets criteria at 0.65" ESP	Meets criteria at 0.50" ESP
1	4.0	2	3/4	variable speed	Yes	Yes
2	4.5	1	1	constant torque	Yes	Yes
3	3.5	2	3/4	variable speed	Yes	Yes
4	2.5	1	1/3	control logic	Yes	Yes
5	4.5	2	1	variable speed	Yes	Yes
6	2.0	1	1/2	constant torque	Yes	Yes
7	2.5	1	1/2	constant torque	Yes	Yes
8	5.0	1	1	constant torque	Yes	Yes
9	3.5	2	1/2	multi speed	Yes	Yes
10	5.0	2	1	multi speed	Yes	Yes

All ten furnaces tested were capable of meeting the proposed requirements. In one case, Furnace #3, fan efficacy at the maximum fan speed exceeded 0.45 W/cfm and a settings adjustment was required to produce a speed that delivered greater than 350 cfm/ton at less than 0.45 W/cfm. The adjustment involved setting two sets of dip switches on the furnace control board to produce the appropriate fan speed.

Because this was the only furnace that was unable to meet the proposed Title 24 requirements at maximum speed, it was further evaluated to determine if it is likely to meet the 2019 Federal requirements. Insufficient time was available to perform the full FER test procedure, which requires firing the furnace, so testing to enable an estimation of FER was performed. The differences between the full FER test procedure and the testing conducted to estimate FER are that: 1) The FER test procedure requires firing the furnace, and 2) the FER test procedure calculates airflows from temperature rise, furnace efficiency, static pressures and other parameters rather than performing a direct airflow measurement.

Testing to estimate FER was conducted by:

1) Selecting the maximum speed, adjusting to 0.65 IWC static pressure, and recording power and airflow. This test point establishes the system curve upon which the heating and constant circulation speed tests are also performed.

2) Reducing fan speed to the low (1st stage) heating setting as specified in the Federal test procedure for the FER rating, and recording power and airflow. For the heating speed test, the FER test procedure requires that that "In instances where a manufacturer specifies multiple airflow-control settings for a given function to account for varying installation scenarios, the highest airflow-control setting specified for the given function shall be used". In this case, the furnace was equipped with a dip switch setting to adjust heating airflow, so the higher speed setting was selected.

3) Reducing fan speed to the default constant circulation fan speed, and recording power and airflow.

Sets of measurements were made at external static pressures of 0.65 and 0.70 IWC to cover the range of static pressures allowed by DOE in the FER test procedure. Table 4.2 shows the variables used to determine the fan's tested FER and its maximum allowable FER. The measured results show that this furnace is likely to have a FER rating above 280, exceeding the maximum allowable FER of 247. Therefore, even though it can be configured to meet the proposed 0.45 W/cfm limit for California, this fan is not likely to meet the 2019 federal FER requirements.

Table 4.2 Calculation of FER for Furnace # 3

Qmax @ 0.5 IWG	**High Heating Capacity**	**Low Heating Capacity**	**HCR**	**HH**	**CH**	**CCH**	
1475	58000	38000	0.655	1267	640	400	
Heating Speed	**flow at max speed**	**ESP at max speed**	**Emax**	**Eheat**	**Ecirc**	**maximum FER**	**Tested FER**
high @ 0.70	1336	0.70	632	228	55	**247**	**287**
high @ 0.65	1370	0.65	644	225	54	**247**	**281**

5 Conclusions

A variety of furnace fans that are representative of today's low to moderate cost BPM furnaces were tested. All of the tested furnace fans were able to demonstrate compliance with the proposed fan efficacy limit of 0.45 W/cfm, while still producing at least 350W/cfm airflow at the typical rated cooling speed static pressure of 0.5 IWC. All of the tested furnaces were also compliant with the proposed Title 24 requirements when evaluated on a system curve corresponding to the Federal test procedure for the 2019 furnace fan efficacy requirements. Nine of the ten furnaces were capable of meeting the proposed requirements at the maximum speed setting. One of the furnaces required a settings adjustment to produce a compliant fan speed. Further testing determined this furnace is unlikely to meet the 2019 Federal standards.

6 References

1. *EERE-2010-BT-STD-0011-0118, Documentation of Changes between the draft Final Rule submitted to the Office of Information and Regulatory Affairs (OIRA) and the issued Final Rule*

2. *ANSI/ASHRAE Standard 37-2009, Methods of Testing for Rating Electrically Driven Unitary Air-Conditioning and Heat Pump Equipment, ASHRAE, 1791 Tullie Circle NE, Atlanta, GA 30329, 2009.* http://www.techstreet.com/ashrae/products/1650947

3. *ANSI/ASHRAE Standard 51-1999 (ANSI/AMCA Standard 210-16), Laboratory Methods of Testing Fans for Aerodynamic Performance Rating, ASHRAE, 1791 Tullie Circle NE, Atlanta, GA 30329, 1999.* http://www.techstreet.com/ashrae/standards/ashrae-amca-51-2016?product_id=1929730

4. *ANSI/ASHRAE Standard 103-1993 Method of Testing for Annual Fuel Utilization Efficiency of Residential Central Furnaces and Boilers, ASHRAE, 1791 Tullie Circle NE, Atlanta, GA 30329, 1992.* http://www.techstreet.com/ashrae/standards/ashrae-103-2017?product_id=1985882

5. *Federal Register/Vol. 79, No. 128, July 3, 2014, Code of Federal Regulations,Title-10, Chapter II, Subchapter D, Part 430, Subpart B, Appendix AA, Uniform Test Method for Measuring the Energy Efficiency of Residential Furnace Fans.* *http://www.ecfr.gov/cgi-bin/text-idx?rgn=div5&node=10:3.0.1.4.18#ap10.3.430_127.m*

6. *Residential Furnace Blower Laboratory Test Plan. Prepared by PG&E Applied Technology Services (ATS) for PG&E Codes & Standards In collaboration with Proctor Engineering Group and the California Energy Commission, September 2017.*

Res Furnace Fan Test Plan - final 11-10-17.c

Residential Furnace Blower
Laboratory Test Plan

Prepared by

PG&E Applied Technology Services (ATS)

Prepared for

PG&E Codes & Standards

In collaboration with:

Proctor Engineering Group
California Energy Commission

September 2017

Pacific Gas and Electric Company
Applied Technology Services
3400 Crow Canyon Road, San Ramon, California 94583

CONTENTS

1 Introduction

The purpose of these tests is to determine whether the ECM blower motors in a representative sample of non-weatherized furnaces can meet the proposed Title 24 requirement of delivering at least 350 cfm/ton of air using 0.45 W/cfm or less, at reasonable levels of duct static pressure. This is accomplished by testing each fan's performance at different speed settings and outlet static pressures, in order to create performance curves for each fan.

In addition, if any tested fans can't meet the proposed Title 24 requirements, more testing will be done to see if non-compliant fans meet the maximum federal Fan Efficiency Ratio (FER) of $0.044 \times Q_{max} + 182$ (for non-weatherized, non-condensing furnaces), in watts per thousand cfm. This FER standard is mandated for all furnace fans manufactured in or imported to the United States, and goes into effect on July 3, 2019. The mandate is part of the Code of Federal Regulations, which refers to a ruling by the US Department of Energy.

2 Tested Equipment

Ten furnaces with ECM blower motors have been selected for testing, and are listed in Table 1. The furnaces come from five different manufacturers, range between 40,000 to 100,000 Btuh in heating capacity, and are designed to be combined with cooling coils ranging from 2 to 5 tons of cooling capacity. They have Annual Fuel Utilization Efficiency (AFUE) ratings between 80 and 96. All of these furnaces have ECM blower motors, with sizes of ⅓ HP, ½ HP, ¾ HP or 1 HP. Two of the blower motors can be set to four different speeds, six have five operating speeds, and two are variable speed motors. The ECM motors are also controlled in two different ways: A) by holding torque constant over all operating conditions, B) by holding flow constant over all operating conditions.

Table 1: List of Test Furnaces

Furnace #	Motor HP	Speeds	ECM Descriptor	Heating Stages	AFUE	Heating Capacity, Btuh	Cooling Capacity, tons
1	3/4	variable	variable speed	2	80	61000	4.0
2	1	5	constant torque	1	92	82000	4.5
3	3/4	variable	variable speed	2	96	58000	3.5
4	1/3	5	control logic	1	80	36000	2.5
5	1	variable	variable speed	2	80	70000	4.5
6	1/2	5	constant torque	1	95	28000	2.0
7	1/2	4	constant torque	1	95	38000	2.5
8	1	4	constant torque	1	80	79000	5.0
9	1/2	5	multi speed	2	80	48000	3.5
10	1	5	multi speed	2	96	96000	5.0

3 Experimental Setup

Using the HVAC test facility, ATS staff shall conduct testing of ten packaged residential furnaces for blower performance, in terms of CFM per watt at different levels of external resistance. The test apparatus will utilize existing systems in the ATS HVAC lab to provide measurement of airflow at different levels of backpressure. Due to equipment crowding in the “Indoor Room” of the lab, the test furnaces will be placed in the “Outdoor Room” with their discharge ducted to the Indoor Room airflow measurement apparatus. Backpressure at the furnace discharge will be set and maintained through a combination of changing the number of open nozzles in the airflow apparatus and adjusting the speed of the booster blower downstream of the apparatus.

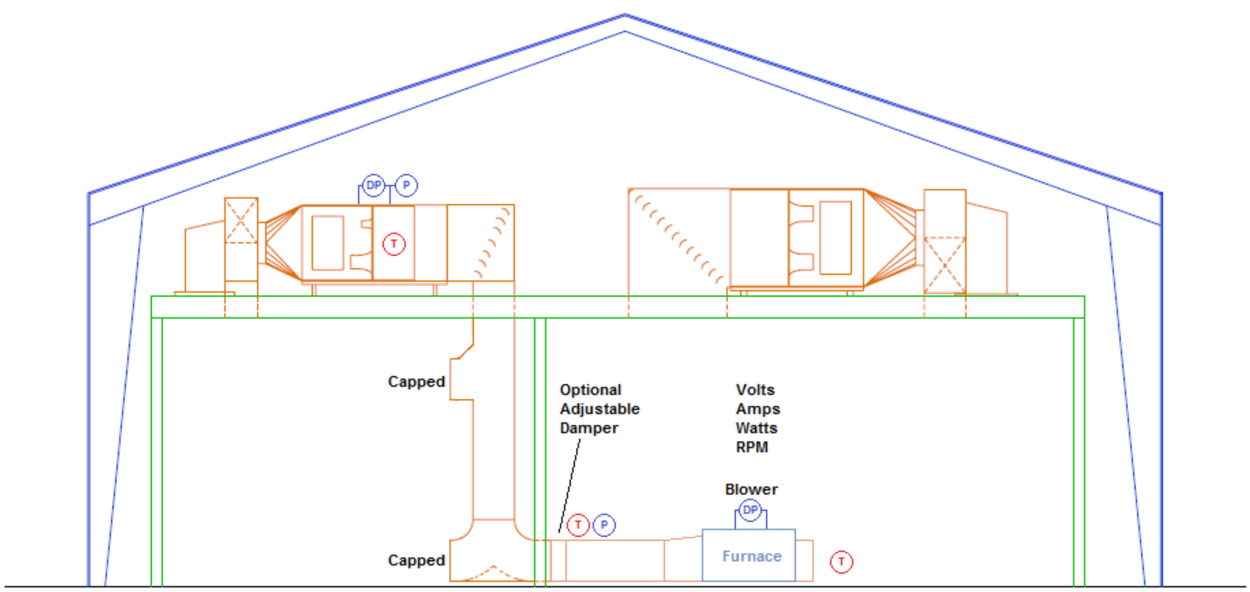


Figure 1: HVAC Lab Setup for Furnace Tests

Optionally, a damper may be placed downstream of the pressure measurement to provide additional resistance if not enough flexibility is possible using the selected nozzle combinations and by keeping the air velocity through the nozzles within the range recommended by Standards (3,000 to 7,000 fpm). This may not be advisable as it may create more potential for duct leakage.

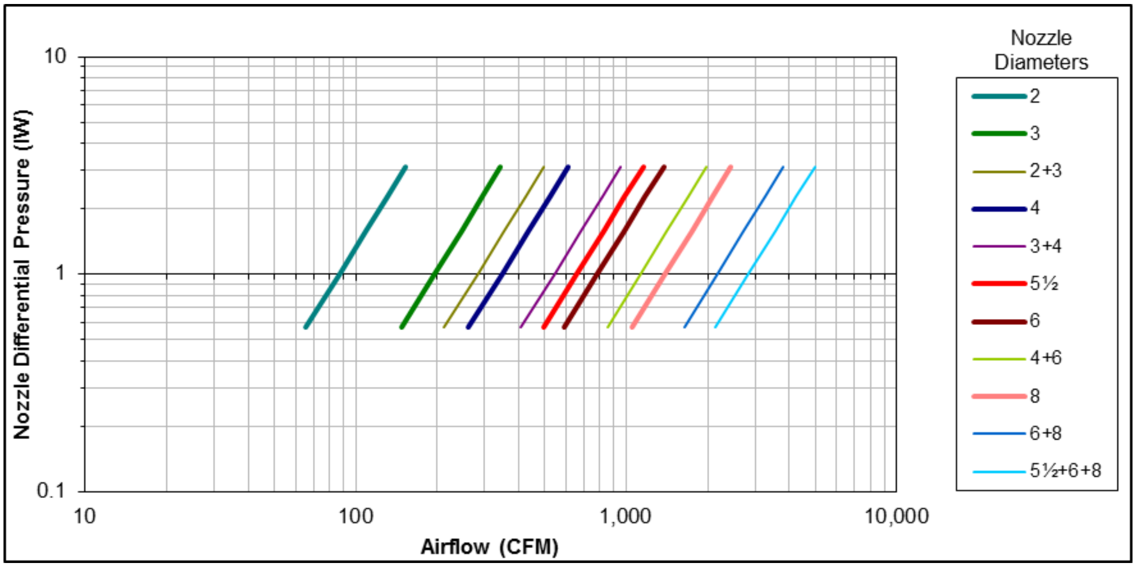


Figure 2: Airflow Apparatus Operating Range

All testing is performed with a free or short ducted inlet (<12 inches) and a ducted outlet. The location of the pressure measurement for backpressure shall be done in accordance with ASHRAE Standard 37-2009. There are two ASHRAE Standards that specify minimum straight duct length and use of flow straighteners and settling means to ensure reliable pressure measurements. The 2012 DOE procedure for furnace blower testing references AMCA 210/ASHRAE 51-1999, while the current draft of the procedure revision references ASHRAE 37-2009. The main difference is that ASHRAE 51-1999 requires a flow straightener, as well as a longer length of duct than ASHRAE 37-2009 (see Figure 3). The preference is to use ASHRAE 37 to save space and to reduce errors from duct friction.

Pressure measurement setup per ASHRAE 37: (DOE e-CFR document references this method.)	Test setup per AMCA 210/ASHRAE 51: (DOE 2012 PDF document references this method – longer duct plus straightener.)

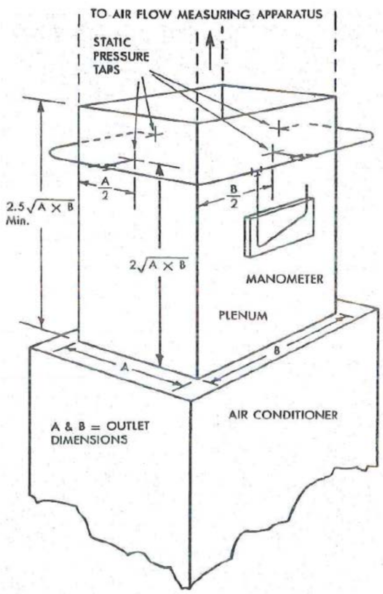
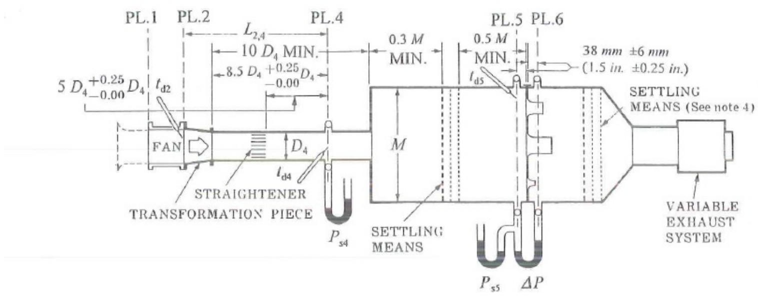


Figure 7a External static pressure measurement.



NOTES

1. Dotted lines on fan inlet indicate an inlet bell and one equivalent duct diameter which may be used for inlet duct simulation. The duct friction shall not be considered.
2. Additional ductwork of any size, including elbows, may be used to connect between the chamber and the exit of the 10 D minimum test duct.
3. Variable exhaust system may be an auxiliary fan or a throttling device.
4. The distance from the exit face of the largest nozzle to the downstream settling means shall be a minimum of 2.5 throat diameters of the largest nozzle.
5. Minimum M is determined by the requirements of 6.3.1 for this figure.

FLOW AND PRESSURE FORMULAE

$$*Q_5 = \sqrt{2}\, Y \sqrt{\Delta P / \rho_5}\, \Sigma(CA_6)$$

$$Q = Q_5 \left(\frac{\rho_5}{\rho}\right)$$

$$V_4 = \left(\frac{Q}{A_4}\right)\left(\frac{\rho}{\rho_4}\right)$$

$$*P_{v4} = \left(\frac{V_4}{\sqrt{2}}\right)^2 \rho_4$$

$$P_{v2} = P_{v4}\left(\frac{A_4}{A_2}\right)^2\left(\frac{\rho_4}{\rho_2}\right)$$

$$P_{t1} = 0$$

$$P_{t2} = P_{s4} + P_{v4} + f\left(\frac{L_{2,4}}{D_{h4}} + \frac{L_e}{D_{h4}}\right) P_{v4}$$

$$P_t = P_{t2} - P_{t1}$$

$$P_s = P_t - P_v$$

*The formulae given above are the same in both the SI and the I-P systems, except for Q_5 and P_{v4}: In the I-P version, the constant $\sqrt{2}$ is replaced with the value 1097.

Figure 10 Outlet Duct Setup-Multiple Nozzles in Chamber

ANSI/AMCA STANDARD 210 ANSI/ASHRAE STANDARD 51 29

Figure 3: Standard Pressure Measurement Options

From recent testing of a split system heat pump using the ASHRAE 37 outlet duct configuration, 10 second pressure measurements over at least a half hour were found to vary by less than 0.0062 IWG at a static pressure of 0.1 IWG, and by less than 0.0048 at a static pressure of 0.45 IWG. We aim to set static pressure for this furnace fan test to within ±1% of the highest static pressure test value of 0.9 IWG, or to within ±0.009 IWG. Even though the furnaces tested will not have a cooling coil to help settle the flow, we feel confident that the shorter Standard 37 outlet duct configuration can meet this level of accuracy.

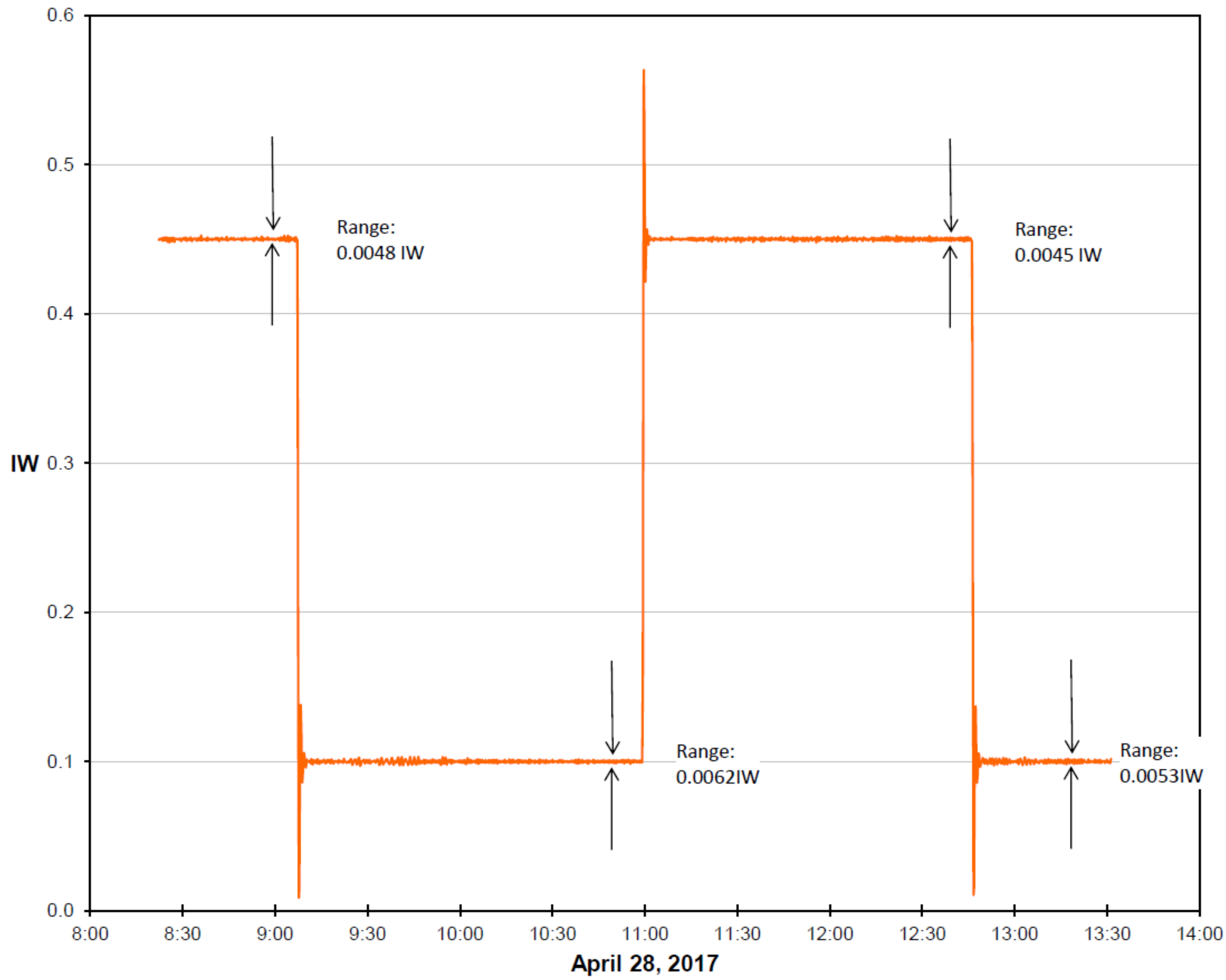


Figure 4: Recent Test holding Fixed Backpressure

The length of the transformation piece (from the furnace outlet, which varies in size with each furnace, to the length of duct where outlet static pressure is measured) will vary in order to accommodate the requirements of Section 6.2.5 and Figure 5 of ASHRAE Standard 51-1999 for the maximum angle of convergence or divergence of the duct wall.

Great care must be taken to keep duct leakage to a minimum, since no leakage corrections are made to the test results. Use mastic or foil tape to seal the transformation piece at the furnace outlet and outlet duct connections. Look, listen, and feel for any air leaks at all duct connections in the test apparatus after each new furnace has been installed, and reseal leaks with mastic or foil tape as needed.

All furnaces are to be initially positioned for horizontal airflow. A subset of four to six furnaces is to be tested again in up-flow or down-flow position with additional ducting. Due to height restrictions, an elbow may be needed in either up-flow or down-flow orientation at the test unit discharge prior to the pressure measurement.

The temperature rise across the blower (with or without the burner in operation) will be measured as the difference between two thermocouple arrays. A short duct (12 inches) may be attached to the intake side of the furnace to provide a structure to hold the thermocouples in place. If used, the backpressure measurement will be a differential static pressure measurement between the manifold on the discharge side and a manifold attached to the short intake duct. The temperature rise is of interest even with the burner off as an indication of how much heating the motor actually does. No filters will be used.

The furnace burner will not be fired for any performance curve testing, but may need to be fired if any FER testing (described later in this test plan) is performed. The downstream temperature array will be installed such that when the burner on the furnace is activated, the temperature sensors will not “see” the hot surfaces in the furnace. This generally means the array is placed downstream of an elbow and/or a mixing device. Figure 5 shows the recommended locations from ASHRAE 103

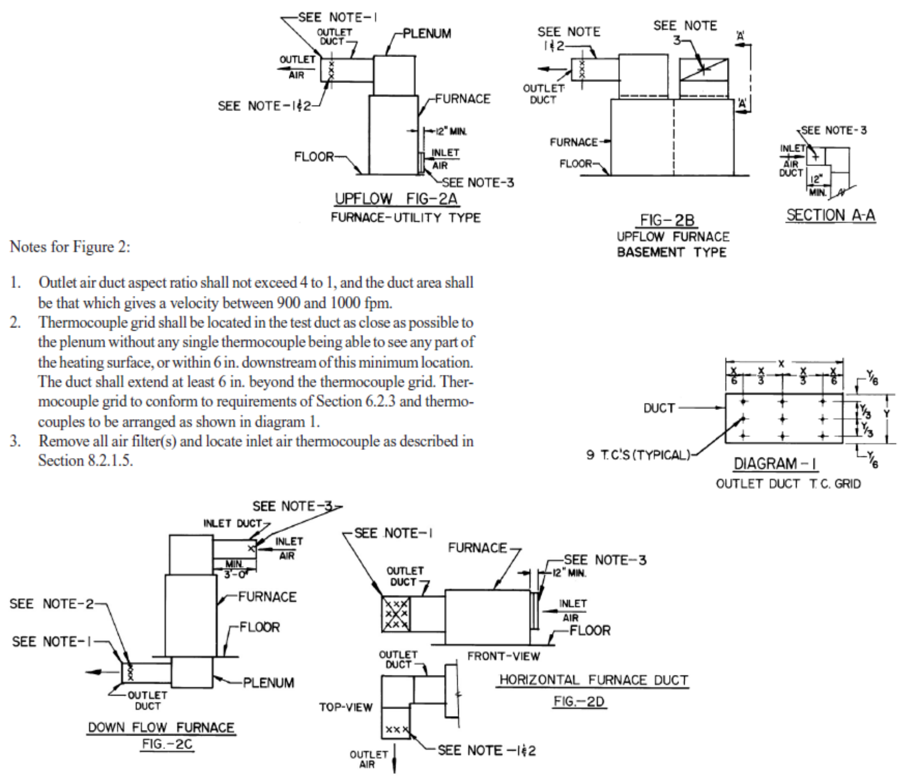


Figure 2 Duct and plenum arrangement for gas, oil, and electric forced-air central furnaces (including direct vent).

Figure 5: Temperature measurement setup per ASHRAE 103

4 Instrumentation

The controllable parameters of the test include:

- o Blower speed setting
- o Furnace external resistance (or differential pressure)
- o Return air temperature or density

- Supplied voltage (within 1% of nameplate voltage; held via a voltage regulator)

The dependent variables to be measured include:

- Airflow rate (cfm, referenced to return air density)
- Power consumption (watts), and power quality, of furnace input and blower only
- Blower rotational speed (rpm)
- Blower pressure rise
- Blower temperature rise

Table lists the instrumentation already installed in the HVAC test lab that will be used for these tests.

Table 2: Instrumentation List

Measurement	Instrument	Manufacturer / Model	Accuracy
Barometric Pressure	Multi-function weather station on roof of building	Vaisala WTX520	±0.007 PSIA (±50 Pa)
Return air dry-bulb temperature	Average of 4 Type-T thermocouples arrayed in a 2×2 grid across the intake duct, or 4 RTDs.	Therm-X Burns Engineering	±0.5°F ±0.2°F
Return air dew-point temperature and/or wet bulb temperature	Chilled mirror dew point sensor Paired wet and dry bulb RTDs	General Electric Optica Burns Engineering	±0.36°F ±0.2°F
Supply air dry-bulb temperature	Average of 9 Type-T thermocouples arrayed in a 3×3 grid across the supply duct and downstream of the static pressure measurement taps, and not "visible" to the heated burner surfaces if it needs to be activated.	Therm-X	±0.5°F
Supply-return differential pressure	Pressure transmitter attached to manifolded pressure taps at center of each side of duct entering and leaving the unit	Rosemount 3051C	±0.04% of span (-0.5 to 1.5 IW)
Blower differential pressure	Pressure transmitter connected between the taps on either side of the blower (i.e. across the furnace partition).	Rosemount 3051C	±0.04% of span (-1 to 3 IW)
Supply airflow station upstream static pressure	Pressure transmitter attached to manifolded pressure taps at center of each side of the flow box upstream of the nozzle partition	Rosemount 3051C	±0.04% of span (-1 to 3 IW)
Supply airflow station differential pressure	Pressure transmitter attached to manifolded pressure taps at center of each side of the flow box on both sides of the nozzle partition	Rosemount 3051C	±0.04% of span (0 to 4 IW)
Supply airflow station dry bulb temperature	Single fast-response RTD upstream of nozzles	Burns Engineering	±0.2°F
Unit Supply Power, Voltage and Current	Two elements of a 3-element true-RMS power meter with outputs for total power, voltage and current. One element is for the input to the furnace and the other is just for the blower.	Yokogawa WT330	±(0.1% of reading +0.1% of range)
Blower Speed	Optical tachometer reading reflective tape on indoor blower impeller.	Monarch ACT-1B	±1 RPM or 0.005% of reading
Gas Quantity (if needed)	Diaphragm meter with pulse output (2000 counts per cubic foot)	American Meter AC-250 with IMAC pulse head	
Gas Flow Rate (if needed)	Thermal mass flow meter	Sierra SmartTrak 100	±1.0% of full scale
Gas Heating Value (if needed)	Natural gas chromatograph	Rosemount 370XA	±0.025% repeatability

All pressure and temperature instruments will be calibrated against laboratory standards prior to testing.

5 Test Procedures

Various operating conditions are simulated by controlling static pressure at the furnace outlet. Static pressure control is done by adjusting flow nozzle combinations and/or adjusting the speed of an auxiliary exhaust fan, according to Section 6.4 of Reference 2.

The test facility has the ability to control inlet conditions by adjusting temperature and humidity levels in the inlet chamber. For the fan curve performance tests, air density should be held within ± 0.5% of 0.075 lbm per cubic feet. This is the density designated as "Standard Air" in Section 3.2.7 of Reference 2.

In addition, adjustments may be made to the static pressure at the furnace outlet in order to keep the value of "k" constant to within ± 1% for each fan. The value of k is calculated as:

$$k = P / (\rho \times N^2),$$

where P is the outlet total pressure found by adding the static pressure in the outlet duct to the barometric pressure at the fan inlet, and N is the fan rotational speed. The duct air density, ρ, is calculated using equations 8.1 through 8.4 from Reference 2, based on barometric pressure, inlet dry and dew point or wet bulb temperatures, and the static pressure and dry bulb temperature in the outlet duct.

Voltage supplied to the unit under test will be held to within 1% of the nameplate voltage via a voltage regulator.

5.1 Fan Performance Curve Testing Procedure

Once each furnace has been installed, and all ducts have been carefully sealed, adjust the inlet conditions to reach an air density of 0.075 lbm/cubic feet ± 0.5%.

Adjust the fan motor speed taps for the highest airflow setting. Adjust exhaust fan and throttling valves until an outlet duct static pressure of 0.1 inches of water gauge (IWG) has been reached. Allow the system to come to steady state, then record the measurements listed in Table 2. Data recording will be done at a rate of every 10 seconds and averaged over 10 minutes, subject to the test tolerances specified in Reference 1. Keep adjusting exhaust fan and nozzles to reach successive outlet static pressures of 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, and 0.9 IWG, and take steady state readings at each static pressure. Using information about the flow nozzle areas, calculate fan airflow based on the dry-bulb and differential pressure measurements taken across the nozzle or chamber and using the appropriate equations from Section 8.3 of Reference 2.

Note that the static pressure for each test can be within a tolerance of ±1% of the highest static pressure reading to be made during these tests, which is within ±0.9×1% = ±0.009 IWG. The static pressures to aim for (0.1, 0.2, 0.3 IWG, etc.) may also be adjusted slightly to keep the value of “k” constant, as described above.

5.2 Fan Energy Rating (FER) Testing

FER testing will only be needed for fans that cannot supply at least 350 cfm per ton of nominal cooling capacity at top speed and a static pressure of 0.5 IWG, while using 0.45 watts per cfm or less. The FER test procedure for furnace fans without an added cooling coil in place has three basic steps:

1. At the maximum (cooling) fan speed setting and a fan outlet static pressure between 0.65 and 0.70 IWG, measure fan energy characteristics.

2. Keeping the throttle position and exhaust fan settings as they are, adjust the fan to its fan-only / continuous fan setting, usually the lowest fan speed setting, and measure fan energy characteristics.

3. Again keeping the throttle position and exhaust fan settings as they were in step 1, adjust the fan to its **maximum** heating speed setting, fire up the furnace burner to its **lowest** heat rate setting (equal to its maximum setting for single stage furnaces), make sure the inlet air is heated by at least 18 degrees Fahrenheit, and measure fan energy characteristics once equilibrium has been reached.

Because this testing is being completed on a short deadline, and other testing is underway in the ATS laboratory, the furnaces are to be located in the “outside room” of the ATS laboratory. This section of the lab does not have easy access to gas lines or an exhaust gas flue. Therefore the heating measurements will be performed at room temperature, without firing up the furnace burner. For the same reason, the calculation to estimate FER will reference directly measured airflow instead of calculated airflow based on temperature rise and steady state furnace efficiency.

The same test apparatus from the Fan Performance Curve testing can be used as long as the furnace can also be supplied with natural gas, is hooked up to an appropriate flue, and is fired according to specifications, all as laid out in ASHRAE Standard 103-2007.

Based on these three measurements, FER is calculated as follows:

$$FER = \frac{(CH \times E_{Max}) + (HH \times E_{Heat}) + (CCH \times E_{Circ})}{(CH + 830 + CCH) \times Q_{Max}} \times 1000$$

The values of E represent the power use of the fan in watts at each fan setting, Q max is the maximum nameplate fan flow in cubic feet per minute (CFM), and the operating hours are defined as CH = annual cooling hours (640), CCH = annual constant circulation hours (400), and HH = annual heating hours (830/HCR). HCR is the heating capacity ratio defined as the flowrate at the maximum heating speed divided by the maximum nameplate flow rate of the unit (usually the maximum cooling speed). More information about the FER test procedure can be found in Reference 4.

6 References

1. ANSI/ASHRAE Standard 37-2009, *Methods of Testing for Rating Electrically Driven Unitary Air-Conditioning and Heat Pump Equipment*, ASHRAE, 1791 Tullie Circle NE, Atlanta, GA 30329, 2009. http://www.techstreet.com/ashrae/products/1650947

2. ANSI/ASHRAE Standard 51-1999 (ANSI/AMCA Standard 210-16), *Laboratory Methods of Testing Fans for Aerodynamic Performance Rating*, ASHRAE, 1791 Tullie Circle NE, Atlanta, GA 30329, 1999. http://www.techstreet.com/ashrae/standards/ashrae-amca-51-2016?product_id=1929730

3. ANSI/ASHRAE Standard 103-1993 *Method of Testing for Annual Fuel Utilization Efficiency of Residential Central Furnaces and Boilers*, ASHRAE, 1791 Tullie Circle NE, Atlanta, GA 30329, 1992. http://www.techstreet.com/ashrae/standards/ashrae-103-2017?product_id=1985882

4. DOE Title-10, Chapter II, Subchapter D, Part 430, Subpart B, Appendix AA, *Uniform Test Method for Measuring the Energy Efficiency of Residential Furnace Fans*. *http://www.ecfr.gov/cgi-bin/text-idx?rgn=div5&node=10:3.0.1.4.18#ap10.3.430_127.m*