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Comparing Residential Furnace Blowers for Rating and Installed Performance

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ABSTRACT

The objective of this study was to assess the performance of residential furnace blowers for both heating, cooling and air distribution applications and to compare their performance at DOE/ARI rating conditions (for AFUE and SEER) and at real installed conditions. A testing program was undertaken at two laboratories to compare the performance of furnace blowers over a range of static pressure differences that included standard rating points and measured field test pressures. Three different combinations of blowers and residential furnaces were tested. The laboratory test results for blower power and airflow were combined with DOE2 models of building loads, models of air conditioner performance, standby power, as well as igniter and combustion air blower power to determine potential energy and peak demand impacts. The results show distinct differences between the two types of furnace blower motor technology: Permanent Split Capacitor (PSC) and more efficient Brushless Permanent Magnet (BPM). The high static pressure differences in real installations reduce the advantage that BPM driven blowers have at DOE/ARI rating conditions such that for cooling the two motor technologies have essentially the same power consumption although the reduction in airflow for the PSC driven blower results in 10% lower air conditioner efficiency. For heating, the advantage of the BPM blower is approximately halved when changing from standard test conditions to installed conditions, although the BPM blower has the advantage of maintaining airflow that avoids the safety implications of the PSC blower's lower airflow. The BPM blower retains its advantage for multi-speed systems that can operate for significant numbers of hours in low-fire mode. To better reflect blower performance it is recommended that appliance rating test procedures be amended to use realistic system static pressures of between 0.5 and 0.8 in. water (125 and 200 Pa) and that utility rebate programs ensure that rebates are provided for multi-speed systems and/or systems that have a field measured low static pressure difference below 0.5 in. water (125 Pa).

INTRODUCTION

The blowers in residential furnaces typically move heated or cooled air through a duct system that distributes the air and then returns it to the furnace. Usually the blowers are double inlet models with air entering the centrifugal blower wheel at both sides. The motor mounts inside one side of the blower. Some systems also use the central blower to distribute ventilation air or to mix air to improve comfort and reduce stratification.

Although furnaces, air conditioners and heat pumps have become significantly more efficient over the last couple of decades, residential forced air system blowers have not experienced similar improvement. The most common blowers have been shown by field testing to have efficiencies of only 10% to 15% (Phillips 1998 and 1995, and Gusdorf et al. 2002). These low efficiencies indicate that there is significant room for improvement of both electric motor and the aerodynamic performance of furnace blowers.

The U.S. Environmental Protection Agency (EPA) and the California Energy Commission (CEC) are both considering accounting for the electricity use of furnaces and furnace blowers. The EPA requirements are still being decided, but are likely to either be a fixed kWh/year number (available from the GAMA Directory (GAMA 2006)) or kWh/year proportional to the furnace output or input. For example, the GAMA directory already lists "electrically efficient" furnaces whose electrical consumption is 2% or less of total annual energy consumption. This approach therefore uses test data from furnaces evaluated at the AFUE rating conditions of extremely low external static pressure. The CEC proposal for the 2008 California Residential Building Efficiency Standards is to require field testing of airflow and power consumption and use a W/1000 cfm metric (Wilcox 2006), where credit would be given for systems using less than 400 W/1000 cfm (while simultaneously requiring more than 350 cfm/ton of cooling capacity). The CEC proposal has the advantage of testing systems as they are actually installed.

An important consideration in analyzing forced air system blowers is that essentially all of the wasted electricity is manifested as heat. This extra heat reduces air conditioning cooling performance and effectively acts as an electric supplement to fossil-fueled furnaces. For heat pumps, this heat substitutes for vapor compression-based high COP heating and effectively reduces the COP of the heat pump.

This study combines the results of field tests to determine typical operating conditions with detailed laboratory performance mapping to determine the power consumption of the blowers. Additional calculations and modeling were used to account for the interactions of the blowers with HVAC equipment to account for performance issues such as the extra heating effect of the blowers and the effect on air conditioner performance with airflow.

The results of this study are important to several constituents. From a national and state public policy point of view, if the EPA and CEC wish to make informed decisions regarding blower performance it is critical that actual field performance is document and understood. This allows the setting of reasonable performance expectations and credits for better performance. If utilities (an the commissions that oversee them) want to have rebate programs for more energy efficient blowers they need to know how blowers really perform in houses so that the rebates can be justfied. A better understanding of the key aspects of blower performance also allows any rebate programs to better define the blowers that are rebated (for example, differentiating between single and variable speed) and the appropriate level of rebate.

CHARACTERISTICS OF RESIDENTIAL BLOWERS

There are two types of blowers used in residential furnaces. Both blowers have similar blower wheels but they have different electric motors: Permanent Split Capacitor (PSC) and Brushless Permanent Magnet (BPM).

PSC blower

Permanent split capacitor motor driven blowers are by far (>90% of the residential market) the dominant motor used in residential furnace blowers used today. The single-phase PSC motors are six-pole induction motors with a synchronous rotation speed of 1200 rpm. They can operate at several fixed speeds over a range of airflow rates, with highest airflows about 1.5 times the lowest airflows. The speed is set by using different electric current taps that result in different slip, or lag from synchronous speed, of the rotor. Different speeds are necessary to match the different airflow requirements for heating and cooling operation, and allow a single blower to have a wider range of applications than if it operated at a single speed.

The blower wheel has many narrow chord forward curved bent sheet metal blades, with large gaps between the wheel and housing. The housing has one opening on each side with the direct drive motor located in one of these openings, and a rectangular discharge. This side entry means that the airflow pattern inside the air handler cabinet is fairly convoluted as air typically enters the bottom of the cabinet, flows around the housing, then changes direction 90° to enter the blower wheel. Also, unlike older belt-drive blowers, the mounting of the electric motor in the inlet restricts the flow on that side of the fan.

Variable Speed BPM blower

Brushless permanent magnet motors electronically control the rotating stator field by shifting the field to different coils in the windings. The rotor consists of permanent magnets directly mounted on the shaft of the motor. By varying the voltage and frequency of the electrical current to the stator coils, the motor can be made to rotate over a wide range of speeds and torques. The blower and motor combination can provide a constant airflow across a wide range of static pressures through programming controls based on the performance of the blower.

A key characteristic related to the wide speed range of BPM blowers is their ability to operate at much lower airflow rates, making them more suitable for continuous fan operation used for mixing and/or distribution of ventilation air. The ability to operate at much lower airflows (usually about 2.5 times less than the maximum airflow) results in the use of considerably less power at low fan speeds. The blower wheel and housing are the same as those used with PSC blowers.

BLOWER PERFORMANCE METRIC

The most useful blower performance metric combines both airflow (L/s or cfm) and power consumption (W). Two combinations are in common usage: L/s/W (cfm/W) or Watts/ m^3 (Watts/1000 cfm). When interpreting the results, it is important to realize that there is a limit on L/s/W (cfm/W) ratings for 100% efficient operation. The limit is 1000 L/s/W per Pascal (8.5 cfm/W per inch of water). At a typical operating pressure difference of 125 Pa (0.5 in. water), the limit is 8 L/s/W (17 cfm/W). At lower pressures, the limit increases and at higher pressures it decreases. This dependence of the cfm/W limit on pressure is illustrated graphically in Figure 1. Clearly, there are large potential benefits for low static pressure systems.

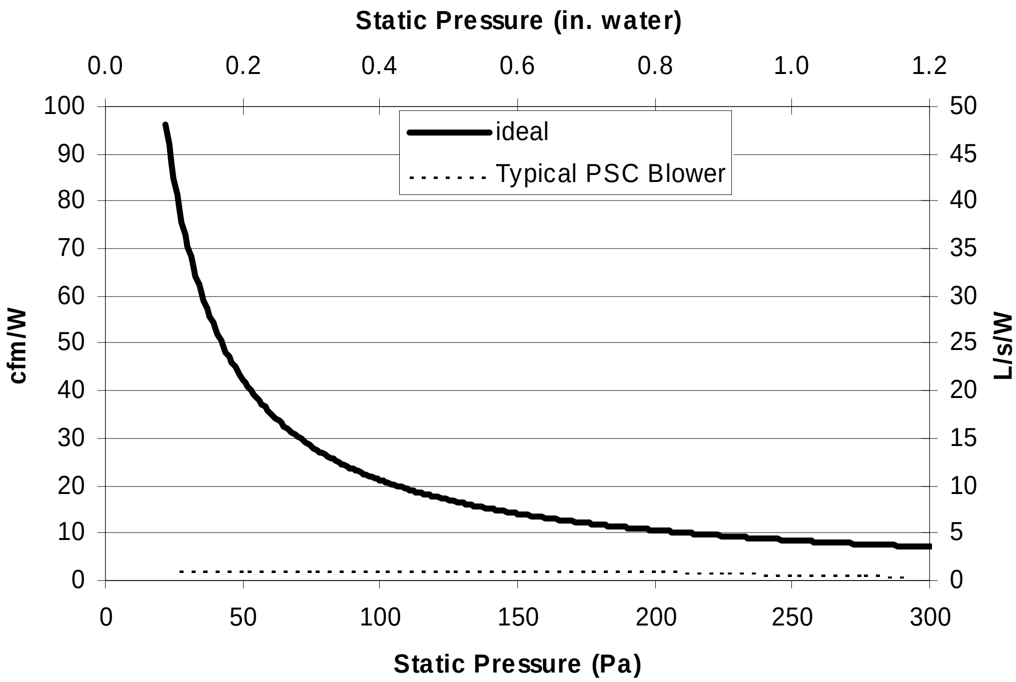

Figure 1. Maximum theoretical flow per Watt rating for different static pressures compared to a typical residential unit

FIELD STUDIES

Field studies by many researchers (see the Field Testing Bibliography) have shown that existing fans in residential air handlers typically consume about 500W, supply about 1 L/s/W (2 cfm/W), and have efficiencies on the order of 10% to 15%. The results of a recently completed California Energy Commission field survey (Wilcox 2006) that focused on new construction in California showed similar results of 1 L/s/W (2 cfm/W), but even higher power consumption, with an average of about 700W per system, due to larger systems being installed in new homes. In cooling mode these systems had a median static pressure difference of 200 Pa (0.8 in. water).

A Canada Mortgage and Housing Corporation (CMHC 1993) study showed that typical furnace fan efficiencies are on the order of 15%, but poor cabinet and duct design can reduce this to about 7%. The spread from best to worst systems was on the order of ten to one indicating that performance depends strongly on individual installations. Another Canadian study by Phillips (1998 & 1995) performed field tests on 71 houses and found air handler efficiencies in the range of 10-15%.

The Energy Center of Wisconsin (Pigg (2003a and 2003b) and Pigg and Talerico (2004)) tested 31 houses with new (less than three years old) furnaces during the heating season. Almost all the BPM blower furnaces used more electricity than their DOE test procedure ratings suggest: with a median of 82% above rated values. This was attributed to the static pressures in these field installations being much higher than those used in rating procedures. The external static pressures used in test procedures are typically 50 or 57.5 Pa (0.20 or 0.23 inches of water) depending on the capacity (DOE Furnace Test procedure[1] and ARI 2003). The measured field data showed a range of 60 to 475 Pa (0.24 to 1.9 in. of water) with an average of (125 Pa) 0.5 in. of water at the high fire rate.

Natural Resources Canada (NRC) tested two side-by-side calibrated test houses to evaluate the energy savings for replacing PSC blowers with BPM blowers for continuous fan operation (Gusdorf et al. (2002

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[1] Code of Federal Regulations, Title 10, Part 430, Subpart B, Appendix N, Uniform Test Method for Measuring the Energy Consumption of Furnaces and Boilers.

and 2003)). The PSC blower efficiencies were in the range of 10 to 15% with BPM blower efficiencies of 17 to 18%. The biggest differences were for continuous operation, where the BPM blower was six times more efficient than the PSC blower by being able to operate at about half the flow rate of the PSC blower. At half the flow the system static pressure differences are reduced by a factor of four, and as shown in Figure 1, low pressure differences yield opportunities for much more efficient operation. The results of the NRC study showed that for a continuously operating fan in the heating season there was a 74% reduction in electricity use from a BPM blowser (26% of the whole-house electricity use). There was a corresponding increase in natural gas usage in the heating season of 14% to account for the reduction in waste heat from the electric motor. For cooling, the savings were 48% of fan energy and 21% of all air conditioner use.

In addition to the above work several unpublished studies have reached similar conclusions and produced similar results. For example, 300 systems in Texas that received a HERS rating for ENERGYSTAR had static pressures from 175 Pa to 250 Pa (0.7 to 1.0 in. water) (Chesney 2006). Of particular importance are the static pressures that were typically 125 Pa (0.5 in. water) for heating and 200 Pa (0.8 in. water) for cooling.

FURNACE BLOWERS TESTED IN THE CURRENT STUDY

Table 1 summarizes key characteristics of the furnaces and blowers tested in this study (Furnace #2 and #3 are the same furnace with different blowers). The furnaces were tested in a horizontal configuration. The burners did not operate during the test and no cooling coils or filters were installed.

Table 1. Blower and Furnace Characteristics

Furnace	Blower wheel & Blower motor	Controls
Furnace # 1 80 kBtu/h 2.5 – 3 Ton AC	Forward curved blades (10x7 Blower) with PSC motor (1/3 hp)	Speed taps on motor
Furnace # 2 88 kBtuh 3.5 ton AC	Forward curved blades (10x8 Blower Size) with PSC motor (1/3 hp)	Speed taps on motor
Furnace # 3 2-stage, 88 kBtuh 1.5- 4 Ton AC	Forward curved blades (10x8 Blower) with BPM motor (½ hp)	Circuit board in furnace

LABORATORY TESTS

Tests were performed in two laboratories under controlled airflow and static pressure difference conditions. The static pressure range included three key test points:

1. AFUE/SEER pressure differences of about 50 to 62.5 Pa (0.2 to 0.25 in. water)
2. Manufacturer's maximum rated pressures of about 125 Pa (0.5 in. water)
3. Cooling airflow operating points from field testing of about 200 Pa (0.8 in. water).

The first laboratory tests were conducted using a full-scale duct system and test chamber. The test chamber was a 9.8 m (32 ft.) long, 2.4 m (8 ft.) wide, 2.4 m (8 ft.) tall box over "crawl-space" containing the ducts. The furnaces were placed on a stand outside the chamber and connected with insulated flexible ducting to the test chamber. The supply ducts were made of flexible insulated duct and were mounted on hangers in the crawlspace. Total system airflow was measured using a high precision flow nozzle (±0.5% of measured flow) located in the return duct upstream of the return plenum. Inlet and exit pressures were measured upstream and downstream of the fan using electronic pressure sensors (±1.5%). The locations for these pressure measurements were carefully chosen after experimenting with several pressure probe placements in order to avoid unstable or extreme results caused by non-uniform flows. The supply plenum pressures were determined by averaging together four static pressure probes in four corners of the plenum. Fan electrical power use was measured with a true power meter (±1%), which also gives details of power factor and an harmonic analysis. All the data were recorded using five-second time averages after waiting for readings to stabilize for about one minute. These first laboratory tests used register dampers to control the airflow and system static pressures and included evaluation of air inlet size and location together with the effect of cabinet restrictions. The tests performed at the second laboratory used an apparatus similar to those in AMCA 210 (1999). The furnaces were mounted horizontally, with the bottom of the furnaces open to a room. Air exiting the furnace traveled through a duct system to an array of flow nozzles that were used to measure the airflow rate. An auxiliary fan at the exit of the apparatus was used to control the airflows and system pressures. The use of this auxiliary fan allowed these tests to achieve lower static pressure differences than the first laboratory tests whose minimum airflow was set by the resistance of the duct system. Static pressure differences were measured relative to the room from which the furnace drew air downstream of the furnace exit using a tubing ring connecting four pressure taps. Other information, such as air temperatures, barometric pressure, motor power consumption and rotational speed were recorded together with the airflows and pressures.

Air inlet size and location

The standard or baseline performance was determined with the air entering each furnace through the bottom of the furnace. In many installations, return duct design and furnace placement often mean that air enters through the sides of the cabinet or through multiple locations. To investigate the effects of different air entries, tests were performed that varied the number, size and location of the air entry into the furnace cabinet.

Restrictive Cabinets

Several researchers have observed that the clearance between blowers and the inside of the blower cabinet often appears to be restrictive. Wilcox (2006) reported that the poorest performing blowers were in the largest (5 ton) systems where the large blowers required to move the airflows required by the 5 ton systems left small clearance between the blower and the blower cabinet. The effect of cabinet restrictions was evaluated by inserting rigid materials (either wall board or rigid insulation foam) against the walls of the cabinets that face the blower openings. Several thicknesses of materials were used. All the tests had the air entering the bottom of the cabinet (the normal configuration). The gap between the blower inlet and cabinet walls was varied from 25 mm (1 in.) to 75 mm (3 in.).

RESULTS

More complete details of all the test results and experimental methods can be found in Walker (2006) and Walker and Lutz (2005). The following is a summary of the most significant results and trends for Furnace #2 (PSC) and #3 (BPM).

Airflow

The PSC and BPM blowers have very different changes in airflow with static pressure difference despite having the same blower wheel and housing configuration, as shown in Figures 2 and 3. For the PSC blower the airflow is reduced as static pressure difference increases. In high speed mode the PSC blower airflows at 250 Pa (1 in. water) are less than half those at zero static pressure difference. At other blower speeds, the differences are less drastic but have the same trend. In contrast, the BPM blower tends to maintain airflow as static pressure differences increase. This is only true up to a point. Above about 300 Pa (1.2 in. water) the flow drops off dramatically.

The PSC blower airflows at high speed (used for cooling) reduced from 800 L/s (1650 cfm) to 550 L/s (1150 cfm) going from the rating pressures to operating pressures (200 Pa (0.8 in. water)). This 240 L/s (500 cfm) reduction would lead to about a 10% reduction in air conditioner performance using the algorithms in ASHRAE Standard 152 (ASHRAE 2004). This 10% corresponds to a full point of Energy Efficiency Ratio (EER) degradation for a new air conditioner. The BPM blower shows negligible airflow reduction at all speed settings.

In heating mode at medium airflow the PSC blower airflow was 650 L/s (1300 cfm) at the 125 Pa (0.5 in. water) typical of heating systems that is the maximum rated pressure difference by the manufacturer. This is 50 L/s (100 cfm) less than the flow at rating conditions. This small air reduction flow is unlikely to result in any severe safety issues due to operating on the high limit switch. However, for a poor system that has high static pressure difference in heating mode the airflow drops by about 200 L/s (400 cfm) and this could induce high supply air temperatures. This could present a safety problem and result in operation on the high-limit switch.

The maintenance of airflow is also important for duct distribution system losses. Low airflow leads to more extreme duct air temperatures and lower duct air velocities. This leads to greater duct heat loss via conduction through the duct walls. Algorithms in ASHRAE Standard 152 were used to estimate changes in duct conduction losses in changing from flows at AFUE/SEER rating pressures to flows at operating pressures. The changes were less than the changes in air conditioner performance and were in the range of 1% to 2%.

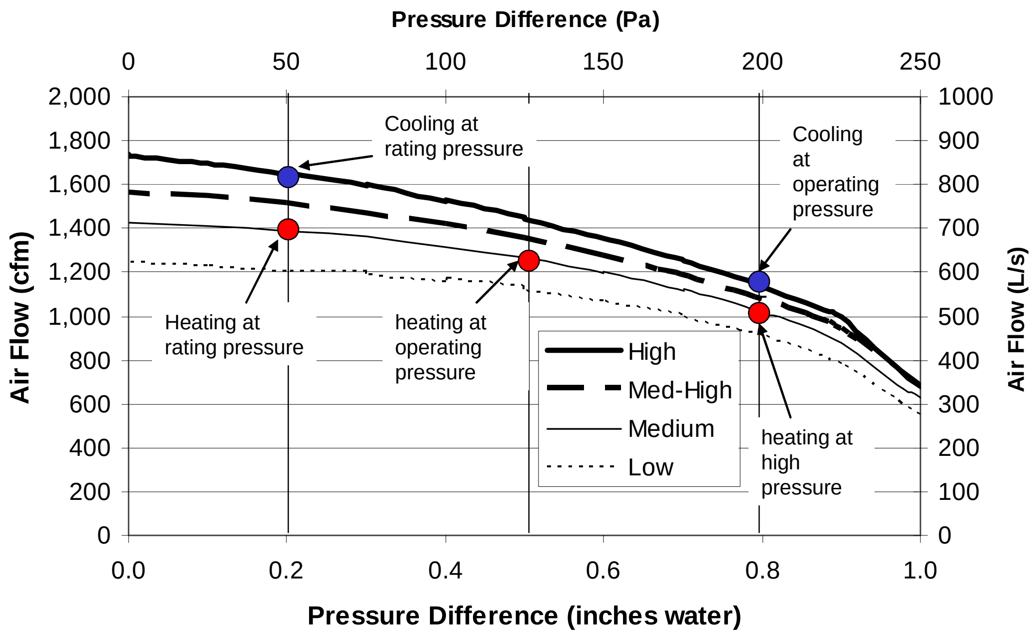

Figure 2. PSC blower changes in air flow at different operating conditions and pressure differences

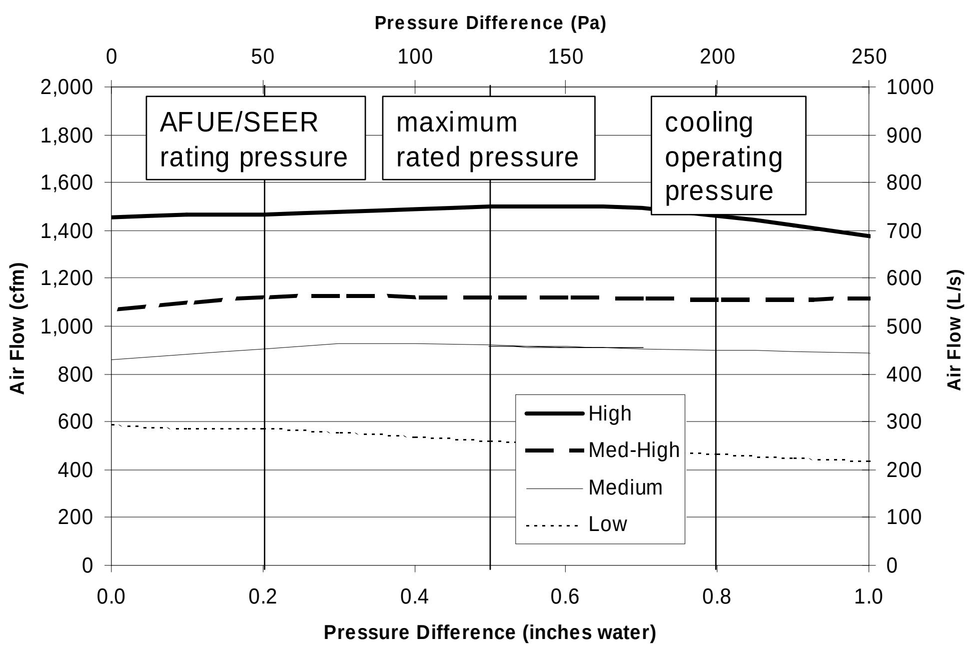

Figure 3. BPM blower changes in air flow at different operating conditions and pressure differences.

Power Consumption

The power consumption for PSC and BPM blowers are shown in Figures 4 and 5. For the PSC blower the power goes down with increasing pressure difference. Conversely, the BPM blower that keeps relatively constant airflow requires more power as pressure difference is increased. For cooling at high speed the PSC blower uses less power than the BPM blower (550 W vs. 600 W). The results at the rating point show that the PSC blower uses considerably more power than the BPM blower (750 W vs. 300 W). Comparing power consumption for heating requires that the same operating point in terms of air flow are used to make a fair comparison. Taking the medium PSC tap airflow at rating conditions as the reference indicates an airflow of 700 L/s (1400 cfm). For the BPM blower this is slightly below high speed operation and Figure 5 includes an approximate perfromance line for a BPM operated at the right speed to match the PSC airflow. The power consumption in heating mode at 125 Pa (0.5 in. water) is about 500 W for the PSC blower and 475 W fo rthe BPM blower. At rating conditions the PSC blower used 550 W compared to about 300 W for the BPM blower . These results show how important it is to compare blowers at their actual operating conditions rather than current rated conditions.

At lowest speed operation the BPM blower has a big advantage because it can operate at lower airflows and has better low static pressure difference performance. The PSC blower on low speed connected to a typical duct system will have about 500 L/s (1000 cfm) of airflow and use about 400 W at a static pressure difference of 175 Pa (0.7 in. water). On the other hand, the BPM blower will move 275 L/s (550 cfm) and use only 75 W at a static pressure difference of 75 Pa (0.3 in. water). Results similar to these for continuous fan operation have also been reported in field studies (Pigg 2003a and 2003b).

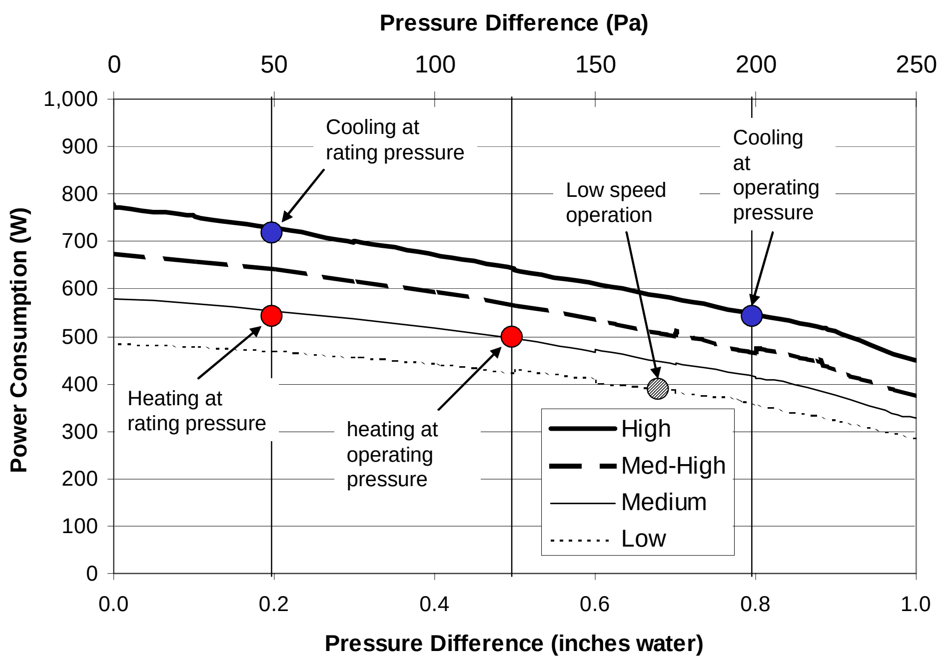

Figure 4. Power consumption at different operating points for a PSC blower.

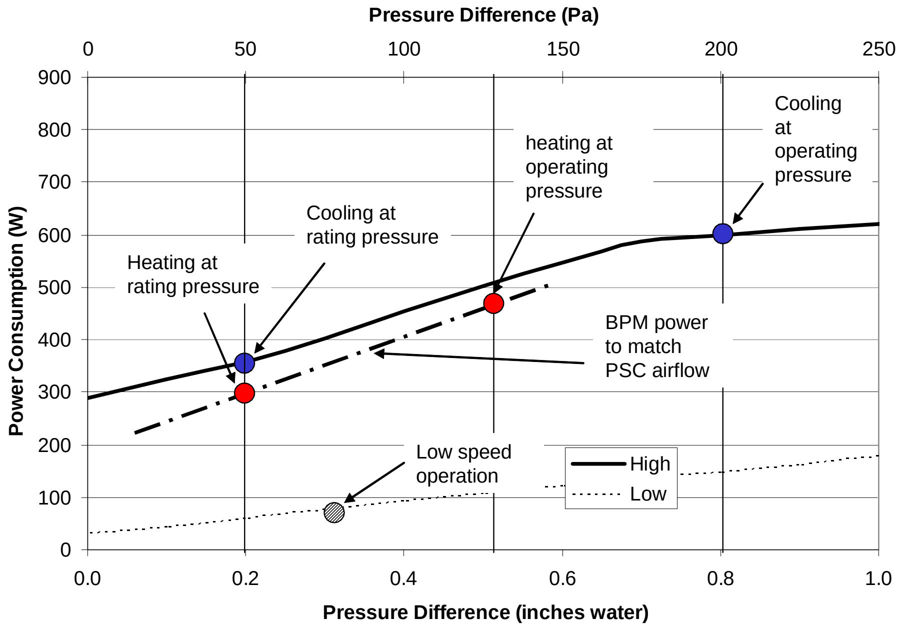

Figure 5. Power consumption at different operating points for a BPM blower.

Performance rating

The performance rating of airflow per unit power (L/s/W or cfm/W) convolves both the airflow and power consumption variability into a single metric. Figures 6 and 7 illustrate the efficiency rating for the two different motor types. For the PSC blower, all blower speeds have essentially the same efficiency level of about 1 L/s/W (2 cfm/W) up to about 200 Pa (0.8 in. water). Above this pressure difference the efficiency gradually decreases. For the BPM blower, the efficiencies are high at lower pressure differences and for lower blower speeds. For low speed operation (and with correspondingly low pressure differences of 25 to 50 Pa (0.1 to 0.2 in. water) for typical systems) such as used continuous operation for mixing and filtration the BPM blower operates at its best and provides more than 5 L/s/W (10 cfm/W). This is five times better then the PSC. The BPM blower also changes significantly with increasing pressure difference. Above 200 to 250 Pa (0.8 to 1.0 in. water) the BPM blower efficiency degrades to similar levels to the PSC blower.

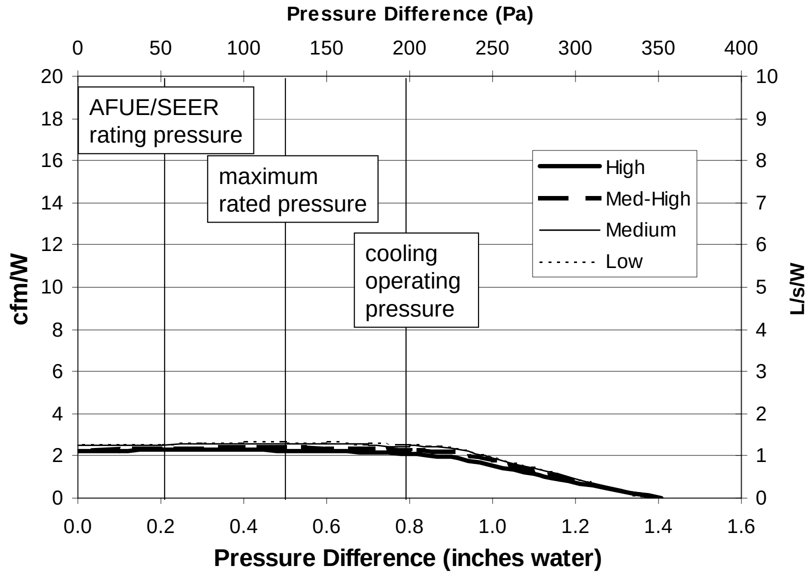

Figure 6. PSC blower performance rating.

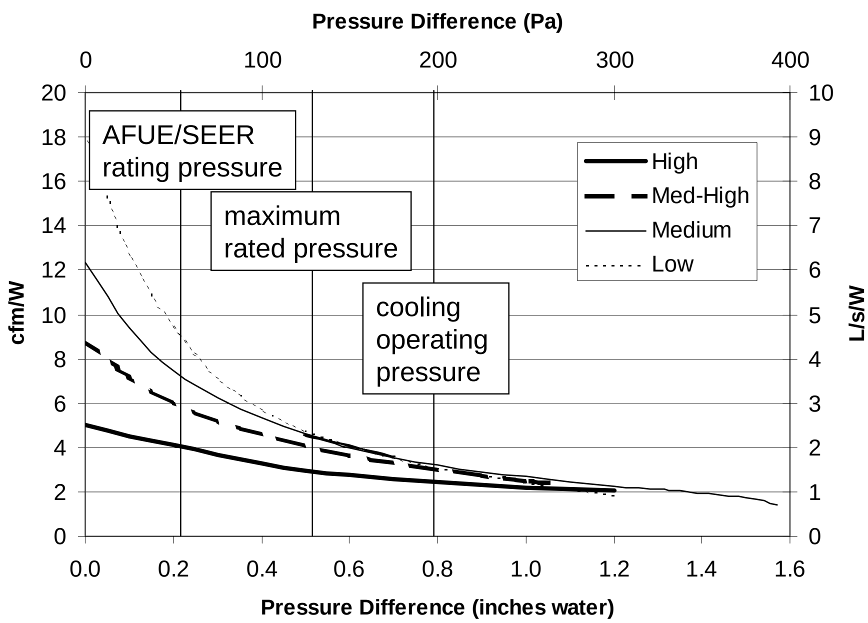

Figure 7. BPM blower performance rating.

Air Inlet Size and Location Effects

For Furnace #1 with the PSC blower the normal bottom entry gave the best performance. The airflow and L/s/W (cfm/W) changes are on the order of a 5 to 10 % decrease for the different openings. The biggest effect on airflows is a reduction of about 10% for an opening on the motor side of the blower only. This is probably because the motor presents a significant blockage to airflow from this side. The BPM blower showed less variability with air inlet configuration at high speed.

Effect of cabinet restrictions

For the PSC blower, the effect of reducing the gap between the cabinet and the blower inlet was small at low speeds (5% or less) but increased significantly at higher speeds. At high speed the efficiency and airflow were reduced by about 15% when clearance was reduced to about 25 mm (1 inch).

Power factor

The significance of power factor lies in the fact that utility companies supply residential customers with volt-amperes, but bill them for watts (commercial and industrial custmomers often pay power factor charges). In addition, power factors below 1.0 require a utility to generate more than the minimum volt-amperes necessary to supply the real power (watts) that leads to increased generation and transmission costs. For the PSC motor, the power factor ranged from 0.7 to 0.9, with the lower power factors at high-speed settings and high pressures. For the BPM motor the power factor ranged from 0.53 to 0.62 with higher power factors at higher speed. The BPM motor results showed a gradual increase in power factor to a peak at about 250 to 350 Pa (1 to 1.4 in. water) pressure difference then decreasing after this point. The PSC motors had power factors that typically decreased by about 5% to 10% as pressure difference increased. The BPM motors also generated large odd order harmonics due to the current being highly non-sinusoidal. These results indicate that widespread use of BPM motors may pose problems to utilites due to increased generation (and distribution). However, it is possible to condition the power of these motors using capacitors - although the BPM blowers currently on the market do not do this.

COMPARING PERFORMANCE FOR MULTI-SPEED SYSTEMS

Lutz et al. (2006) took the blower results reported here and used them in a DOE2 simulation to calculate hourly heating and cooling loads over a year for a house in the California Central Valley. The results of their analysis are reported here. They used these loads to determine heating and cooling runtimes and energy consumption. The furnace cycling rate and occurrence of high-fire operation were based on field studies by Pigg (2003a and 2003b) and Pigg and Talerico (2004)). These studies showed staged gas furnaces typically operate such that high-fire mode is only used to recover from setback, and that the majority of operation is in low-fire mode. An 80% AFUE furnace was used with a capacity of 26 kW (88 kBtu/h) and 17 kW (58 kBtu/h) in high fire and low fire respectively. As an air conditioner, it operated at a 12.3 kW (3.5 ton) nominal capacity at a single high speed.

Three system curves were used: 1. based on the DOE test procedure pressures, 2. based on the manufacturers rating and 3. for a typical California duct system.

The model of the furnace and air conditioner included the following: standby energy use of 5 W for the PSC blower and 9 W for the BPM blower, energy used by the draft inducer including pre and post purge for every cycle, on and off blower delays and igniter energy use for each cycle, effect of changing airflow and outdoor temperature on air conditioning efficiency, reduction in natural gas use due to blower motor heating and the increase in air conditioner operation due to blower motor heating.

Four blower options were examined: single stage PSC blower, single stage BPM blower, two-stage PSC blower, and two-stage BPM blower. Figure 8 summarizes the results of the DOE2 simulations. It is clear from these results that care must be taken when determining blower motor energy use and energy savings because the system effects (i.e., the duct system the furnace is connected to) are the same magnitude as the differences between blower motors. For a typical duct system the energy savings are minimal for a single-stage furnace. The two-stage PSC blower uses more energy than the single-stage PSC blower and Variable Speed BPM blower. This is because the PSC blower two-stage furnace operates for longer resulting in additional draft inducer operation. Because the burner heat input to the furnace did not scale directly with the air flow, at low speed operation the delivery temperatueres were lower leading to proportioanlly longer runtimes than the ration of air flow rates. Two-stage operation also resulted in reductions in air conditioner performance and increases in duct losses as discussed earlier. The two-stage BPM blower uses the least energy because its reduced blower energy requirements more than offset the losses of two-stage operation.

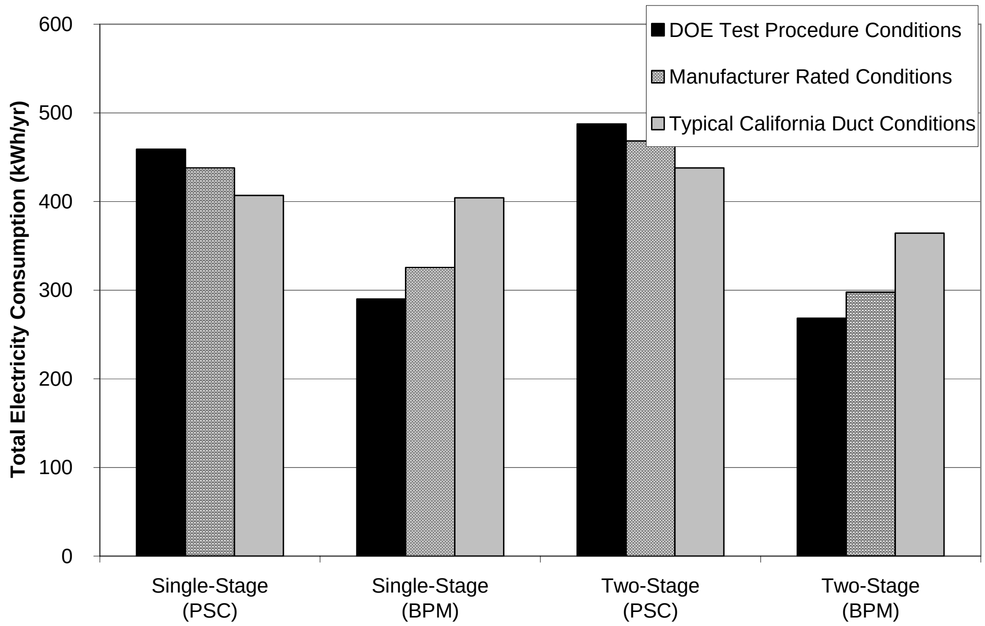

Figure 8. Summary of total energy consumption for four blower furnace design options for three duct systems design conditions

Summary and Conclusions

These laboratory tests and modeling efforts have examined only a small sample of furnaces and examined a single California climate; however, these general conclusions can be broadly applied based on input from furnace manufacturers and the test results from other unpublished studies. Specific furnace/blower combinations will have different airflow characteristics, efficiency ratings and pressure difference sensitivity, but the general trends and observations will still apply. Analysis of the detailed laboratory investigations and energy use analysis in this study has shown that:

- BPM and PSC blowers have distinctly different performance characteristics that must be accounted for when proposing performance specifications.
- BPM blowers have better performance in terms of maintaining airflow at typical system pressures and reduced power consumption compared to PSC blowers. However, the advantage for BPM blowers is marginal at high pressures above about 200 Pa (0.8 in. water).
- As system pressures increase, the PSC blower power consumption decreases but the airflow is reduced.
- Power consumption for PSC and BPM blowers are very different at current rating conditions, but the differences are reduced significantly in real installations due to duct static pressures that are much higher than at rating conditions.
- Annual energy use is about the same for PSC and BPM blowers in typical field installations with single-stage heating or cooling equipment, wheras the BPM blower is about 30% better at rating conditions.
- Two-stage equipment that operates for a significant fraction of the year at lower capcaity and airflow has the biggest potential benefit from the use of a BPM blower.

- Use of BPM blowers in place of PSC blowers in high pressure drop systems will allow design flow rates to be met, but may in fact increase energy consumption unless a systems approach is taken.
- To better reflect blower performance it is recommended that appliance rating test procedures be amended to use realistic system static pressures of between 0.5 and 0.8 in. water (125 and 200 Pa) and that utility rebate programs ensure that rebates are provided for using a BPM blower instead of a PSC blower in multi-speed systems and/or systems that have a field measured low static pressure difference below 0.5 in. water (125 Pa).
- BPM blowers have a big advantage over PSC blowers at low airflows used for mixing and air distribution, using about one fifth the power.
- One important utility issue with BPM blowers is their lower power factor that leads to increased generation and distribution costs. For PSC blowers, the power factor ranged from 0.7 to 0.9, with the lower power factors at high-speed settings and high pressures. For BPM blowers the power factors range from 0.53 to 0.62 with higher power factors at higher speed.
- As well as the external static pressure effects, the airflow patterns within blower door cabinets also affect performance. Side entry, particularly on the motor side of the blower should be avoided. Restrictive cabinets that have little clearance around the blower also reduce blower performance. Airflow reductions are about 15%, with similar reductions in L/s/W (cfm/W) ratings when clearance is reduced to about 25 mm (1 inch).

From the national or state appliance rating and public policy viewpoint, this study indictes that considerbale care needs to be taken when developing rating requirements, and that currently available data may be inadequate. Until changes are made to current ratings, or new rating procedures are developed, efficiency labels (and other consumer information), rebates and/or tax credits may be misrepresentative.

RECOMMENDATIONS FOR FUTURE WORK

Only a small sample of furnaces were evaluated in the laboratory tests. To be more definitive, it would be a good idea to test more furnaces from a range of manufacturers. In addition, furnaces over a range of capacities should be tested to see if the general results from the testing described in this report are applicable in all cases. Lastly, the energy analysis could be extended to cover other climate zones with different ratios of heating to cooling.

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