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Experimental performance evaluations and empirical model developments of residential furnace blowers with PSC and ECM motors

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ABSTRACT

The study reported herein is to experimentally evaluate and compare the performance of blowers driven by permanent split capacitor (PSC) motors and electronically commutated motors (ECMs) in residential non-weatherized, non-condensing gas furnaces. As a first step, twelve units from four manufacturers were selected, with six having PSC blowers and the other six having ECM blowers. Then, these blowers were tested in a well-instrumented laboratory facility with a nozzle airflow chamber. The furnace blower performance was characterized in terms of measured airflow rates and blower powers over a pressure range of 0.1–1.2 in. w.g. (25–300 Pa). Overall blower efficiencies were also determined from the airflow, pressure, and power measurements. The results of this study showed that PSC and ECM blowers have significantly distinct airflow and power performance in response to increasing external static pressures (ESPs). In addition to performance evaluations, empirical models that describe the airflow and efficiency behaviors of the PSC and ECM blowers with respect to external static pressures (ESPs) were developed from the experimental data. Of special importance, these empirical models can be used for the investigation of energy consumptions in residential central HVAC systems with PSC and ECM blowers at various operating conditions.

1. Introduction

In the United States, over 60% of homes have central warm-air furnaces for space heating and cooling, and furnace blowers account for an annual electricity use of 3.81×10^{10} kWh nationwide, which is 2.6% of the site electricity consumption and 1.1% of the total energy use in the residential sector [5]. Traditionally, these blowers have been driven by permanent split capacitor (PSC) motors, which are split-phase alternate current (AC) induction motors with starting capacitors. Recently, a growing number of manufacturers have started to provide blowers equipped with electrically commutated motors (ECMs), which are brushless direct current (DC) motors with permanent magnet rotors and ball bearings.

Compared with traditional PSC blowers, advantages of using ECM blowers include the capability of maintaining constant airflow rates over a pressure range and the use of less power at conditions of low flow resistances. For example, Biermayer et al. [3] showed in a series of laboratory experiments that ECM blowers had less airflow decreases compared with PSC blowers as the flow resistance was increased. Also, Walker and his colleague [12–15] conducted a series of laboratory measurements on the power consumptions of PSC and ECM blowers. Their results showed that power consumptions of the PSC blower decreased as a result of increasing the flow resistance. In contrast, power consumptions of the ECM blower increased with the increasing flow resistance.

Although previous experimental studies, such as laboratory measurements performed by Biermayer et al. [3] and by Walker and his colleague [12–15], provide important information for characterizing the performance of PSC and ECM blowers, the breadth of currently available data may not be adequate for the development of national appliance rating standards and public policies due to the fact that only a small sample of furnace blowers has been tested [14]. For instance, the results reported by Biermayer et al. [3] were based on only one PSC and one ECM blower, while the Walker's studies [12–15] measured only one PSC blower and two ECM blowers.

Another concern arising out of having only a few experimental studies is whether the findings are typical enough to draw conclusions that can be applied in all cases. For example, Lutz et al. [8] and Franco et al. [6] reported measurements of constant airflow rates of an ECM blower over a pressure range of 0–1.0 in. w.g. (0–250 Pa). However, recent experimental results showed that even for an ECM blower increases in the flow resistance could

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result in airflow reductions as much as 25%, with increasing airflow reductions at conditions of higher blower speeds and higher flow resistances [16]. The discrepancy of airflow measurements from ECM blowers in two different studies indicates significant performance variations, even for the same category of blower type. Hence, it is necessary to extend laboratory measurements to more PSC and ECM blowers over a larger range of operating conditions in order to further characterize the blower performance.

The study reported herein experimentally evaluates and compares the performance of PSC and ECM blowers. A total of twelve (12) different commercially available furnace blowers, namely six PSC blowers and six ECM blowers, were tested in a well-instrumented laboratory setting. Blower airflow and power measurements were conducted over a range of external static pressures (ESPs) and blower speeds. The blower overall efficiencies were also calculated based on the measured airflow, pressure, and power data. In addition to experimental evaluations, empirical models that characterize PSC and ECM blower airflow and overall efficiency behaviors as a function of the external static pressure (ESP) were developed from the statistical analysis of the experimental data.

2. Test method

All twelve (12) blowers tested in this study are from residential non-weatherized, non-condensing gas furnaces made by four major manufacturers in the United States, with six (6) PSC blowers and six (6) ECM blowers. All blowers are designed with forward-curved blades, although the blower wheel dimensions vary from unit to unit. Table 1 summarizes the key characteristics of blower assemblies that were tested in this study.

2.1. Experimental setup

Fig. 1 is a schematic of the experimental test setup, which includes a test unit, supply and return ducts, and a nozzle airflow chamber, with all components in the horizontal position. Because the focus of this study is the blower performance only and the fact that the evaluation of heating and cooling performance is beyond the project scope, burners were not operating during the tests nor were the cooling coils installed. Conditioned laboratory air at a uniform and constant temperature was used in all tests. To simulate field installations, supply and return ducts with the same cross-sectional dimensions as the supply and return air openings on the furnaces were built and attached to the test units by following the requirements in ASHRAE [2]. Following the specifications in this standard, the length of the supply duct is 2.5 equivalent diameters, and the length of the return duct is 1.5 equivalent diameters. In addition, static pressure taps that were made according to ASHRAE [1] were installed at the center of each surface on both supply and return ducts so that average static pressures could be measured.

Blower airflow rates were measured by using a nozzle airflow chamber that was built in accordance with the requirements of ASHRAE [1]. This chamber has a nozzle board consisting of one 1-in. (25 mm), one 3-in. (76 mm), and four 5-in. (127 mm) nozzles, which allows the same chamber to be used for the airflow measurement over an airflow range of 11–3300 ft^3/min (0.005–1.557 m^3/s). An assist blower, which is controlled by a variable frequency drive (VFD), is attached to this chamber and used to achieve variable external static pressures (ESPs). Ambient conditions were monitored by a stand-alone psychrometric station that featured two temperature transmitters, for dry-bulb (DB) temperature and wet-bulb (WB) temperature measurements, as well as a barometric transmitter. Air pressures were measured by using pressure transmitters with a 4–20 mA output, and the supply voltage to the furnace blower was stabilized at 115 ± 0.5 V by using a variable transformer.

2.2. Test procedures

Extensive field measurements show that the external static pressure (ESP) in installed conditions varies from 0.31 to 1.12 in. w.g. (77–279 Pa) [4]. In order to cover the entire operating

Table 1
Characteristics of furnaces and blowers tested in this study.

Blower	Manufacturer	Blower motor	Motor size, hp (W)	Blower wheel size, in. (mm)	Speed	Heating output capacity, kBtu/h (kW)	Add-on cooling capacity, kBtu/h (kW)
Blower #1	A	PSC	1/3 (249)	10×6 (254 × 152)	4 Speeds	High: 54 (15.83) Low: 36 (10.55)	36 (10.55)
Blower #2	A	ECM	1/2 (373)	10×6 (254 × 152)	4 Speeds	High: 54 (15.83) Low: 36 (10.55)	36 (10.55)
Blower #3	A	PSC	1/3 (249)	10×6 (254 × 152)	4 Speeds	54 (15.83)	36 (10.55)
Blower #4	A	PSC	1/3 (249)	10×7 (254 × 178)	4 Speeds	48 (14.07)	36 (10.55)
Blower #5	A	ECM	3/4 (559)	11×8 (279 × 203)	4 Speeds	54 (15.83)	48 (14.07)
Blower #6	A	PSC	1/3 (249)	10×6 (254 × 152)	3 Speeds	54 (15.83)	36 (10.55)
Blower #7	B	ECM	1/2 (373)	10×8 (254 × 203)	3 Speeds	58 (17.00)	24–36 (7.03–10.55)
Blower #8	B	PSC	1/3 (373)	10×10 (254 × 254)	4 Speeds	High: 74 (21.69) Low: 58 (17.00)	18–36 (5.28–10.55)
Blower #9	B	ECM	1/2 (373)	10×10 (254 × 254)	4 Speeds	High: 97 (28.43) Low: 85 (24.91)	30–42 (8.79–12.31)
Blower #10	C	PSC	1/3 (249)	10×6 (254 × 152)	4 Speeds	56 (16.41)	36 (10.55)
Blower #11	C	ECM	3/4 (559)	10×10 (254 × 254)	4 Speeds	92 (26.96)	24–60 (7.03–17.58)
Blower #12	D	ECM	1/2 (373)	11 × 8 (279 × 203)	4 Speeds	High: 47 (13.77) Low: 24 (7.03)	36 (10.55)