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The impact of operating pressure on residential bathroom exhaust fan performance

Peng Yin [a,*], Michael B. Pate [b], James F. Sweeney [b]

[a] University of Louisiana at Lafayette, Lafayette, LA 70504, United States
[b] Texas A&M University, College Station, TX 77843, United States

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ABSTRACT

This study quantified the performance impact of increasing operating pressure on residential bathroom exhaust fans based on the comparative analysis of airflow, efficacy, and loudness on more than 80 different residential bathroom exhaust fans with alternate current motors. The fan performance data were measured in a well-instrumented laboratory environment that includes a calibrated nozzle airflow chamber and a six-microphone reverberant sound chamber. Fan airflow rates, efficacies, and loudness were experimentally determined to investigate the impact of external static pressure (ESP) on fan performance at the rating pressure of 0.1 in. w.g. (25 Pa) and the higher field-observed pressure of 0.25 in. w.g. (62.5 Pa). An analysis of results showed that fan performance was strongly affected with increasing the ESP. For example, when the ESP was increased from 0.1 to 0.25 in. w.g. (25–62.5 Pa), the average value of fan airflow rate decreased by 19%, efficacies were penalized by 16%, and the loudness increased by 75%.

1. Introduction

Residential bathroom exhaust fans (i.e. local exhaust fans) are used to remove moisture and eliminate odors emanating from bathrooms, lavatories, toilets, and other rooms containing similar sources of contaminants. These fans are often ceiling mounted and exhausted to the outside through ducting and a vent cap, which is normally installed on the roof. However, in a few cases, exhaust fans are installed in an exterior wall, which eliminates the need for extensive ductwork. The performance of bathroom exhaust fans is characterized in terms of the airflow rate, efficacy, and loudness. All of these performance metrics are rated at an external static pressure (ESP) of 0.1 in. w.g. (25 Pa) according to the Home Ventilating Institute [8,9]. In addition, a growing number of building codes impose a minimum performance requirement on bathroom exhaust fans for energy efficiency. For example, the 2012 International Energy Conservation Code [11] requires a minimum efficacy of 1.4 ft^3/min per Watt (0.7 L/s per Watt) for exhaust fans with airflow rates below 90 ft^3/min (45 L/s), while fans with airflow rates above 90 ft^3/min (45 L/s) have a specified minimum of 2.8 ft^3/min per Watt (1.4 L/s per Watt). Moreover, [6] regulates a maximum loudness of one (1.0) sone for continuous exhaust fans and three (3.0) sone for demand-controlled systems at the rating pressure of 0.1 in. w.g. (25 Pa).

Compared with other mechanical ventilation systems, bathroom exhaust fans have several advantages, including low initial costs, high reliability, and simple installations [2,12]. However, it has been reported that in reality few local exhaust fans are working properly [1]. For example, in a field study conducted by [13], measurements on 43 bathroom exhaust fans showed that actual airflow rates were between 8% and 105% of the rated values with an average of 67%, which indicates a significantly reduced airflow rate for units in the field. Another study reported that exhaust fans performed at 71% of their rated airflow rates on average, with a measured range from 35% to 113% [15]. In the same study, it was also found that 11 out of 88 fans performed at less than half of their rated airflow capacities. Aldrich [2] attributed these airflow decreases in field-installed fans to excess pressure drops caused by extensive fan outlet ducts, stating that most exhaust ducting systems induce a pressure drop close to 0.25 in. w.g. (62.5 Pa), which is higher than the assumed ESP of 0.1 in. w.g. (25 Pa) for the exhaust fan rating condition. Because of the good representativeness of fan performance at installed conditions, the airflow data at the higher pressure of 0.25 in. w.g. (62.5 Pa) is increasingly used for fan selection. For instance, ANSI/ASHRAE Standard 62.2 [6] provides an alternative approach for exhaust fan selection based on the airflow data at 0.25 in. w.g. (62.5 Pa) in addition to using the airflow data at the rating pressure of 0.1 in. w.g. (25 Pa). Although the above studies revealed the existence of higher ESPs than the rating pressure of 0.1 in. w.g. (25 Pa) at installed conditions, few studies are attempting to quantify and document the performance impact of increasing ESPs on exhaust

* Correspondence to: Department of Mechanical Engineering, PO Box 44170, Lafayette, LA, United States.
E-mail address: peng_yin@louisiana.edu (P. Yin).

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fans, resulting in limited available data for charactering the fan performance at the higher ESP of 0.25 in. w.g. (62.5 Pa). For example, HVI maintains a directory [10] that documents the performance of certified products, including fan airflow rate, loudness, and power measurements at the rating pressure of 0.1 in. w.g. (25 Pa). However, this HVI directory does not provide information on fan power and loudness at the field-observed pressure of 0.25 in. w.g. (62.5 Pa), with the reason being that the release of power and loudness data at higher ESPs is not a mandatory requirement. The release of airflow data at the higher ESP of 0.25 in. w.g. (62.5 Pa) is also optional to fan manufacturers. The failure of providing data representing the actual performance in installed conditions prevents HVAC practitioners and home owners from choosing appropriate exhaust fans suitable for their diverse ventilation requirements. Of greater importance, the lack of data documenting the performance impact of increasing pressures on exhaust fans fails to promote the low pressure drop duct design, which is an important factor to determine the airflow delivered from an exhaust fan [14].

The objective of the study reported herein is to experimentally evaluate the performance impact of increasing operating pressure over a broad range of typical residential bathroom exhaust fans equipped with alternate current (AC) motors. The fan selection covered major brands available in the U.S. market and represented products from 20 fan manufacturers. Airflow rates, efficacies, and sound levels of 82 exhaust fans were measured over the entire operating pressure range from the zero static pressure point (i.e., maximum airflow) to the shut-off point (i.e., zero airflow) in well-instrumented laboratory facilities that are equipped with a calibrated nozzle airflow chamber and a six-microphone reverberant sound chamber. A comparative analysis was conducted on the measurements of airflow rate, efficacy, and sound level that were collected at pressures of 0.1 and 0.25 in. w.g. (25 and 62.5 Pa) to quantify the impact of increasing ESPs on fan performance, with the low pressure of 0.1 in. w.g. (25 Pa) being the fan rating condition and the high pressure of 0.25 in. w.g. (62.5 Pa) representing the field installed condition.

2. Experimental facilities and test procedures

The fan performance in this study was characterized by the measured airflow rate, efficacy, and loudness obtained during aerodynamic and sound performance tests. In the aerodynamic test, the fan airflow rate and power were measured over an ESP range. In the sound test, the noise generated from the exhaust fans was determined at the rating pressure of 0.1 in. w.g. (25 Pa); however, 20 of the 82 test samples were also tested for loudness at the higher pressure of 0.25 in. w.g. (62.5 Pa). This section describes the experimental setups and testing procedures for both the aerodynamic and sound performance tests.

2.1. Aerodynamic test setup and procedures

As shown in Fig. 1, the experimental setup for the aerodynamic tests includes a fan, a short piece of outlet duct, a nozzle airflow chamber, and an assist blower. The test unit is horizontally ducted to the airflow chamber by using a uniform duct that has a length of 2.5 equivalent diameters based on the dimensions of the fan outlet area. The outlet airflow chamber was built in accordance with the requirements of ANSI/ASHRAE Standard 51 [5], and it has a nozzle board consisting of five nozzles with diameters of 0.95 in. (24 mm), 1.35 in. (34 mm), 3.03 in. (77 mm), 4.27 in. (109 mm), and 6.75 in. (172 mm), which allows the same chamber to be operated over a wide range of airflow rates. An assist blower, which is controlled by a variable frequency drive (VFD), is attached to this chamber and used to achieve varying chamber static pressures. Ambient conditions were monitored by a stand-alone psychrometric station that featured two temperature transmitters for dry-bulb (DB) and wet-bulb (WB) temperature measurements, as well as a barometric transmitter. The ESP and the nozzle differential pressure were measured by using air pressure transmitters with a 4–20 mA output. The supply voltage to the test unit was stabilized at 120 $\pm$0.5 V by using a variable transformer.

The aerodynamic testing procedures used in this study strictly adhere to HVI Publication 916 [9]. First, the shut-off static pressure was measured at the condition of no airflow by blocking all of the nozzles. Then, after unblocking the nozzles to achieve a steady-state airflow condition, 10 evenly spaced ESP points were determined and used to span the entire fan operating range from the zero static pressure point to the shut-off point, with two pressure points being 0.1 and 0.25 in. w.g. (25 and 62.5 Pa). The selection of the other eight pressure points varied from unit to unit because of different fan operating ranges and distinctive performance characteristics. At each of the ten ESP points, the corresponding airflow rate through the known open-nozzle areas in the airflow chamber was calculated by using the nozzle differential pressure measurement. The measured airflow data were then converted to the standard air condition by using a density of 0.075 lb_m/ft^3 (1.2 kg/m^3) so that the airflow performance of different units could be directly compared, regardless of environmental conditions occurring during data collections. While taking airflow measurements, the fan rotational speed was measured by using a non-contact, digital tachometer. The electrical performance was also measured by using a power quality analyzer. The simultaneously measured and recorded electrical data included voltage, current, and both real and apparent power. Table 1 shows the instruments used in the aerodynamic tests, along with their specifications and accuracies.

2.2. Sound test setup and procedures

As shown in Fig. 2, the experimental setup for sound measurements includes a reverberant sound test chamber that was built according to ANSI/ASA S12.51 and HVI Publication 915 [5,8]. The chamber walls were constructed with heavy-duty, multi-layer insulation materials to eliminate undesirable air infiltration and

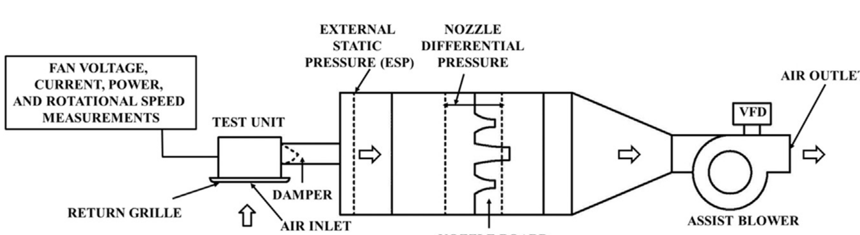

Fig. 1. Experimental setup with nozzle airflow chamber for aerodynamic testing.