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Study of bathroom ventilation fan performance trends for years 2005 to 2013—Data analysis of loudness and efficacy

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ABSTRACT

Whole-house ventilation, which is defined as systems that supply and exhaust or relieve ventilation air for a residence, has been a mandatory provision since the announcement of IECC 2012. As a result, an increasing numbers of publications and standards are now addressing residential ventilation in terms of performance and efficiency. In addition, loudness is increasingly addressed in standards and guidelines, especially in the last decade as it is now considered to be a significant factor for certified performance ratings of ventilation fans. Because of the above interest in fan performance, this paper provides statistics of bathroom ventilation fan tests and their results for an almost decade-long period from 2005 to 2013. Also, the paper interprets these statistics with regards to the recent development of residential ventilation standards and guidelines.

In order to investigate year-to-year changes, this paper first evaluates changes in loudness ratings for the test period 2005–2013, and its relevance to applicable standards, including ASHRAE 62.2. Then, noticeable transitions in loudness and efficacy in specific time frames are investigated. The test results of DC-motor high-efficiency bathroom fans are also compared to AC-motor fans. Relationships between performance variables and loudness are investigated, and formulated by developing regression models.

1. Introduction

Whole-house ventilation that supplies and exhausts or relieves ventilation air for a residence appeared as a new mandatory provision in the 2012 International Energy Conservation Code (henceforth, IECC) in section R403.5 [1]. Although the concept of whole-house ventilation has been discussed [2,3] for the last two decades as a result of ASHRAE 62.2, the application of international mandatory regulations meant that ventilation fans must meet more robust requirements for performance and energy consumption throughout the qualification process. The Department of Energy (DOE) also announced a new residential fan efficiency code in 2012 [4] as an assisting description of IECC 2012 R403.5. As well as defining the concept of whole-house ventilation, the DOE 2012 code also provided quantitative measures for fan efficiency in terms of efficacy, which is defined as the ratio of volumetric flow rate (VFR) and power in units of ft^3/W min or L/W s. For instance, bathroom fans whose volumetric flow rates are below 90 ft^3/min (42.5 L/s) are required in the code to meet a minimum efficacy of 1.4 ft^3/W min (0.66 L/W s).

The introduction of a ventilation code to IECC 2012 escalated the necessity of studying performances and efficiencies of various ventilation fans. In addition, several governmental agencies have published U.S. household energy-consumption statistics and trends, which has accelerated energy demand and consumption discussions. For instance, the Annual Energy Review (AER) and the Annual Energy Outlook (AEO) provide annual summaries and predictions for residential energy intensity in the U.S., which is measured by annual energy use per household unit [5,6]. The AEO 2013 Reference case expects declines in the energy intensity of residential demand of about 22% from 97.2 million Btu (28.5 MW) in 2011 to 75.5 million Btu (22.1 MW) in 2040. With regards to electricity demand, a decrease from 12.3 MW to 11.5 MW from 2011 to 2040, which is about 6%, is anticipated. However, electricity consumption in heating, cooling, and ventilation continues to increase by 70 kWh per household in the same period with several facts in the recent AER and AEO explaining this increase. First, space cooling consumption is expected to increase by 42%, which overshadows space and water heating decreases of 20%. Second, although the AEO Reference case assumes improved

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efficiency as a result of standards, average household square footage is expected to expand from 1662 to 1858 ft^2 (154.40 to 172.61 m^2), which accordingly demands an increase in HVAC overhead. Based on these observations and forecasts, the IECC 2012 ventilation code is an important element in encouraging better indoor comfort while achieving higher energy efficiencies.

It is important to note that the ventilation performance rating requirements in IECC 2012 R403.5 are limited in scope to volumetric flow rate and efficacy. Missing from the requirements are noise limits even though loudness is a major factor affecting the performance of ventilation devices in the general context because (1) sound power represents a thermodynamic loss due to turbulent and structural vibration [7] and (2) noise from the fan can have an influence on physical and psychological stress [8].

Several leading standards or publications, such as HVI 915 [9], AMCA 301 [10], and ANSI/AHRI 260 [11], have established acoustic rating procedures for ventilation fans, with these rating procedures being widely accepted by industry and trade organizations. In addition, these procedures are routinely used by testing laboratories as they measure and evaluate fan noise performances. Furthermore, ASHRAE 62.2 specifies the maximum loudness level in units of sone for different types of ventilation fans [12]. For example, ASHRAE 62.2 specifies that demand-controlled mechanical exhaust fans with rated volumetric flow rates less than 400 ft^3/min or 200 L/s be rated for loudness to a maximum of 3 sone. However, the same standard does not consider a minimum efficiency of mechanical ventilation fans in contrast to other standards such as IECC 2012. In addition to the lack of efficiency requirements, ASHRAE 62.2 does not categorize different types of 'demand-controlled' ventilation fans for the sound rating. It is widely accepted fact that kitchen range hoods operate at higher volume flow rates and thus generate more noise than bathroom ventilation fans, with both of them being demand-controlled. Furthermore, most bathroom fans run at volumetric flow rates under 130 ft^3/min (61.4 L/s) [13]; therefore, using 3 sone for fans less than 400 ft^3/min is not a practical limit for bathroom fans. It should also be noted that IECC 2012 R403.5 classifies volumetric flow rates for bathroom fans into two range categories, namely below and equal to or greater than 90 ft^3/min (42.5 L/s).

Manufacturers are interested in sound ratings of residential fans, and as such, they view a residential ventilation fan performance as not being merely limited to air flow performance but also to acoustic and noise characteristics. In response to industry demands, the Home Ventilating Institute (HVI) and the Air Movement and Control Association (AMCA) as well as the aforementioned rating standards and publications now provide requirements for certified sound tests for ventilation fans.

Various studies by academic and governmental sectors have been conducted for evaluations and predictions of the residential ventilation performances for different types of fans. As a milestone to the Energy Star 2.0 Program, the U.S. Environmental Protection Agency (EPA) conducted analysis on 51 different fans having different volumetric flow rates from 50 ft^3/min (24 L/s) to 1200 ft^3/min (566 L/s) [14]. The agency found large efficacy distributions, ranging from 0.2 ft^3/W min (0.1 L/W s) to 8.5 ft^3/W min (4 L/W s), and they concluded that there was no clear trends for different types of ventilation fans in their efficacies versus volumetric flow rates. This observation of no clear trends is also supported by other studies that categorized types of ventilation fans, and conducted performance evaluations for individual fans. For instance, studies performed by Delp and Singer [15,16] revealed that many residential range hoods or cooking exhaust devices are operating more than 200 ft^3/min or 90 L/s at 0.1 in water gauge or 25 pa, while generating noises more than 4 sone of loudness. However, the study was limited to testing only 7–15 range hoods depending on installation type and price, with only limited details of energy efficiencies and noise being presented. Studies for other residential ventilation devices such as bathroom fans have had the same constraints of limited sample volumes, i.e. the number of ventilation devices tested. For bathroom ventilation fans, most studies have been conducted for ventilation schemes and air exchange rates along with different ventilation configurations [17,18], operation schemes [19], and electrical power sources and motors [20,21]. However, those studies were limited in size and did not provide extensive performance measurements and evaluations. Of special importance, an energy performance study by McWhinney et al. pointed out that ventilation fans can be expected to have potentials of energy savings up to 65%, which is significant considering such a large market (nearly 6 million units) being open [22]. Therefore, a need exists for not only more studies of residential ventilation devices in terms of multi-year performance analysis, but also a study of an extensive number of ventilation devices.

As an HVI certified testing laboratory for residential ventilation devices, the laboratory facilities used in this study have conducted both airflow and sound tests of ventilation devices for several decades. Therefore, this paper summarizes the sound and airflow performance of bathroom ventilation fans over a 9 year period from 2005 to 2013 with the purpose being to evaluate and analyze fan performance from both statistical and established energy code standpoints. Specifically, this paper presents loudness as a sound performance, and fan efficacy as an energy performance for a large number of multi-year bathroom ventilation fan tests. In addition to an evaluation and analysis of almost a decade of laboratory data, this paper also develops relationships and correlations among efficacies, sound ratings, and other variables.

2. Testing procedure

The data taken, evaluated, and analyzed in this study utilized a semi-reverberant sound test chamber and test set-up shown in Fig. 1 which conforms to ANSI standard S12.51 and HVI 915 [9,23].

The test chamber is constructed with heavy duty, multi-layer insulating walls in order to eliminate any undesired infiltration of airflow as well as noise transmissions through the structure. Also, as per standard requirements, the test chamber has non-parallel walls for the purpose of obtaining the uniform reverberation characteristics over all surfaces. At each of the four chamber corners, acoustic baffles are located and equipped in order to minimize three-dimensional standing waves. The chamber inlet is connected to an insulated labyrinthine duct with a throttling device for adjusting the static pressure and volumetric flow of a fan under test. Also, the chamber outlet is connected to an anechoic muffler that prevents the entry of environmental sounds. Six random incident microphones and preamplifiers are used for all tests, and their placement has been determined by the multiple-microphone qualification process as described in ANSI S12.51. Test conditions including temperature, humidity, atmospheric pressure, and the fan static pressure are monitored and controlled by data acquisition devices and control software. Relevant instruments and data acquisition equipment along with corresponding uncertainties are listed in Table 1. Of special importance for every instrument, certified calibrations are maintained so that the uncertainty of the resulting sound data can be analyzed.

The procedure used for measuring the sound pressure levels of a fan in the semi-reverberant chamber conforms to HVI 915. Each set of sound tests for a fan consists of 4 major steps, namely the unit, the first background, the RSS, and the second background measurement. Pre-test setup and post processing also take place. In the pre-test setup, a fan under test is warmed up by operating it for at least 30 min, or until the power and voltage reading are stable at any given operating value (e.g., 35 W at 120 V), whichever is longer.