Steven Winter Associates, Inc.
Improving the Built Environment Since 1972

Does Your Exhaust Fan Suck?

Srikanth Puttagunta | Steven Winter Associates, Inc.

February 7, 2018

Abstract

You likely don't even think about it when using the bathroom. Flip the switch, hear the exhaust fan, and everything is working as it is intended…right? Far too often, the answer is NO and it is no fault of the user. Sure, homeowners should take a minute each year to vacuum the inside of the exhaust fan housing, but otherwise, these fans should just work. So why do so many of them not work as intended? Hint…it all depends on how it was sized and installed.

Introduction

The purpose of exhaust ventilation is to remove contaminants (including moisture) that can compromise health, comfort, and durability. Exhaust fans are one of the simplest mechanical systems in your home, but decades of experience working in homes has shown us that even the easiest things can get screwed up. Far too often, exhaust fans rated for 50 or 80 cubic feet per minute (cfm) of air removal are actually exhausting less than 20 cfm. In theory, the exhaust fan should be installed in a suitable location and then ducted to the outside via the most direct path possible. However, the installation of an exhaust fan can involve up to three trades; an electrician typically installs and wires the unit, an HVAC contractor supplies the ductwork, and the builder/sider/roofer may install the end cap termination. What could go wrong?

As energy efficiency standards and construction techniques have improved over time, new and retrofitted buildings have become more and more air-tight. This air-tightness can lead to moisture issues if not properly addressed. Quickly removing moisture generated from showers is a key component of any moisture management strategy. While manufacturers have made significant advancements in the performance, durability, and controls of exhaust fans, it can all be side-stepped by a poor installation.

So how do you correct this issue? Proper installation, of course, but the only way to be certain is to measure the exhaust airflow after installation. In a recent project, I inspected what appeared to be a perfectly installed exhaust fan (exhaust fan collar facing the exterior wall and five feet of straight sheet metal duct to a side wall termination cap) and it sounded like it was pulling a lot of air. However, when I actually tested the 80 cfm rated fan, it was only pulling 5 cfm. After a little investigation, I found that the installer used screws to secure the duct to the exhaust fan collar and the screws impeded the opening of the built-in backdraft damper. So while eyes and ears can help, the only way to truly verify performance is by quantitative measurement.

This paper summarizes a "blind" study on the performance of a number of exhaust fans and discusses the variation that exists in similarly rated fans. It also provides information on potential installed pressure drop of exhaust fan ductwork. Finally, a best practices guide to installing exhaust fans is provided.

Background

The ability of an exhaust fan to move air is dependent on the amount of static pressure that the fan must overcome between the fan and its termination outdoors. The static pressure, typically measured in inches of water gauge (“ w.g.), depends on the size and length of ductwork, the number and type of bends in the ductwork, and the type of termination cap. Current exhaust fans are rated for outputs at static pressures of 0.1” w.g. as the industry standard and 0.25” w.g. if they are ENERGY STAR rated. These pressure ratings are meant to represent various typical installation configurations. However, the current rating demarcations of 0.1 and 0.25 do not accurately reflect the reality of many installation procedures. Fan housing installations like those shown in Figure 1 are not great but exhaust fan DC motor technology may be able to overcome these duct restrictions (and restrictions of the termination cap). Unfortunately, it is far too common to see fan installations like those shown in Figure 2.

Figure 1. Common Installation Issues: Immediate bends after exhaust fan and 180° turns due to poor planning during installation.

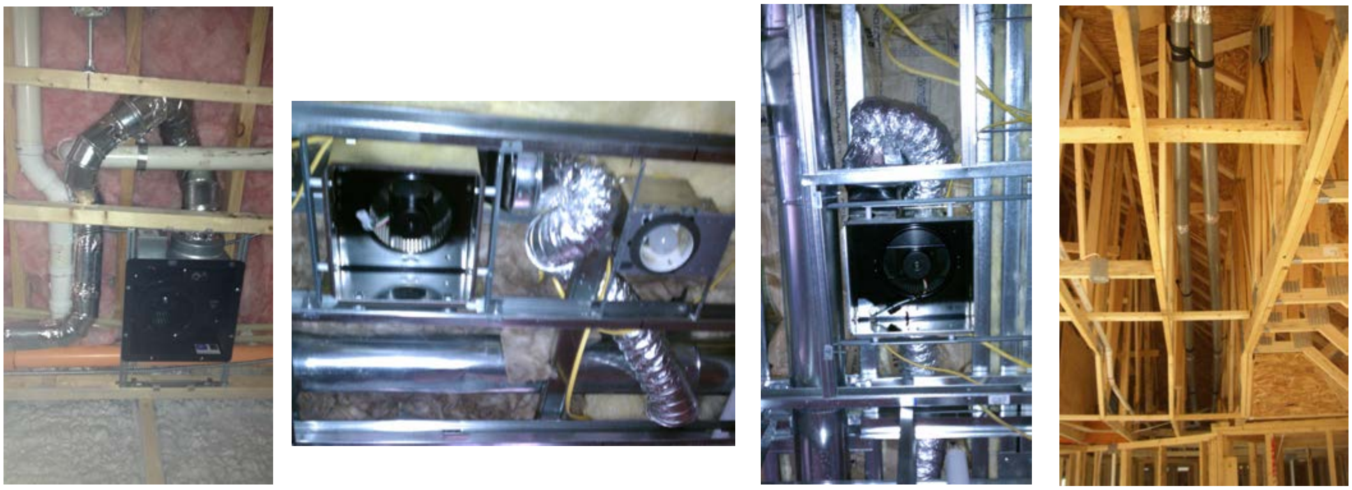


Figure 2. Convoluted or extremely long duct runs can dramatically reduce exhaust fan flow rates

While flex duct has its advantages, it adds resistance when used for exhaust fan ducting. Its flexibility enables contractors to force the duct to do things it really shouldn’t and it is rarely installed per manufacturer's specifications: "Install duct fully extended, do not install in the compressed state or use excess lengths."

As installation practices have a significant impact on fan performance, it is essential to measure airflow rates to verify proper operation. This is why Raters doing ENERGY STAR® certification are required to be testing all local mechanical exhaust flow rates. Category 8 of the Rater Field Checklist for ENERGY STAR Certified Homes, Version 3/3.1 (Rev. 08), says Rater-measured airflow is required for compliance. Whether this is being properly enforced is a separate matter.

The "Blind" Study

To get a comprehensive performance dataset for a number of exhaust fans, the Riverside Energy Efficiency Laboratory (REEL) was engaged for a "blind" study. REEL is the HVI/ESTAR neutral, third-party testing facility. In total, 7 multi-speed fans, 7 single speed fans, and 6 low-profile fans from six manufacturers were sent to REEL without manufacturer markings. In general, ten-point airflow tests were conducted on each fan. Testing adhered to standards used in the industry, namely, ANSI/AMCA Standard 210 and HVI Publications 916 and 920, where applicable. While the dataset is extensive, this paper focuses on the 50, 80, and 110 cfm ventilation rates, as these are the most common specified fan speeds for bathrooms. These fan curves show the relationship of airflow that will be delivered at various static pressures of the duct system.

Figure 3 shows fan curves for single speed fans that were tested. The units are rated for 80 cfm unless noted otherwise in the legend (two are rated for 70 cfm and one for 90 cfm). While all of these fans performed in a similar manner, would it surprise you that two of the fan curves in Figure 3 are for exhaust fans that use DC motors? People often assume that all DC motors fans are the same and result in constant airflow for a range of static pressures (let's say up to 0.4" w.g.).

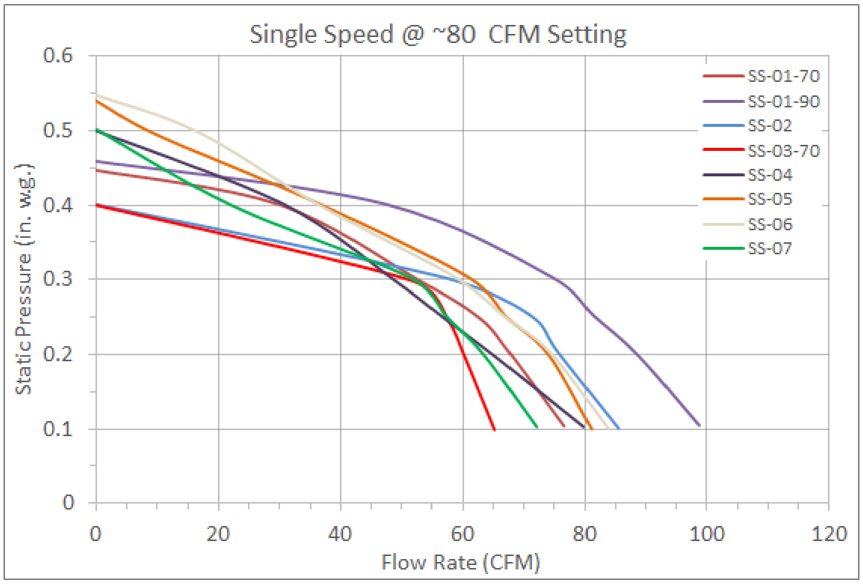


Figure 3. Performance Data for Single Speed Exhaust Fans

It is clear in this data (Figure 3) that flow rates decrease rapidly when static pressure rises over 0.3” w.g., as it often does in real world installations. Oh, are you still wondering which two fans have DC motors? It is actually SS-05 and SS-06. A bit surprising, isn’t it?

Low-profile exhaust fans have become quite popular due to the low clearance requirements for these fan housings. However, as shown in Figure 4, only one fan (LP-01) that uses a brushless DC motor was able to maintain the 80 cfm performance at static pressures up to 0.4” w.g. The rest of the fans (including LP-04, which also uses a DC motor) show a steady degradation of airflow as the static pressure increases over the 0.1” w.g.

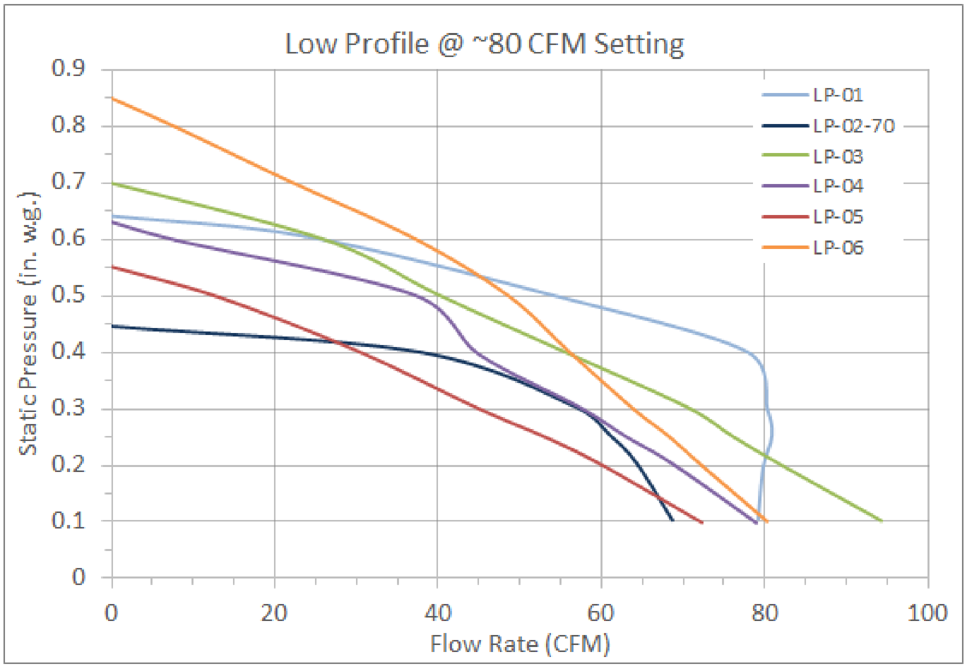


Figure 4. Performance Data for Low Profile Exhaust Fans

For multi-speed fans, the fan curves for the 50, 80, and 110 cfm fan settings are shown in the following charts (if test data was available), as they are the most common flow rates specified for bathrooms. Figure 5 and Figure 6 show the performance of tested multi-speed fans operating at 50 cfm and 80 cfm settings, respectively. All of the multi-speed fans incorporate a DC motor except one (MS-02). For the two better performing fans (MS-01 and MS-05) at the 50 cfm setting, the rate of flow degradation only increased significantly once static pressure exceeded 0.5” w.g.

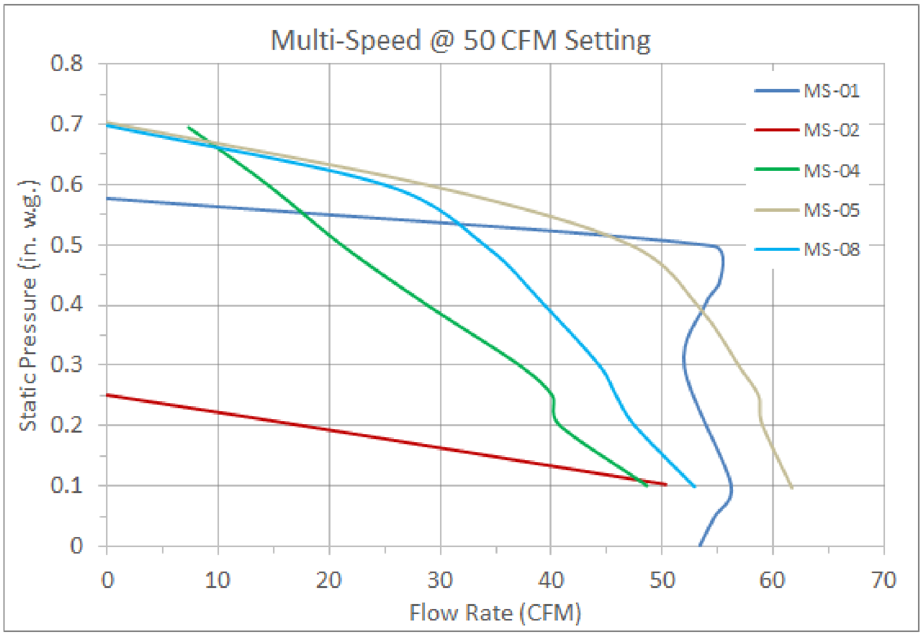


Figure 5. Performance Data for Multi-Speed Exhaust Fans Operating at 50 cfm Setting

For the five better performing DC motor fans at the 80 cfm setting, the rate of performance degradation for these multi-speed fans did not increase significantly until static pressure exceeded 0.4” w.g.

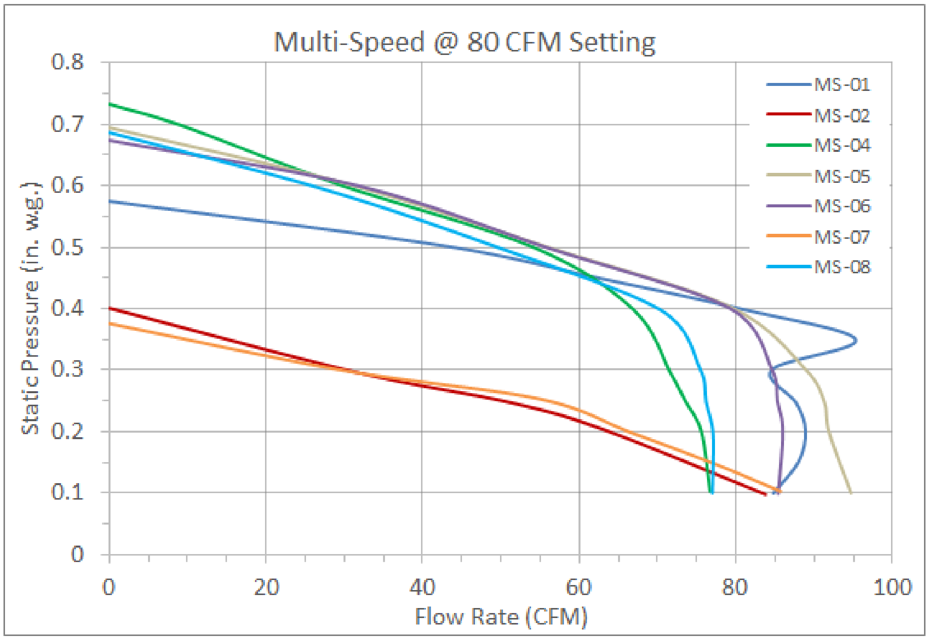


Figure 6. Performance Data for Multi-Speed Exhaust Fans Operating at 80 cfm Setting[1]

---

[1] It is unclear if the 0.35” w.g. data point for the MS-01 fan is an accurate measurement or if the lab technician may not have allowed the fan speed to stabilize before taking the reading.

Test results for multi-speed fans at the 110 cfm setting are shown in Figure 7. Two fans delivered rated flow rates until static pressures reached approximately 0.3” w.g. (MS-01, MS-05). At lower speeds (and air velocities) these fans could maintain rated flow rates at approximately 0.4” w.g.

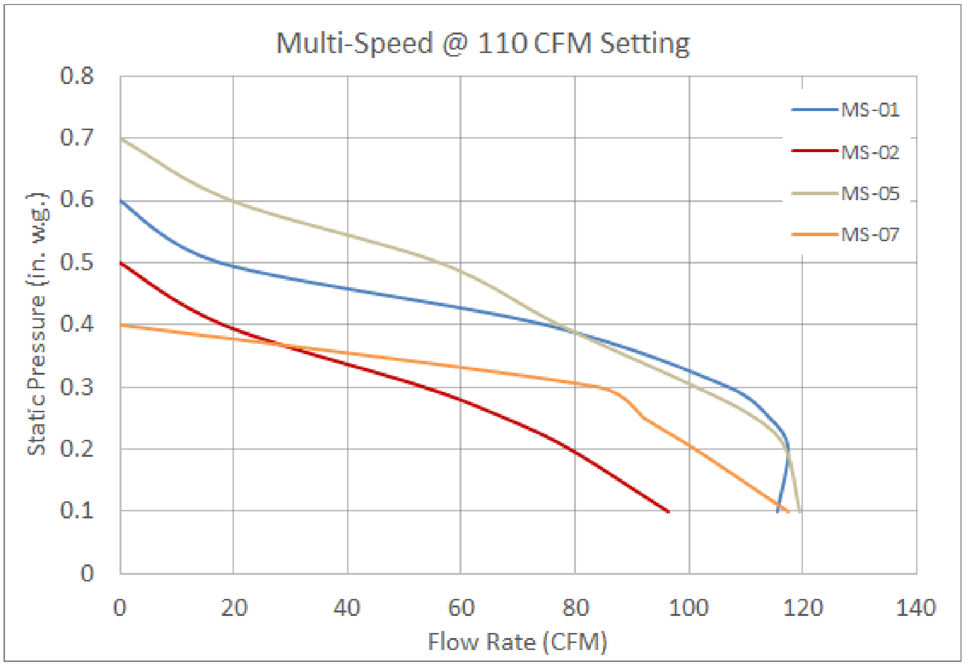


Figure 7. Performance Data for Multi-Speed Exhaust Fans Operating at 110 CFM Setting

For the majority of the multi-speed fans, exhaust airflow tended to be more consistent up to 0.4” w.g. at the middle range (~80 cfm) of their available speed settings. At other speeds, the rate of fan degradation with respect to rises in static pressure seems to be more drastic.

While the data shows that some fans with DC motors have better performance, there is often this misconception that all DC motor exhaust fans maintain the rated flow rate nearly perfectly in all installation scenarios. This is simply not the case. Performance is really dependent on the specific fan model. Therefore, fan curves for specified equipment need to be reviewed along with calculations of the static pressure drop (a ductulator can be used) based on the anticipated ventilation duct components and pathway.

The Solution

Exhaust fans are the primary method to remove odors and pollutants—especially water vapor—from bathrooms. However, these fans often perform very inefficiently and poorly—exhausting a very small fraction of the design or desired flow rates. Better design and installation of exhaust fans is certainly needed (see Bathroom Exhaust Ventilation Best Practices on the last page).

Even with the best installation practices, the only way to ensure success of exhaust fans is by actually verifying performance. Commissioning of exhaust fan operation is usually very straightforward. First, verify that the fan actually turns on when switched on (or when programmed to turn on). Exhaust air flow rate can be easily measured with a flow hood[2] or flow meter (Figure 8). If delivered flow rates do not match design rates (within ~10 cfm), inspect the duct system (when possible) to see if there are any obstructions, if back-draft dampers are operating properly, etc.

Figure 8. Measuring Exhaust Flow with a Flow Hood and Exhaust Fan Meter.

It can also be beneficial to measure flow rate at the outdoor terminal of the duct run. A large disparity in measured flow rates between the exhaust fan and termination measurement implies leakage. If possible, trace the exhaust duct run and inspect for disconnects, crimps, leaks, etc.

Finally, it would be beneficial if fan manufacturers tested and reported performance at higher static pressures to better reflect real-world installations. Exhaust fans are commonly specified based on rated performance at 0.1 or 0.25” w.g. However, as the airflow increases above 40 cfm with 4” duct, 0.1” w.g. is rapidly approached or exceeded simply with the inclusion of a termination cap (roof cap typically being more restrictive than a wall cap[3]); never mind the rest of the ductwork and typical poor installation practices.

To demonstrate how fans typically perform in real life scenarios, SWA ran tests on a multi-speed fan set to 80 cfm and attached ducts to approximate “typical” installations. A 4” insulated flex duct was connected to the exhaust fan. A straight, 90°, or 180° bend (2 diameter bend radius) was placed right after the exhaust fan. The rest of the 20 foot flex duct was run straight either taut (⟹) or loose (⟿). At the end of 20 feet, a typical metal side wall termination cap was installed. Figure 9 shows the exhaust fan curve versus the in-house testing by SWA. Except for the short 8 feet of straight ductwork to a side wall cap (equaling ~48 feet of total equivalent length of ductwork), all cases resulted in a static pressure of greater than 0.25” w.g. For these tests, switching to a roof cap termination with a 90° bend and 4 feet of rise at the end of the flex duct resulted in an average static pressure increase of ~0.07” w.g.

---

[2] There can be challenges to measuring exhaust airflow of a DC motor exhaust fan with a powered flow hood; as the fan and powered hood may keep trying to compensate for each other.

[3] http://oaktrust.library.tamu.edu/handle/1969.1/ETD-TAMU-2011-05-9399

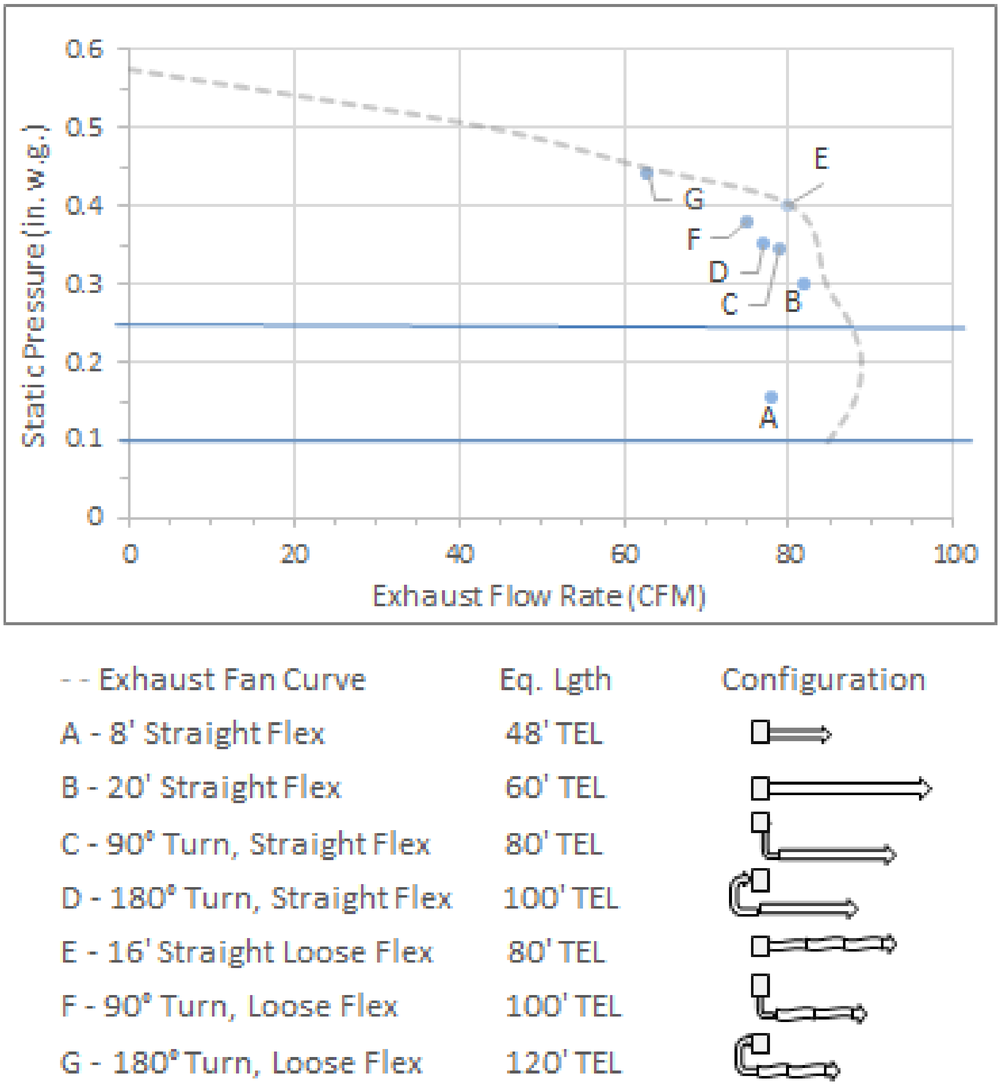


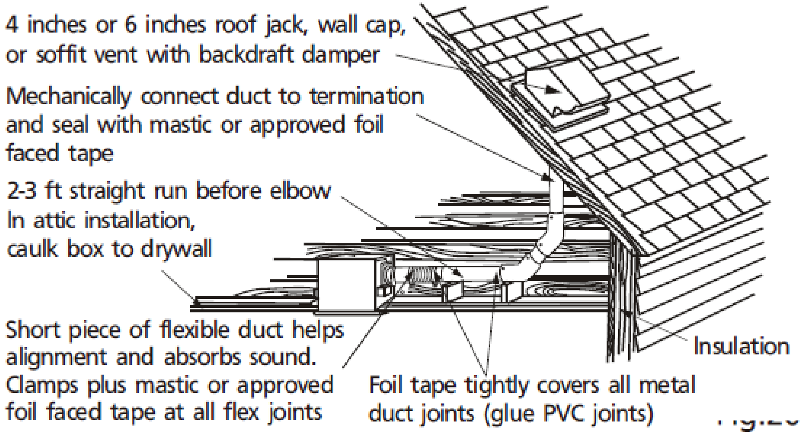
Figure 9. Impact of Duct Configuration on Static Pressure

It would behoove the industry to move away from the 0.1” w.g. rating, consider the 0.25” w.g. rating as the new minimum performance rating baseline, and provide a 0.4” w.g. rating value to better represent common installation scenarios.

Bathroom Exhaust Ventilation Best Practices

Install a properly sized, ENERGY STAR® rated ceiling mounted exhaust fan to remove moist air and odors from bathrooms.

- Select an exhaust fan that is capable of providing desired ventilation rate (accounting for pressure drop of ductwork).
- If the exhaust fan has two ducting collar size options (typically 4” and 6”), always use the larger duct size if possible.
- The exhaust fan should be located at the highest point in the bathroom (typically ceiling) and located near (within ~5 feet) the shower. If locating directly over bathtubs or showers, ensure that the fan unit is UL listed for use over those areas. It will also need to be connected to a GFCI protected branch circuit.
- Fan outlet should be oriented toward the direction of the duct run to the final termination location to avoid extra bends or elbows in ducting.
- A backdraft damper will be installed between the outlet side of the fan and the exterior to prevent reverse air flow when the fan is off. Many exhaust fan housings come with an integrated backdraft damper. Ensure that the backdraft damper is not impeded when securing ductwork to the exhaust fan housing collar.
- Fan should be ducted in accordance with manufacturer specifications. Provide two feet of straight duct run from the fan exhaust port to the first elbow in the duct run. Smooth metal duct is preferred over flex duct and the ductwork should be slightly pitched to have any potential condensation drain to the exterior rather than back into the bathroom.
- Exhaust ducts should always terminate outdoors (refer to applicable codes for vent termination clearance requirements). Running exhaust ductwork up to a vented attic or just in front of an attic vent (gable, ridge, or soffit) is not sufficient. The exhaust should be fully ducted to a point exterior to the home.
- Carefully select the duct end termination, as they can have significant performance differences. Select an HVI-certified termination whenever possible. In addition, terminating the exhaust ductwork in a soffit vent can be challenging. Unless an energy-heel truss is used, there is typically minimal space to adequately transition the ductwork to a vertically connected soffit termination without kinking the ductwork. If a soffit vent is used, select a horizontal duct connection.
- Duct connections should be sealed with appropriate tape or mastic.
- Insulate ductwork if it passes through unconditioned space(s) prior to the exterior termination.



For more information, please contact sri@swinter.com