The Pennsylvania Housing Research Center

Obtaining Proper Ventilation: A Case Study in Residential Exhaust Fan Performance

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INTRODUCTION

As energy efficiency and building performance have taken on a larger role in the construction industry, expectations regarding indoor air quality have also increased. While commercial buildings have been incorporating elaborate HVAC systems and designs for years, the complexity and performance of residential systems has seen a markedly slower progression. Ventilation systems, in particular, have experienced limited implementation into the average new home on the market today.

ENVELOPE TIGHTNESS

New homes built to current codes and above code energy efficiency programs are much tighter than in the past. Air sealing the building envelope is one of the most cost effective ways to reduce energy consumption in a home. However, reducing infiltration rates across the envelope without providing some other means of ventilation comes with risks to building occupants and the performance of the overall structure.

Allowing a House to "Breathe"

Previous generations of builders and homeowners embraced the concept of allowing a home to breathe. It was thought that the needs of building occupants with regard to fresh air were satisfied by outside air entering through leaks in the building envelope. While these natural infiltration rates often exceeded the needs of the occupants, they typically came at a cost. These envelopes were much less efficient, more prone to mold growth and structural degradation, and were much less comfortable to the building occupants.

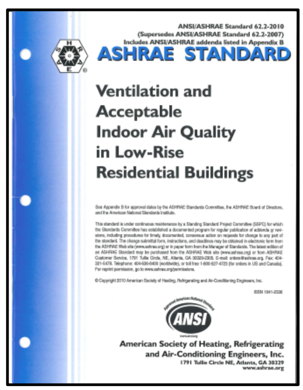
"Build Tight; Ventilate Right"

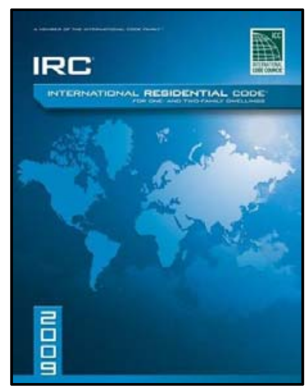
Modern residential construction methods have had a significant effect on the tightness of the overall building envelope. Many factors contributed to this trend, including consumer expectations with regard to energy efficiency, progressive building codes, and the popularity of voluntary third party compliance programs such as Energy Star.

As the trend of tighter buildings picked up steam, code requirements addressing the need for proper ventilation have not kept pace. Although a consensus among building scientists has led to the concept of "Build Tight; Ventilate Right", many builders opt out of any voluntary deliberate methods of mechanical ventilation when their goal is to keep costs under control. The recommended approach, though, is a tight building envelope with quantifiable mechanical ventialtion. By controlling the amount and location of ventilation in a home, the likelihood of uncomfortable drafts and mold growth is greatly diminished.

CURRENT CODES & STANDARDS

With regard to current practices addressing building ventilation, there is a notable disconnect between the "code minimum" and recommended practice.





2009 International Residential Code

During review of the 2012 International Residential Code, the Commonwealth of Pennsylvania opted to not adopt the 2012 IRC, effectively extending the life of the 2009 version for an additional code cycle, or another three years.

The 2009 IRC addresses household ventilation in Section R303 (Light, Ventilation, and Heating). This section effectively provides two options for compliance:

1. R303.1 states that all habitable rooms shall have an aggregate glazing area of not less

than 8% of the floor area of such rooms, with a minimum operable area to the outdoors of 4% of the floor area being ventilated.

2. Exception #1 to Section R303.1 allows for a mechanical ventilation system capable of providing 0.35 air changes per hour in the room if it is installed in lieu of the operable glazing criteria. This exception also allows for a whole house mechanical ventilation system capable of supplying outdoor ventilation air at a rate of 15 cubic feet / minute (CFM) for each occupant. The latter option assumes two occupants for the master bedroom and one occupant for each remaining bedroom.

Consumer-driven design trends have increased the amount of windows for all habitable rooms in homes, allowing builders to easily satisfy the operable area requirement of R303.1. However, relying on occupant behavior to provide ventilation (opening and closing of windows) creates problems with constistency and proper management. Also, with the prominence of efficient heating and cooling systems, there are fewer days than in the past when a homeowner would be likely to open their windows and allow fresh air to enter their home.

ASHRAE Standard 62.2-2010 – Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings

While the 2009 IRC often allows builders to avoid the installation of a dedicated mechanical ventilation system, ASHRAE (American Society of Heating, Refrigerating, and Air Conditioning Engineers) has developed a standard which takes ventilation a step further than the IRC. Although this standard represents a higher performance standard than code minimum, it is currently only voluntary. ASHRAE 62.2-2010 mandates adherence to a minimum mechanical ventilation rate. This rate is quantified using the following equation:

$$Q_{fan} = 0.01A_{floor} + 7.5(N_{br} + 1)$$

Where Q_{fan} = fan flow rate (CFM),
A_{floor} = floor area (ft^2), and
N_{br} = number of bedrooms.

The ventilation rate prescribed in ASHRAE 62.2-2010 can be provided through a supply, exhaust, or balanced system.

Mechanical Ventilation System Types

There are three common methods for providing mechanical ventilation in residential buildings: exhaust-only, supply-only, and balanced systems.

Exhaust-only systems transfer air from the interior to the exterior with a fan, such as a bath fan, while relying on random infiltration to draw in ventilation air. These systems are most appropriate in cold climates where the majority of the time the air outside is dry relative to the inside. Cold, dry outside air drawn through random infiltration creates little condensation risk.

Supply-only systems transfer air from the exterior to the interior with a fan.The fan slightly pressurizes the house so that stale air leaves the house via random exfiltration. This strategy is not appropriate in cold climates because relatively warm, moist air from the interior is forced into building assemblies where surfaces are cold for long portions of the year. This scenario can lead to condensation.

Balanced systems ventilate through approximately equal amounts of air simultaneously exhausted from and supplied to the house. This keeps the house under neutral pressure, and so is appropriate for any climate. Balanced systems typically involve heat recovery ventilators (HRV's) or energy recovery ventilators (ERV's). Besides a greater level of control over ventilation air, these units also allow for temerping of incoming fresh air, yielding greater overall energy efficiency.

PHRC CASE STUDY

One of the simplest ways in which mechanical ventilation can be provided for a home to meet either the R303.1 exception in the 2009 IRC or the ASHRAE 62.2-2010 ventilation requirement is through the use of a dedicated bath exhaust fan. The operation of a bath fan for the purpose of local or whole house ventilation is similar to its normal operation (via switch), although a slightly more elaborate control setup allows for operation at a predetermined continuous CFM rate (see Figure 1).

In order to develop a greater understanding of this simple exhaust-only ventilation strategy, the PHRC commissioned a performance evaluation of 88 exhaust fans in 30 different homes built by a local Pennsylvania builder. The purpose of this study was to investigate the true ventilation performance of these systems as well as the effect of installation methods on the fan operation. The builder works with a certified Home Energy Rating System (HERS) rater to conduct performance testing on their homes. Part of the overall testing sequence involved air flow testing of each exhaust fan within the home, as well as overall blower door testing.

Figure 1: Exhaust only mechanical ventilation.

Methods

The airflow testing of each exhaust fan was performed by the HERS rater using a piece of equipment manufactured by the Energy Conservatory, called a FlowBlaster™. The FlowBlaster™ is a powered flow hood and has previously been established to be significantly more accurate in determining air flows than other non-powered methods.

The powered flow hood is placed over the fan while it is running, and a variable speed fan in the flow hood apparatus is turned up until there is zero pressure in a chamber between the hood's fan and the exhaust fan. Zero pressure means the flow of the hood's fan is equal to the flow of the exhaust fan. A flow reading is then taken from the flow hood. The flow hood reading is then equal to the exhaust fan flow.

Exhaust fan flows were measured twice – once with all windows closed and once with the bathroom window open. The two measured flows were compared to see if the tightness of the house had any impact on fan performance. Standard blower door tests were also performed to quantify house tightness.

Fan systems were inspected at the rough-in phase of construction. The length of ducts was measured and recorded. The degrees of bend present in each duct run were also measured and recorded. This was relatively subjective given the nature of flex duct, which can be bent at arbitrary angles. According to flex duct manufacturer Hart & Cooley, five feet, ten feet and 30 feet in equivalent length should be added for each 45, 90, and 180 degree offset ("S" shaped), respectively. Total equivalent length was calculated in this case study by adding the actual length of duct plus ten feet for every 90 degrees of bend. This is a relatively crude measure and does not include the effects of flex duct that had excessive length and therefore was not pulled tight.

Results

On average, fans tested performed at 71 percent of their rated flow with a range from 35 to 113 percent. Of the 88 fans, eleven (11) performed at less than half their rated airflow and six (6) fans yielded a flow rate greater than their rated flow. Although the installation of the exhaust fan duct lines greatly varied, the Total Equivalent Length did not have a statistical effect on the exhaust fan performance versus rated flow.

The average house tightness was 2.8 ACH50, which is well under the 2009 International Energy Conservation Code limit of 7.0 ACH50, and slightly under the 2012 IECC requirement of 3.0 ACH50. House tightness did not make a difference in fan performance as there was virtually no difference between tests performed with windows open versus shut. Even the tightest home at 1.8 ACH50 did not show a significant difference in fan flow between the two tests.

DISCUSSION & RECOMMENDATIONS

The performance of the exhaust fans assessed in this study was very inconsistent. This supports the notion that mechanical ventilation within the residential construction industry is still in its developing stages. There is also some validity to the idea that fan flows should be tested to ensure the systems are providing adequate ventilation. Fan flow testing may be particularly important in tight houses with whole-house fans that are intended to promote acceptable indoor air quality for the entire home.

It is likely that, despite finding no correlation between fan flow and total equivalent length (TEL) of duct, duct installation is the cause of many of the underperforming fan systems. It is also likely that the method used to assess TEL did not accurately capture the amount of resistance to airflow resulting from the bends and sagging in the flex ducts. Recording the total degrees of bend did not account for the turn radii of individual bends. Some ducts made sharp turns while others were more gradual. In addition, some of the ducts were stretched tight and others were sagging or were bunched up in places. The HERS rater also discovered that the mechanical crew was leaving excess lengths of flexible duct hanging over the soffit for the siding crew to attach to the soffit vents. The amount of extra duct varied greatly. The siding crew was then attaching the soffit vents and shoving the extra into the soffit instead of cutting the duct to the proper length, yielding inconsistent results.

Figure 2: Excessive turns in duct line.

Based on overall observations from this case study, the following are some tips for properly installing residential exhaust fans:

1. Account for mechanicals during the design phase – This will help to reduce conflicts between exhaust systems and other features of the house like framing, plumbing and HVAC ducts.

2. Use smooth duct (e.g. sheet metal) – Smooth duct has less resistance to airflow than flex duct because it does not have any ridges that increase friction.

3. Keep duct runs as short as possible – The further the air has to travel the more friction it encounters, slowing its flow.

4. Keep duct runs as straight as possible – Avoid bends when feasible, particularly within the first two feet of the fan. When bends in flex duct are necessary, make them as gradual as possible. Avoid 180 degree ‘S’ and ‘U’ turns (see Figure 2).

5. Orient the fan in the appropriate direction – Very often the fan is installed such that the outlet of the fan is on the opposite side as the exterior exhaust terminal. Frequently an electrician will install the fan and an HVAC contractor will install the duct. The electrician may not know, or think about, the location of the exterior exhaust terminal, and the HVAC contractor will not reorient the fan once it has been installed. This results in severe turns in the duct close to the fan housing which may drastically reduce overall airflow.

6. Cut flexible ducts to fit – Flex ducts should be cut to exactly span the distance from the fan outlet to the exhaust terminal. Any excess duct length will cause sagging and compression of the duct. Flex duct must be pulled tight to achieve the expected amount of airflow.

7. Seal duct connections – Duct connections should be well-sealed with tape or preferably mastic *and* mechanically fastened to fittings with a UL 181 listed plastic or metal clamp. “Beaded” fittings should be used so the clamp, when pulled tight, will not slip off the fitting resulting in air exhausted somewhere within the structure.

CONCLUSION

It is apparent, based on the current state of the industry and highlighted by this case study, that ventilation systems in homes will need to be studied further in order to develop an understanding of best practices. While exhaust fans as mechanical ventilation systems are one option for builders and homeowners, there are many alternatives that offer similar challenges to those documented in this study. It is important to understand the design intent, installation methods, and overall system performance in order to obtain a mechanical ventilation system that truly meets the intent of the builder and the needs of the homeowner.

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