A Field Study of Exhaust Only Ventilation System Performance In Residential New Construction in Vermont

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ABSTRACT

Utility sponsored residential new construction programs in Vermont have provided incentives to encourage builders to install exhaust only ventilation (EOV) systems. One utility program has specified the installation of passive air vents as part of the EOV system. This study was undertaken in order to understand the basic air flow performance of these EOV systems.

Data was collected for 43 single family homes built in Vermont between July 1998 and May 1999. Blower doors were used to measure home air tightness. Digital manometers and pressure pans were used to record pressure differentials created by the EOVs. The pressures induced on the house by the EOV were very low, averaging –1 Pascal. The low pressure implied that the EOV induced only small amounts of air flow through passive air vents, ranging from 2 to 4 cfm, indicating that most of the air drawn into the building by the EOV fan came in through openings other than the passive air vents. Air flow through passive air vents was much more strongly affected by weather conditions than it was by the small pressures induced by the EOV fan. The low inside / outside pressure differential induced by the EOV fan made it unlikely to cause backdrafting *by itself*, but backdrafting must be considered for the house as a whole, including all fans and combustion systems in the house. EOV fans operated at 67% of rated capacity, exhausting 62 cfm on average. The controls for the EOVs were not programmed by the builder or electrician in 45% of the homes.

Introduction

The purpose of the field study was to better understand the air flow performance of EOV systems in new single family homes. The study was contracted in June 1998 by The Vermont Department of Public Service and a group of seven utilities [1]that offered incentives for EOV systems in residential new construction programs.

A fan that exhausts stale air from the building, provides spot ventilation and general ventilation, and is controlled by a programmable timer characterizes an exhaust only ventilation system (EOV) (Stevens 1996). This type of system has become popular with builders in Vermont due to the low cost (Roberson, et al., 1998) and because of incentives offered by utilities. Several studies have been conducted to determine how the ventilation systems are performing (Palmiter and Bond, 1992), (Strunk, et al. 1999) and (Rudd and Lstiburek, 1999).

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[1] Burlington Electric Department, Central Vermont Public Service, Citizens Utilities, Green Mountain Power, Vermont Electric Cooperative, Vermont Gas Systems, and Washington Electric Cooperative.

Scope of Study

All fans analyzed in this study were installed in bathrooms and were ceiling mounted models. Passive air vents are operable devices installed through exterior walls. They are designed to allow air to pass through the device due to pressure differences alone; there is no mechanical assistance built into the device itself.

The major questions that were developed for this study are as follows:

(1) What is the measured airflow through fans installed as part of EOV systems?
(2) How do measured flows compare with rated flows for the fans?
(3) In what direction and at what rate is air flowing through passive air vents?
(4) How are fan controls being set the builders?
(5) Will an EOV system depressurize the house?
(6) Will an EOV depressurize the house enough to cause backdrafting of atmospheric appliances?
(7) Will a tight house reduce fan performance?
(8) Will the EOV sufficiently depressurize the house to draw air in through passive air vents?

It should be noted that the study did not attempt to evaluate EOV system effectiveness in terms of adequacy of ventilation for human health or for indoor air quality. It also did not attempt to evaluate the energy impacts of EOV systems.

Study Population. Tests of 43 EOV systems were undertaken in 43 single-family homes built by 26 builders between July 1998 and May 1999. No one builder accounted for more than three of the homes tested.

Table 1. House characteristics for 43 homes in the EOV study

	Air Tightness CFM50	Estimated Heating Natural Air Changes per Hour	Air Tight-ness ACH50	Heated Floor Area	Number of Bedrooms	Number of Bathrooms
Average	1,118	.29	4.45	2184	3.3	2.5
Maxi-mum	1,888	.59	8.69	4,750	5	4
Minimum	624	.16	2.24	1,080	2	1

Homes ranged from one to five bedrooms, with an average of 3.3 bedrooms and 2.5 bathrooms. Heated floor areas ranged from 1,080 to 4,754 square feet, with an average of 2,184 square feet.

Homes with natural draft combustion equipment[2] represented 16% of the homes surveyed.

Multi-point blower door testing indicated an air leakage rate ranging from 624 to 1,888 cubic feet per minute at 50 Pascals (cfm50) pressure difference between the inside and the outside the house, with a mean of 1,118 cfm50. The data were analyzed to yield estimated natural infiltration rates ranging from 0.16 to 0.59 air changes per hour, with an average of 0.29 air changes per hour. The estimated natural heating season average air changes were calculated using the LBL infiltration model (Sherman and Grimsrud, 1980) and the conditioned volume of the home

Fan Equipment. All the homes studied were equipped with at least one exhaust fan that functioned as mechanical ventilation for the house. Of these, 27 were made by Broan, 14 were made by Panasonic and 2 were made by Nutone. The nominal average airflow rating for the fans was 95 cubic feet per minute (cfm.).

Of the 43 homes, 22 included passive air vents with an average of 3.7 vents per house. Of these, 71 were Fresh 80's distributed by DEC International and 11 were Airlet 100's manufactured by American Aldes Ventilation Corporation.

Controls and Settings. Approximately half the fans (20) were controlled by programmable timers manufactured by Grasslin Controls Corporation (Model KM 2/1). These timers offer 24 hour programming with up to 36 on\off operations per day. Another 10 were controlled with timers of similar function manufactured by others. Six were controlled by Tamarack Technology's Airetrak timer, a solid state device that can be programmed underneath the conventional switch plate to run a set fraction of each hour at a set speed. A button that protrudes through the switch plate can be pressed to have the fan run full speed for 20 minutes. On/off switches controlled another two fans. The type of control for five systems could not be identified primarily because the controls were not installed at the time of the inspection. Seventeen (46%) of the 37 fans with known controls were found with duty cycles of 0%. It is assumed that neither the builder nor the electrician made an attempt in these cases to set the control. Four (11%) of the 37 fans were set to continuous operation (100% duty cycle).

Ducting and Vent Termination Equipment. EOV exhaust ducting usually could not be visually determined at the time of the inspection and EOV testing due to the fact that it had been covered by insulation. The builder provided much of the information. Consequently, ducting type was unknown in 18 of the houses. Of the remaining ducting types, thirteen systems had vinyl flex duct, six had aluminum flex and six had rigid, thin-wall PVC ducting. About 85% of the exterior terminations were the multi-louver type. There were two dryer-vent type terminations with a hood and single flap and one Hartland snorkel-type termination. Duct length for the EOV systems averaged 17 feet.

[2] For the purposes of this study, natural draft combustion equipment is defined as equipment that uses inside air for combustion and the stack effect of heated exhaust combustion products through a chimney or exhaust vent. Power vented combustion devices and sealed combustion devices are not considered to be natural draft combustion equipment.

Description of Study Tools and Methodologies

Measuring EOV air flow. The air flow of the fans in the EOV systems in the study was determined by using a digital manometer in conjunction with a pressure pan. This method has been used successfully in quantifying air flows at vent terminals for ducted distribution systems (Davis 1998).

The digital manometer measures pressure differences in Pascals. The instrument selected for testing pressure differences was the Minneapolis Digital Pressure and Fan Flow Gauge (Model DG-3) manufactured by The Energy Conservatory.[3]

The pressure pan is a sheet metal pan (22" X 15" X 6"). The open edge of the pan is weatherstripped and will make a seal when placed against a flat surface. The bottom surface of the pan has a 9" X 6" opening. The area of this opening can be adjusted from 0 square inches to 54 square inches. A pressure tap is mounted on the bottom surface of the pan. The digital manometer is connected to the tap via 1/4" plastic tubing.

To obtain an air flow reading, the pressure pan was held up to the ceiling completely covering the diffuser for the EOV fan. A tight fit to the ceiling was obtained by pressing the weatherstripped edge to the ceiling. The digital manometer was turned on and the opening in the pressure pan was adjusted to achieve a minimum reading of 1 Pascal. This value was selected as a minimum pressure differential sufficient to obtain a reasonably accurate reading. The reference pressure and the area of the opening on the pan were recorded without the fan in operation. This data was used to calculate the reference air flow.

Then the fan was turned on and the opening was adjusted again to obtain a reading of 1 Pascal or greater. The area of the opening was recorded in square inches.

The calculation of air flow was based on the fluid dynamics principle that flow rate is proportional to the square root of the pressure difference resulting from fluid flow.[4] The formula used to calculate air flow for the study was:

$$\text{Pascals}^{1/2} \text{ X Sq. Inches X } 1.07$$

Where:

Pascals	=	the measured pressure difference across the plane of the pressure pan
Sq. inches	=	the area of the adjustable opening
1.07	=	a constant

The net flow was calculated as the fan flow minus any flow determined by the reference reading.

Measuring pressure differentials across passive air vents. The procedure to measure a pressure differential across an open passive air vent, such as the Fresh 80, required two steps. First a base reading was determined without the EOV in operation. This was accomplished by placing

[3] This instrument has a resolution to 0.1 Pascal with accuracy +/- 1% of the pressure reading or two counts, whichever is greater.

[4] Based on *ASHRAE 1997 Fundamentals*, 2.12. Equation 38.

the pressure pan over the passive air vent and pressing tight to the wall to make a seal. The adjustable opening in the pressure pan was closed and the reference pressure differential was read. Then a second pressure reading was recorded with the EOV in operation. All doors between the EOV and the passive vent were left in the open position. These tests were conducted on each passive vent in the study.

Determination of home air tightness. A Minneapolis Model III blower door was used to measure house air tightness. A single point test (depressurization to 50 Pascals relative to outside) and a multiple point test (five separate readings with descending pressure differentials relative to the outside) were conducted for each home. In homes that had passive vents, two sets of tests were conducted; one with the vents open and one with the vents closed.

House depressurization caused by EOV. The ability of an exhaust fan to ventilate a house depended on its ability to depressurize the house relative to the outside. This depressurization will cause outside air to be brought in for ventilation. Depressurization can also cause backdrafting of natural draft combustion devices when it occurs with significant magnitude. Therefore, the ability to depressurize determined how well the EOV introduced outside air into the house as well as its capacity for interfering with combustion devices. Two methods were used to quantify the EOV ability to depressurize the house:

Method # 1 - Measurement of increased house depressurization at the location of the blower door when the EOV was operating.

Method #2 - Measurement of increased house depressurization at the location of the passive air vent

In Method #1, all operable openings to the outside were closed. A reference measurement of house / outside pressure was recorded at the blower door, and then the EOV was turned on and the pressure difference at the blower door was recorded again. The difference between the two tests was the net effect of the EOV to depressurize the house. This method used the manometer at the blower door – typically set up in a first-floor door of the house -- for the measurement. Typically the EOV was located in a central bathroom on the second floor.

A variation of the Method #1 test was also recorded. In this variation, all operable openings in the house were closed, except for the passive air vents, which were reset to the position as installed by the builder.

In Method # 2, inside / outside pressure differentials were measured at the passive air vents. A base pressure reading without the EOV running and one with the EOV running were recorded. The pressure on the vent induced by the fan was the difference between the pressure with and without the fan running.

EOV System Performance Summary

Installed Capacity vs. Rated Capacity

The measured airflow through the fan varied from 9 cfm to 116 cfm, with an average of 62 cfm. The fan with the 9 cfm flow had a blocked duct. The average rated flow was 95 cfm.

Rated air flows reflect the manufacturer's test of airflow at 0.10" water static pressure. The fan itself may have been moving more air than 62 cfm, but in 70% of the EOV systems, there was a gap between the fan housing and the ceiling sheetrock which allowed for air leakage. With leakage in this area, air may have been moving from between the drywall

Table 2. Measured Exhaust Fan Air Flows

	Measured Air Flow (CFM)	Percent of Rated Capacity
Average	62	67%
Maximum	116	105%
Minimum	9	8%

and the fan into the fan and out of the building, but this air was not counted as ventilating the house, because in most cases this air came from the attic.

In one case a test was done to measure the increase in airflow after the gap was sealed around the fan. The gap totaled approximately 5 square inches of opening between the fan housing and the surrounding sheetrock. With the gap, the net airflow measured at 56 cfm; after sealing the flow was 75 cfm, which was a 34% improvement in performance. The manufacturer's rated capacity of the fan was 110 cfm.

Flows ranged from 8% of rated flow to 105% of rated flow, with an average of 67% of the rated airflow. While the majority of fans did not perform at their rated flow, there were two that were close to rated flow (probably with smooth, relatively short, well-installed ductwork)

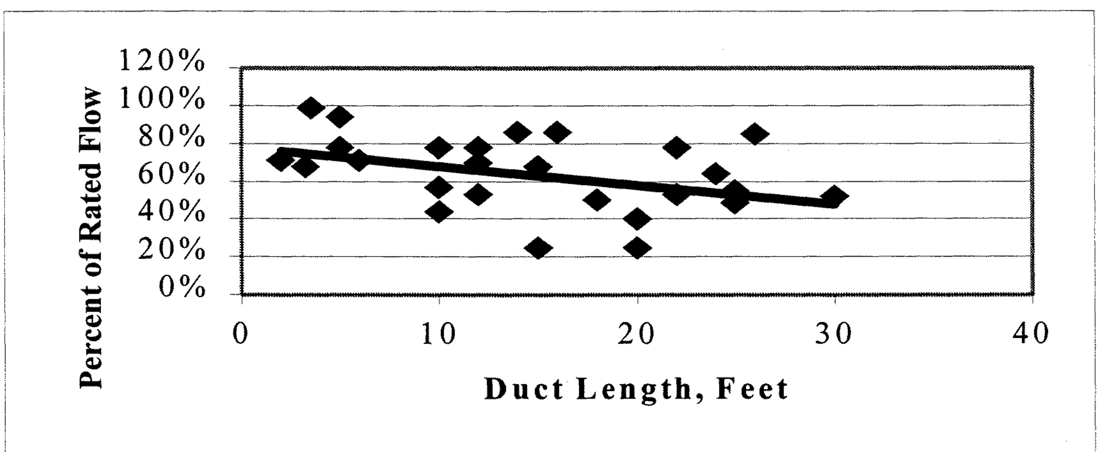

Figure 1. Percent of Rated Flow for EOV Exhaust Duct of Different Lengths

showing that fans can be installed to meet the rated airflow.

Several factors influence flow, including ductwork length, ductwork quality and the gap around the housing. Figures 1 and 2 show trends, but the data had a poor fit to the regression lines due to additional factors affecting flow.[5] However, the data tends to indicate that the longer the duct, the lower the air flow rate and the larger the gap around the housing, the lower the air flow rate.

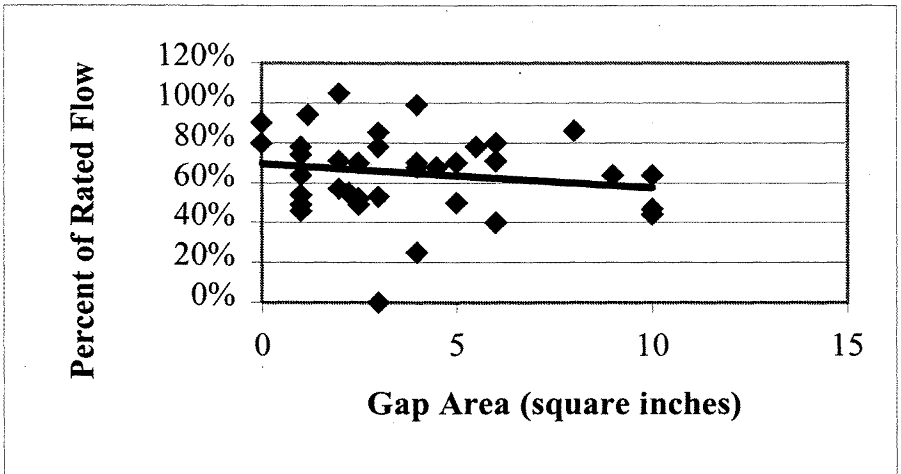

Figure 2. Percent of Rated Flow for EOV Installations with Housing / Ceiling Gaps of Various Sizes

Fans performance in different houses built by the same builder varied widely. In six cases where builders had more than one home in the survey, only two of these builders achieved similar performance for the EOV fan in all of their homes. It should be noted that no data was taken about who actually installed the fan and ductwork, or whether this was done by the builder, the electrician or others.

The data was examined to determine if the air tightness of the house had any effect on the performance of the fan. There was found to be no correlation between the measured EOV fan air flow performance and the tightness of the house.

Ability of EOV to Depressurize House

The net depressurization achieved by the EOV in Method #1 tests, measured at the blower door location and all openings shut, averaged –1.6 Pa for n=25.[6] The net depressurization

[5] For Figure 1, r = 0.16 and for Figure 2, r = 0.03

[6] A total of 33 Method #1 tests were conducted, however eight of the Method #1 tests yielded results that were positive, suggesting that the house was pressurized rather than depressurized when the EOV was turned on. This may be the result of windy conditions during the test and / or operator error. The data for the eight tests were not included in the analysis.

achieved by the EOVs tests measured at the blower door location with passive air vents opened averaged –1.1Pa for n=19.

The net depressurization achieved by the EOV in Method #2 tests, measured at the passive air vents, averaged –0.9 Pa for n=38.

It should be noted that measuring these low pressures was difficult, because the wind could and often did overpower the small pressure induced by the fan. Values would fluctuate widely when the wind was blowing.

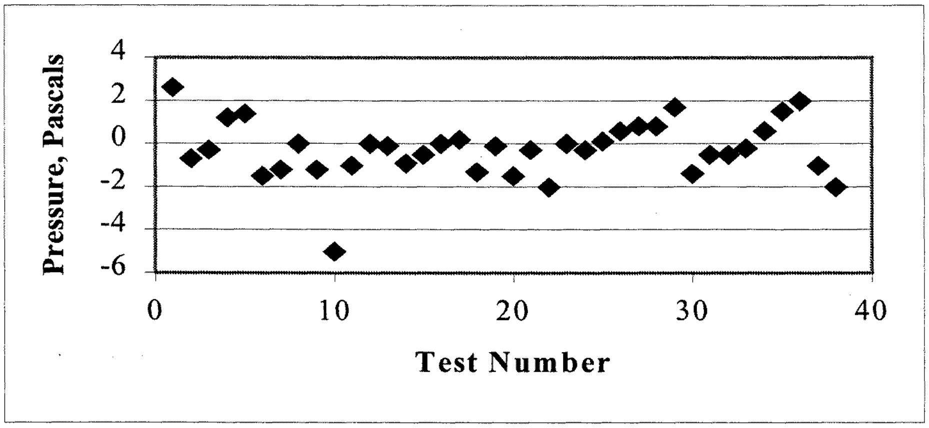

Figure 3. House Pressure with Respect to Outside Measured at Passive Air Vents with EOV Fan Operating

In only 43% of the cases was it clear that running the fan induced a discernible pressure difference at the passive air vent.

Figure 3 plots the pressure differentials at the passive air vents with the exhaust fan on. The data shows a wide scatter both sides of zero, with an average somewhat below zero.

Analysis of Results. The pressures induced by fans in these tests, averaging in the range of –1 Pa, were low relative to pressures induced on a house by natural forces including wind and temperature driven stack effect. As a comparison, calculations of natural infiltration often use a seasonal average of 4 Pascals as the magnitude of these forces. These forces are about 4 times greater than the pressure effects created by the EOV.

The small magnitude of the pressures created by the EOV suggested that the EOV fans would have difficulty causing sufficient negative pressures throughout the house to assure that outside air will be consistently introduced uniformly in sufficient quantities in habitable rooms as the result of fan operation.

Additionally, the consistent, small pressures induced by EOV fans in the study made it unlikely that, *by itself,* the EOV can cause backdrafting of natural draft combustion devices. In most cases, depressurization of 3 Pascals or greater would be necessary to set up conditions for backdrafting. There were a few cases in the study in which the EOV caused house depressurization by 3 Pascals or greater, and these represented less than 10% of the tests. None of the homes in which the depressurization was greater than 3 Pascals had natural draft combustion equipment.

Ability of the EOV to Affect Passive Air Vent Performance

In order to investigate further the ability of the EOV to affect passive air vent performance, another approach was taken. Typical blower door data was analyzed to see if the amount of air flowing out of the house at the EOV would be enough to induce flow into the house through the passive air vents in the absence of weather induced pressures, and if so, how much. Two sets of blower door data were compared to data for a Fresh 80 passive air vent. The blower door test defined the relationship between pressure and airflow through a house. Test data for the Fresh 80 (obtained from the manufacturer) defined the same relationship between pressure and airflow through a Fresh 80. In either case, if the pressure induced is known, airflow rate can be predicted or vice versa. The blower door data was taken from a house of average air tightness in the study (0.29 ACH) and from another slightly looser house (0.41 ACH), for comparison. For each set of data, a regression analysis yielded a slope and intercept for the log pressure/log flow curve. This enabled the prediction of the flow versus pressure relationship at pressures lower than can be easily measured.

Figure 4 shows the predicted flows in the range from 0 to 100 cfm and from 0 to 4 Pa, showing expected flow versus pressure for the houses and also for four Fresh 80's (the typical number of vents found in houses that had them) and for one Fresh 80.

At the average flow found for the exhaust fans of 62 cfm (dashed horizontal line on Fig-

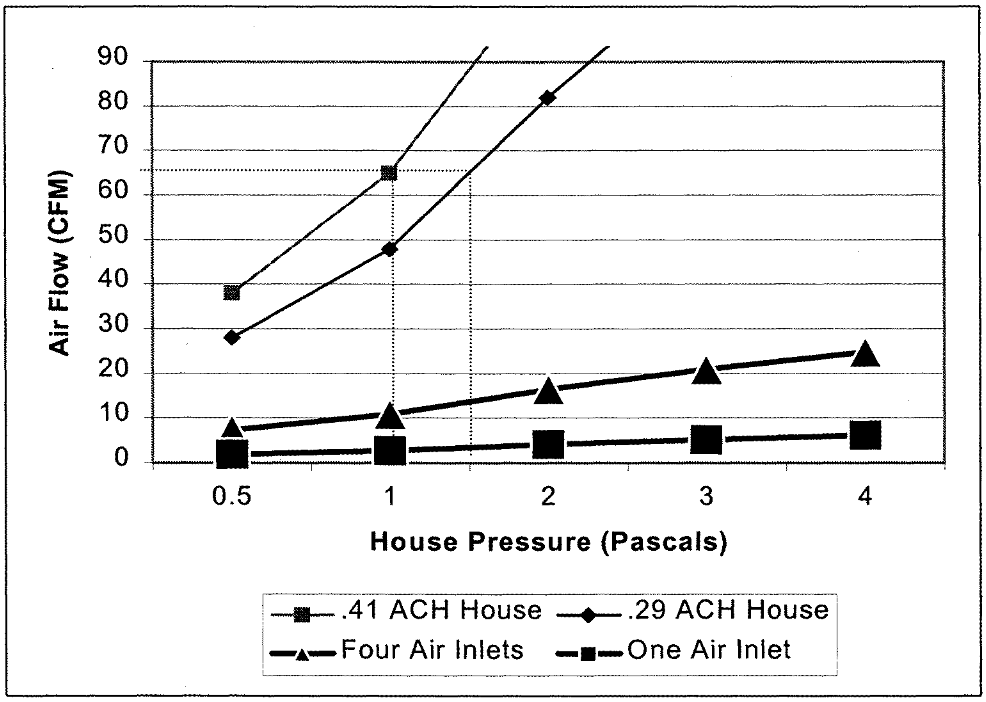

Figure 4. Predicted Passive Vent Air Flows induced by EOV Fan in a "Leaky" Home and a "Tight" Home

ure 4) about -1 Pa pressure would be induced in the house with 0.41 ACH and about –1.5 Pa would be induced in the house with 0.29 ACH. Note that this pressure in the neighborhood of –1 Pa agrees with the measured pressure differences noted in methods previously mentioned.

This -1 to –1.5 Pa pressure will induce about 10 to 15 cfm through four Fresh-80's, or 2 to 4 cfm through one Fresh 80.

It is clear that most of the flow of fresh air into the house induced by the fan must be from locations *other* than the passive vents. Even if the fan air flow were 100 cfm, only 2-1/2 Pa would be induced in the average house, resulting in less than 20 cfm through four Fresh-80's, or 5 cfm through one Fresh-80. These flows through a single passive vent based on the pressure induced by the exhaust fan are lower than the amount of outside air that is often considered adequate – 15 cfm per person. However, as was noted above, natural forces (wind and temperature-driven stack effect) will tend to overwhelm the weak force induced by the fan. Whether those natural forces bring outside air in or inside air out -- and how much air is moved in or out -- depends on the weather conditions at any particular moment.

According to manufacturer's data for a Fresh 80 passive air vent, a 10 Pa inside / outside pressure difference will induce an 11 cfm air flow through the device. To create a 10 Pa pressure difference in a house of the average size in the study with an 80 cfm fan, the level of house air tightness would have to be approximately 250 cfm50. Whether building housing this tight is economically feasible or whether the resources required to build such a tight house might be better applied to a ducted ventilation system to deliver air directly into habitable locations are questions to be considered.

Another way in which the EOV could induce enough air through the passive vents is to increase the size of the exhaust fan in the range of 175 to 200 cfm. However, this would over ventilate the house (due to the natural leaks coming in through locations other than the passive vents), as well as create depressurization problems if there were atmospheric combustion equipment.

It is outside the scope of this report to analyze the seasonal performance of passive air vents. Measurements at the passive air vents were taken under a wide variety of wind and stack conditions. However, it can be noted that for 80 passive vents in which measurement of pressure differential without the EOV fan operating was made (see Method 2 tests), 64% of the measurements indicated that the vent was exhausting inside air, 24% of the vents were supplying outside air to the house and 12% of the vents were not moving air. When the EOV fan was operating 35% of the vents were exhausting inside air, 48% were supplying outside air, and 17% of the vents were not moving air. These data indicate that the fan tends to depressurize the passive vent relative to the reference condition, but not always enough to reverse the airflow if the vent was acting as an exhaust, nor always enough to raise the air flow to a rate that could provide significant air flow if the fan was already acting as an air inlet.

Conclusions

This study resulted in the following findings, conclusions and recommendations:

Installed EOV Fan Capacity. EOVs operated about 67% of capacity on average, with an average of 62 cfm being exhausted when the fan is running. Poor duct installation can degrade performance; a gap between the ceiling sheetrock and the fan housing degrades fan performance and increases building air leakage rates. Many fans are not being installed in a manner that results in full performance. Installers should be trained in fan and duct installation. Standards should specify fan air flows ***as installed***.

EOV Controls. Controls for fans intended for exhaust only ventilation are not being programmed by the builder or electrician in 45% of the homes. Lack of programming of controls results in systems not operating all or part of the time. Consumer information about the correct way to program controls, should be provided either through the builder or manufacturer.

Fan Performance and House Tightness. Air tightness of the house did not have a measurable effect on fan performance. Exhaust-only fans can provide total exhaust air flows to meet a criteria such as 15 cfm per person, even in tight houses. Builders should continue to strive for low air leakage rates in new home construction.

House Depressurization and Backdrafting Caused by the EOV Fan. Exhaust only fans induced very low pressures in the house, on the order of –1 Pascal. Sixteen percent of the homes in the survey included natural draft combustion equipment. The magnitude of depressurization caused by EOV systems makes it unlikely that EOV fans of the size found in the study, *by themselves*, will cause backdrafting of natural draft combustion appliances. However, builders should take precautions to ensure that operation of the EOV in conjunction with other exhaust devices will not cause backdrafting of natural draft equipment, including fireplaces. New construction utility programs and energy code update activities should provide standards and education to eliminate problems associated with natural draft combustion equipment.

Passive Vent Performance Relative to EOV Fan Operation. Where measurable, air flow through passive air vents induced by the exhaust-only fan was very low. Based on the average pressure induced by the EOV in a home of typical air tightness for the homes in the study, 2 to 4 cfm is the range of air flows that could be expected to be induced by an EOV fan through a single passive air vent. Air flow through passive air vents may be into the house and may be out of the house, depending on weather conditions. While the study does not address the seasonal performance of the passive vents, the tests found 35% of the passive vents exhausting inside air, 48% supplying outside air to the house, and 17% with no air movement at the time of the test. More passive vents supplied outside air to the house with the EOV fans in operation than with the EOV fans off. Airflow through passive air vents is affected more by weather conditions and stack effect than mechanically induced pressures created by the EOV. Passive air vents represent a small fraction of the total air leakage area in a house, so the airflow induced by the EOV is much more likely to come in through openings other than passive air vents. It is necessary to monitor national research efforts and/or plan local research into 'effectiveness' of exhaust only systems, where effectiveness is defined as providing adequate outside air in the occupied rooms of the house during periods of occupancy. Without data on effectiveness, it is not possible to recommend for or against the use of passive air vents.

Houses are being built tightly enough that mechanical ventilation should continue to be encouraged. Effectiveness of systems including passive air vents should be studied. Exhaust only ventilation systems can provide an adequate total amount of air flow through a house, but the adequacy of distribution of that air to occupied zones may or may not be adequate. The ability of exhaust only ventilation systems to provide adequate fresh air to occupied rooms requires further study.

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