Washington State Residential Ventilation and Indoor Air Quality Code (VIAQ): Whole House Ventilation Systems Field Research Report

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ABSTRACT

Since 1991, Washington's Residential Ventilation and Indoor Air Quality Code (VIAQ) has required whole-house mechanical ventilation. A random telephone survey of occupants with ventilation systems suggests that occupants are concerned about indoor air quality, believe fresh air is important for health, and would install the same ventilation systems again (Devine, 1999).

After the phone survey, technicians tested envelope/duct leakage, fan flow-rates, and determined operation characteristics in a 31 home sub-sample. Verifying compliance with the VIAQ was the major focus of this research effort.

The code compliance evaluation revealed that ducted intake systems were more often incorrectly installed than exhaust systems and use more energy. Measured mean ventilation system flow rate capacity for all homes was 0.38 Air Changes Per Hour (ACH) (Std. Dev=0.23). The mean value, average natural ventilation rate based on depressurization tests (using the "divide by 20 rule") was 0.34 ACH (Std. Dev=0.13). Most systems were ineffective due to lack of occupant operation. Mean value on time was 2.82 hours per day (Std. Dev=2.57).

Out of 23 homes, 16 did not achieve a 0.35 combined effective ACH. Some homes did not meet the 0.35 ACH ASHRAE Standard 62.2, during milder weather when central mechanical systems operate less. Others homes would have over-ventilated if mechanical ventilation systems had operated continuously, especially during severe weather conditions.

Recommendations include: improved occupant education/instruction and control systems, efficient HVAC motors, tighter ductwork and tighter building envelopes. Simpler and clearer VIAQ code requirements and better system design/installer education efforts are also needed.

Introduction

The Washington State Ventilation and Indoor Air Quality Code (VIAQ) have required the installation of whole house ventilation systems in new homes since July 1991. In 1998, a telephone survey was conducted with results presented at the 1999 ASHRAE Annual Meeting. The survey sample was made up of 235 randomly selected homeowners in homes built since 1991. The purpose of the survey was to evaluate occupants' attitude toward their ventilation systems. Results of the survey suggest that occupants are concerned about indoor air quality, believe fresh air is important for health, and would install the same ventilation systems again (Devine, 1999).

To compare the results of the telephone survey with measurable ventilation system performance data, site evaluations of a sub-sample of 31 homes were subsequently conducted. The major focus of these evaluations was to assess compliance with the VIAQ, while exploring occupant interaction with the ventilation systems, and evaluating installed systems for performance and energy use. Several key questions identified in the research design were explored in the field. These include: How well did the systems perform? Were they installed to code? Did the occupants' responses to the phone survey match site conditions? Were the homes and their ducted systems "tight"? (The VIAQ contains no duct leakage standards; all the homes in the study can be considered standard practice regarding their duct systems.)

Background

The impetus for this study was, in part, the information gathered from state energy code implementation efforts since the early 1980s (Palmiter 1989, Palmiter 1997). Based on this information, the initial assumptions for this study were as follows:

- Occupants are unaware of, dislike, or don't understand how to use ventilation systems in a manner consistent with IAQ and energy conservation.
- Occupants, in general, misunderstand IAQ, or are not concerned about IAQ issues.
- Most homes are equipped with centrally ducted heating systems.
- Most ventilation systems are integrated into centrally ducted heating/cooling systems.
- Most integrated systems are performance based (see below) and current enforcement of performance systems is ineffective. Performance based systems rely on field-testing of ventilation flow rates by the HVAC installer.
- Most occupant complaints are related to integrated ventilation systems.
- Untested integrated ventilation systems may waste large amounts of energy.
- Exhaust systems, while not immune from problems, generally comply with the prescriptive requirements and are not likely to waste large amounts of energy.
- Occupants use exhaust systems more than integrated systems because the controls are easier to find. (Integrated system timers are usually installed on the furnace, while exhaust system controls are usually in a bathroom.)

The VIAQ requires whole house mechanical ventilation systems capable of providing the greater of 0.35 ACH or "15 CFM per bedroom plus 15 CFM", but no more than 0.5 ACH. To meet code, a system must meet either the prescriptive or the performance guidelines. To meet the performance approach the system flow rates must be field measured. The prescriptive requirements were designed to provide installers with a simple way to meet the performance targets in the code. The prescriptive method for exhaust fan sizing is based on minimum duct sizes, maximum lengths and maximum number of elbows, and fan size (Table 1).

The prescriptive method for sizing the outside air ducts connected to the forced air return is similar to that of the exhaust systems but is based on the number of bedrooms (Table 2).

Table 1. Prescriptive Exhaust Duct Sizing

Fan Tested CFM @ 0.25 W.G.	Flex Duct		Smooth Duct	
	Minimum Diameter (inches)	**Maximum Length[1] (feet)**	**Minimum Diameter (inches)**	**Maximum Length[1] (feet)**
50	4	25	4	70
50	5	90	5	100
50	6	No Limit	6	No Limit
80	4	Not Permitted	4	20
80	5	15	5	100
80	6	90	6	No Limit
100	5	Not Permitted	5	50
100	6	45	6	No Limit
125	6	15	6	No Limit
125	7	70	7	No Limit

1. Maximum duct lengths are for systems with no more than three elbows. For each additional elbow subtract 10 feet from length.

Table 2. Prescriptive Integrated Forced Air Supply Duct Sizing

Number of Bedrooms	Minimum Flexible Duct Diameter[1,2] (inches)	Minimum Smooth Duct Diameter[1,2] (inches)
2 or less	7	6
3	8	7
4 or more	9	8

1. Minimum duct diameters are for systems with no more than three elbows. For each additional elbow, increase duct diameter 1 inch.
2. Minimum duct diameters are for ducts no longer than 20 feet. For ducts over 20 feet, increase duct diameter 1 inch.

The VIAQ uses two basic system approaches. One approach uses the forced air heating/cooling system to draw ducted outside air into the return plenum (Figure 1).

The other system relies on a low-sone whole house exhaust fan to exhaust indoor air and includes 3-4 small air intake vents in the building envelope (Figure 2).

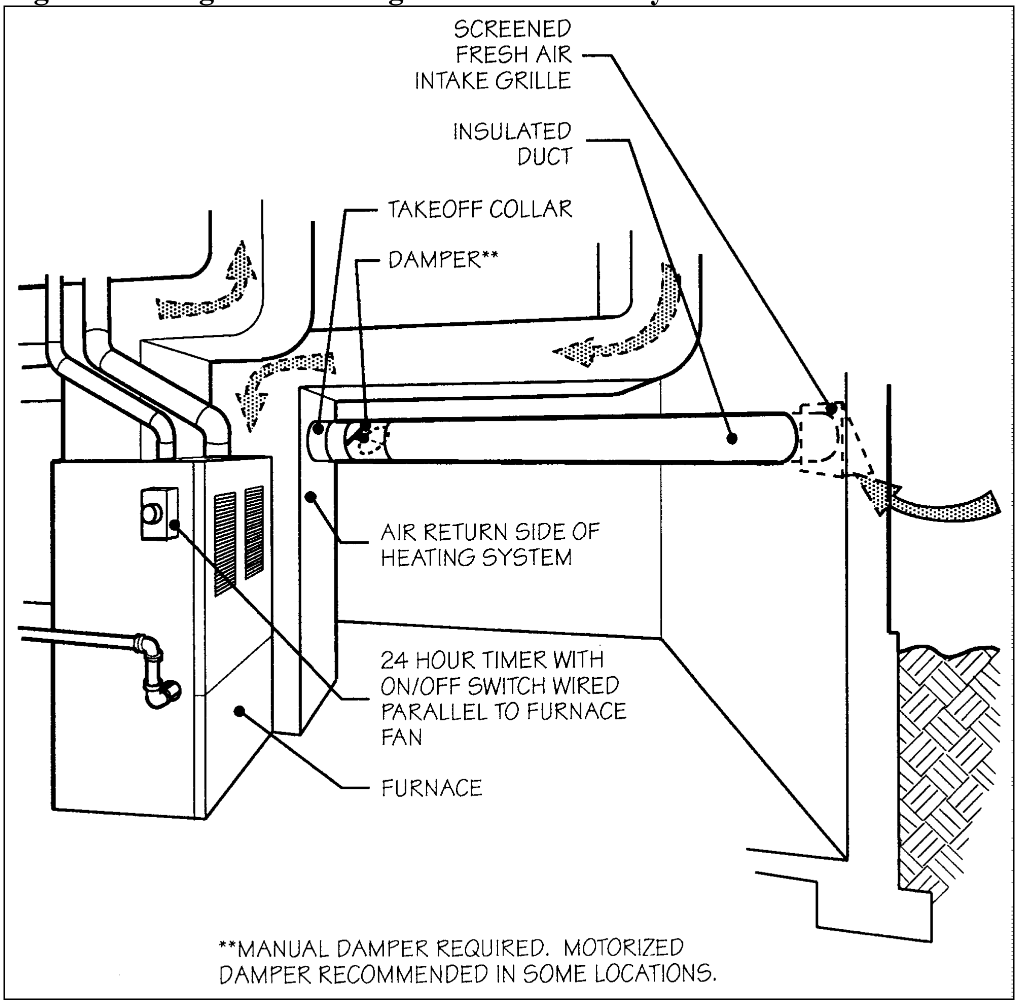
Field Sample

The following six system combinations were encountered during field tests.

System Type #1: Exhaust System with Inlet Vents

A code-described prescriptive exhaust ventilation system, consisting of a timer that activates a quiet exhaust fan. Fresh air is provided through window sash vents or wall ports.

Figure 1. Integrated Heating and Ventilation System



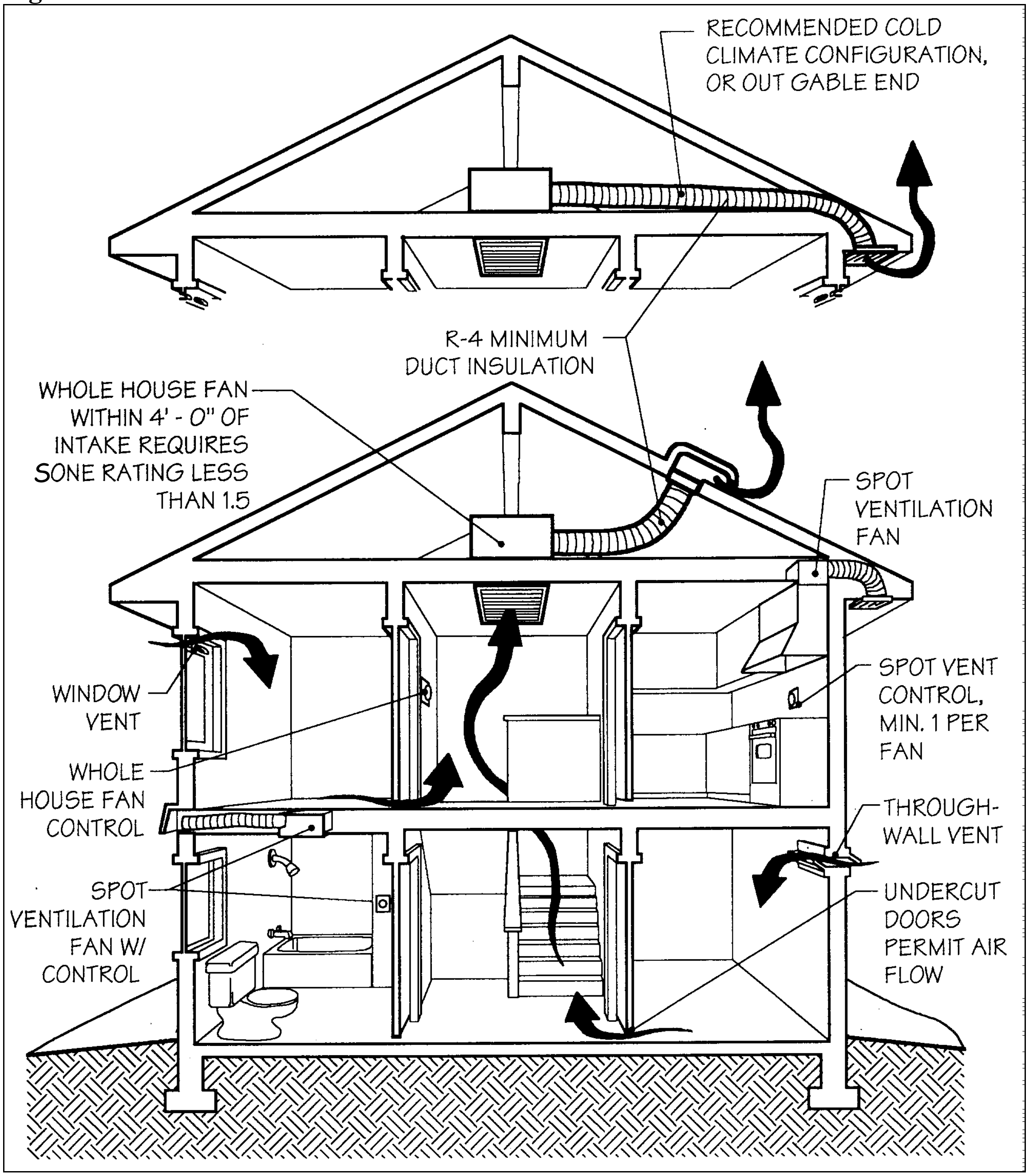
System Type #2: Passive Integrated Exhaust System

A hybrid of prescriptive exhaust and integrated systems, consisting of a timer that activates an exhaust fan. A fresh air duct, which may or may not be equipped with a manual damper, is connected to the return air plenum. This system is passive since the timer does not activate the furnace blower.

System Type #3: Passive Integrated Exhaust System with Mechanical Damper

System #2 augmented with a mechanical damper. A fresh air duct is connected to the return air plenum, which is equipped with the mechanical damper. This system is also passive since the timer does not activate the furnace blower.

Figure 2. Whole House Exhaust Fan with Intake Vents



System Type #4: Integrated HVAC with Mechanical Damper

This is a code-described prescriptive integrated system, consisting of a timer that simultaneously activates the furnace blower and a mechanical damper in the fresh air intake. The fresh air duct is connected to the return air plenum.

System Type #5: Integrated HVAC with Mechanical Damper and Exhaust Fan

This is a code-described prescriptive integrated system, with the addition of an exhaust fan. This system consists of a timer that simultaneously activates the furnace blower, the exhaust fan and the mechanical damper in the fresh air intake. The fresh air duct is connected to the return air plenum.

System Type #6: Integrated HVAC with No/Manual Damper

This is a code-described prescriptive integrated system, but requires calculations based on field conditions or performance tests. This system consists of a timer that activates the furnace blower. No damper, or sometimes a fixed manual damper, is located in the fresh air intake. The fresh air duct is connected to the return air plenum.

Research field data were collected at a total of 31 sites. The sites were selected on the basis of location, heating system type and square footage from a sub-sample of 130 who participated in the phone survey and volunteered for the field survey portion of the project. Fifteen sites were selected in King County, the most populous county and most active in terms of new construction. Ten were selected in Spokane County, the most populous county where more severe weather conditions prevail. Six sites were selected in Thurston County, a rural, moderate growth area with a moderate climate similar to King County. Twenty-one of the selected sites had ducted forced air heating/cooling systems. Ten had other types of systems. Ducted heating systems are prevalent in Washington's new residential construction. Table 3 (included in the "Findings" section) provides field information and summary test results.

Data Collection

Data collected at each field visit included:

Occupant Interview

Each occupant was interviewed on site. The interview was designed to update information collected during the telephone survey, and was adjusted when new questions seemed pertinent. For example, after it was noted that the first few occupants kept two or more large pets, the survey was changed to add number of pets as a variable for analysis.

Ventilation Code Compliance Data

Each ventilation system was examined and all the components, including ducts, dampers, vents, fans and controls were checked to assess their compliance with the code. Compliance with the VIAQ was the major focus of this research effort.

Envelope Air Tightness

Single-point blower door tests at 50 Pa were conducted to determine average air leakage rates. The data collected were used to determine if there was a correlation between envelope tightness, occupant behavior and perceptions regarding IAQ. In reality, air leakage performance varies widely around the average, depending on occupant behavior, climate, HVAC system, and other factors. Fan depressurization testing measured air-leakage of both the envelope and ductwork outside the pressure envelope. These tests were conducted at a single pressure difference of 50 Pa. The "divide by 20 rule" was used to convert ACH @ 50 Pa to seasonal average ACH, due to the lack of field information on leakage class, required to calculate Normalized Leakage Area per ASHRAE Std. 119. Research conducted in the 1980s on similar homes in the Pacific Northwest suggests that a divide by 20-24 rule of thumb range for aggregate samples of homes is appropriate (Palmiter, 2001).

Ducted Forced Air Heating/Cooling System Tightness

Pressure pan tests were conducted in homes with ducted heating systems to help determine whether inadvertent ventilation due to duct leakage affected occupant behavior and perceptions regarding IAQ. These simple tests did not directly measure leakage, but they provided enough qualitative information to indicate whether the system could be considered well sealed or poorly sealed. No duct leakage tests of the supply and return leakage fractions outside the pressure envelope were performed. Therefore duct leakage induced infiltration is not included, in combined effective air change rates, when the HVAC system is operating, but is taken into account when the system is off.

Ventilation System Tests

In each home, the ventilation system was tested for flow. No attempt was made to adjust the systems prior to testing. The control settings were noted to determine total daily hours of use, although the actual time periods and number of cycles were not collected.

Energy Code Compliance

A survey of the home was taken to determine whether the home met the basic requirements of the Energy Code, including those for insulation and windows.

Findings

Code Compliance Rate

Field data were analyzed to determine whether the homes in the field study complied with the letter of the code and also whether they met the intent, in terms of performance. Systems that contained all the proper (type and size) components, including fans, ducts, intakes, dampers, controls and other basic requirements were determined to meet the prescriptive requirements of the code. Systems that met the code's basic requirements for controls, air distribution and total airflow were assumed to meet the performance requirements. In the cases described below, if a system met the prescriptive requirements but failed to meet the performance requirements, the system was found to provide an inadequate amount of fresh air. At three sites, the occupants revealed that they removed or disabled the system timers. For the compliance analysis, these systems were assumed to have timers in place and functioning. No other evidence of system tampering was revealed during the site survey interviews. Only 32% (10/31) of all systems surveyed met VIAQ performance requirements. Slightly more, 39% (13/31) met the prescriptive requirements. In total, 52% (16/31) of all systems met code by either or both methods.

Case 1: Code compliance rate for systems NOT integrated with central heating systems. These systems:

- Are provided with controls that are not typically removed or incapacitated by the occupant.
- Are typically installed according to code.

Exhaust systems met the prescriptive (System #1) requirements for the code 71% (10/14) of the time. Systems meeting the prescriptive code also met the performance targets 60% (6/10) of the time.

Case 2: Code compliance for systems integrated with central heating systems. Integrated systems:

- Require excessive energy to operate the forced air heating/cooling blower motor for ventilation.
- Are typically installed in homes with central forced air HVAC systems, and typically leaky ductwork.
- Cause discomfort/irritation to some occupants when cold air is delivered at supply registers under certain conditions (such as low outside temperature, and the register located near occupant.)
- Are difficult to operate for some residents.
- Are often not installed according to code.
- Were ineffective when using performance based code compliance, (i.e. relying on measured flow rates)

Only 29% (5/17) of the systems integrated with central heating systems (Systems 2-6) met either the prescriptive or performance requirements of the code. Only 18% (3/17) of the systems integrated with central heating ventilation systems met the performance requirements of the code. Integrated systems also met the prescriptive requirements for the code 18% (3/17) of the time. (One system met both prescriptive and performance requirements.)

Specific Compliance Issues

Exhaust systems with inlet vents (System #1). The four systems that failed to meet the prescriptive requirements did so because of insufficient door undercuts, insufficient (CFM) fans and/or missing fresh air intakes. Of the four that failed to meet the performance targets, three provided insufficient airflow, while one exceeded maximum airflow.

Table 3. Air Leakage Rates by Ventilation System Type

VIAQ Ventilation System Type (1-6) (*)	Home Gross Conditioned Floor Area (ft^2)	Measured Ventilation System ACH (A_{Li} - 136)**	Blower Door De-pressure ACH @50 Pa Infiltration (A_I - 136)**	Annual Ventilation System Observed On-Time (hrs/day)	Annual Combined Effective ACH- cont. Operation (A_E)** (hr-1)	Combined Effective Annual ACH w/on-time (A_E)** (hr-1)
System 1:						
Mean	1856	0.35	0.34	3.31	0.49	0.37
Median	1620	0.35	0.32	2.00	0.43	0.34
Max	3630	0.64	0.66	9.00	1.07	0.73
Min	1211	0.11	0.18	0.00	0.30	0.25
Sample (n)	14	14	14	13	14	13
Std. Dev.	692	0.17	0.12	3.18	0.20	0.13
System 2,3 & 5:						
Mean	2514	0.34	0.32	1.58	0.51	0.33
Median	2345	0.25	0.31	2.00	0.36	0.32
Max	3832	0.98	0.46	4.00	1.42	0.46
Min	1290	0.00	0.10 (low)	0.00	0.10	0.17
Sample (n)	11	6	11	9	6	5
Std. Dev.	934	0.37	0.12	1.24	0.47	0.12
Systems 4& 6:						
Mean	2208	0.48	0.38	3.80	0.64	0.43
Median	1963	0.46	0.31	3.50	0.60	0.38
Max	3300	0.77	0.68	7.00	1.05	0.71
Min	1360	0.21	0.22	1.50	0.30	0.27
Sample (n)	6	6	6	5	6	5
Std. Dev.	905	0.22	0	2.02	0.34	0.18
Total systems: 1-6						
Mean	2157	0.38	0.34	2.82	0.53	0.37
Median	1828	0.35	0.31	2.00	0.42	0.34
Max	3832	0.98	0.68	9.00	1.42	0.73
Min	1211	0.00	0.10(low)	0.00	0.10	0.17
Sample (n)	31	26	31	27	27	23
Std. Dev.	851	0.23	0.13	2.57	0.31	0.14
Ducted HVAC systems:						
Mean	2264	0.39	0.35	3.01	0.57	0.39
Median	2251	0.35	0.31	2.00	0.42	0.36
Max	3832	0.98	0.68	9.00	1.42	0.73
Min	1211	0.00	0.10(low)	0.0	0.10	0.17
Sample (n)	23	17	23	20	18	16
Std. Dev.	865	0.26	0.14	2.48	0.35	0.15

(continued)

Table 3. Air Leakage Rates by Ventilation System Type (continued)

VIAQ Ventilation System Type (1-6) (*)	Home Gross Conditioned Floor Area (ft^2)	Measured Ventilation System ACH (A_{Li} - 136)**	Blower Door De-pressure ACH @50 Pa Infiltration (A_I - 136)**	Annual Ventilation System Observed On-Time (hrs/day)	Annual Combined Effective ACH- cont. Operation (A_E)** (hr-1)	Combined Effective Annual ACH w/on-time (A_E)** (hr-1)
Non-Ducted HVAC systems:						
Mean	1852	0.34	0.31	2.29	0.45	0.33
Median	1600	0.39	0.30	0.50	0.41	0.32
Max	3630	0.58	0.47	7.50	0.74	0.50
Min	1250	0.11	0.18	0	0.30	0.25
Sample (n)	8	8	8	7	8	7
Std. Dev.	782	0.19	0.09	2.94	0.15	0.09

***System Types**
1=Exhaust System with Inlet Vents
2=Passive Integrated Exhaust System
3=Passive Integrated Exhaust System with Mechanical Damper
4=Integrated HVAC with Mechanical Damper
5=Integrated HVAC with Mechanical Damper and Exhaust Fan
6=Integrated HVAC with No/Manual Damper
**A_{Li}, A_I, and A_E as defined by ASHRAE Standard 136, Sections 4.3 through 4.5

Passive integrated exhaust (Systems #2 and #3). None of these six systems complied with the performance or prescriptive requirements. These systems, though common, are not described in the code. They rely on an exhaust fan to draw fresh air through the heating system ducts connected to an outside air source. The controls for these systems do not activate the furnace blower, but none drew a measurable amount of outside air through the fresh air intake unless the furnace was on. When the furnace is off, these systems extract make-up air from duct leaks and envelope leaks, where the quality of air is unknown and questionable. Also, four out of six of these systems lacked automatic dampers in the fresh air intake (the fresh air intake is always open) and therefore draw air whenever heating or air conditioning is needed. These four systems waste energy by providing increasing amounts of fresh air when it is needed the least.

Integrated HVAC with mechanical damper (System #4). None of these systems met code requirements. This system is the basic prescriptive "integrated with forced-air system" approach, not requiring field-testing if the ducts are installed according to the tables in the code. The four systems in this survey, however, were not installed with prescriptively installed ducts. None of them met the performance requirements either: three exceeded fresh air limits and one provided insufficient air. The automatic damper allows the occupant control over when the system will draw fresh air; use of the furnace blower ensures a reasonable amount of fresh air will be distributed, as long as the components (especially the ducts) are installed and functioning properly.

Integrated HVAC with mechanical damper and exhaust fan (System #5). Three out of five of these systems met prescriptive and/or performance requirements. These systems utilized an exhaust fan to balance the system, which is not required by code. One system had both an automatic and a manual damper. Only two met the performance requirements for fresh air. Of the three that did not meet performance requirements for fresh airflow, one had a non-functioning (partially open) mechanical damper; one had an incorrectly set manual damper; and one had an excessively long and convoluted fresh air intake duct. The automatic damper allows the occupant more control over when the system operates. The use of the HVAC blower ensures a reasonable amount of fresh air will be distributed, as long as the components are installed and functioning properly. This system utilizes two motors and therefore uses more electrical energy than other systems.

Integrated HVAC with no/manual damper (System #6). One of these two systems met code requirements. Systems with manual (fixed) dampers are allowed prescriptively by code, although testing and/or calculations are required. However, neither of the two systems surveyed had prescriptively sized ducts. One system met the performance requirements. In both cases the occupant complained that the system caused drafts. These systems provide fresh air anytime the air handler is on and therefore ventilate more when heating or cooling duty cycles are highest. The occupants were unaware of the fixed dampers and therefore could not prevent these systems from providing unnecessary ventilation, even if they disengaged the timer.

Component Problems

There were a variety of inoperative systems:

Timers. Three (9.6%) occupants disabled or removed timers and chose not to operate the systems. One of these cases involved an integrated system.

Mechanical dampers. Two of 11 (18%) mechanical dampers were found to be non-functional. One appeared to be properly installed; the other was apparently never electrically connected.

Duct terminus. The code requires the fresh air intake duct terminus (i.e. entry point of outside air to furnace return) be the size of the intake duct or 8 inches in diameter whichever is greater. Typically, the terminus was the same size as the intake duct, which was often 6" or 7" in diameter. At least 4 of 17 (24%) systems otherwise meeting the prescriptive standard failed this requirement.

Energy implications. Given the natural air leakage rates, (Table 3) and significant duct leakage of many homes in this study, the winter use of mechanical ventilation is often unnecessary and typically wastes energy if ventilation systems are operated continuously. The least wasteful is System #1 (the exhaust system not integrated with the furnace) which provides the occupant a great deal of control and uses a relatively energy efficient fan. The amount of energy wasted is greatest in homes that utilize ducted HVAC blowers and ducts outside the conditioned space to distribute fresh air. Systems #3, #4 and #5 (systems integrated with central heating ducts that employ an automatic damper within the fresh air intake) are all equipped with controls easily understood by the occupant. System #3, however, does not activate the furnace blower and therefore consumes less energy during its operation. Unfortunately, System #3 does not function as designed. Systems #2 and #6 (systems integrated with central heating ducts without an automatic damper within the fresh air intake) are the most energy wasteful systems. These systems provide the most ventilation when it is needed least, (i.e. during low outside air temperatures and high heating duty cycles). These systems are not user-friendly. Only one in six of those with systems #2 or #6 said they adjusted the manual damper and that person claimed to adjust it only once. The telephone survey supports the argument that these systems are not well understood by occupants: only 2.6% said they have adjusted the fresh air damper.

Ventilation system capacity. Thirteen out of 26 ventilation systems measured had the capacity to provide at least 0.35 ACH if operated, without any additional natural ventilation, or duct leakage induced infiltration. The mean and median ventilation rate capacity provided by the mechanical systems was 0.38 ACH and ranged considerably from zero to 0.98 ACH, as shown in Table 3.

Blower door test results. Infiltration rates will vary based on weather and climate. Infiltration rates are higher when the weather is more severe and lower when the weather is milder, due to wind and stack effects (ASHRAE 1989). Using the "divide by 20 rule",[1] the mean natural air leakage from both envelope and duct leakage was found to be 0.34 ACH (Std. Dev. 0.13) for the homes in this sample (Table 3). Home leakage ranged from 0.1 to 0.68 ACH. The tightest homes had basements and interior ducts. Homes without basements were found to have higher ACH values. One would expect that basement homes would have lower ACH rates, since ACH requires a volume term and basements, being somewhat below grade, have less leakage paths per unit volume. In addition, basement homes tend to have more supply ductwork within the pressure envelope, and therefore have less duct leakage to outside.

Combined effective ACH. Table 3 provides an estimate of combined natural and measured mechanical ventilation system capacity ACH using ASHRAE 136. Measured ventilation supply and exhaust flow rates are required to determine the unbalanced flow term in ASHRAE 136 in section 4.4. These field data were not available for those homes with ducted systems. The impact of combined ventilation system capacity (excluding duct leakage induced infiltration) using Std. 136 mean value for all homes is 0.53 ACH (Std. Dev=.31). This assumes that the ventilation system is running 24 hours per day throughout the year.

[1] Using ASHRAE Standard 136 methodology, and assuming single story home and 0.82 weather factor (W) reduce the mean natural leakage rate by 0.02 ACH. CFM50 was converted to ELA assuming a flow exponent value of 0.65

Combined effective annual ACH. Table 3 provides an estimate of combined natural and measured mechanical ventilation system capacity ACH using ASHRAE 136 section 4.4 taking into account the ventilation system operation time reported by the occupants. The impact of combined ventilation system capacity (excluding duct leakage induced infiltration) for all homes is 0.37 ACH (Std. Dev=0.14). Table 3 also provides the ventilation systems median value on time reported, the combined effective annual ACH is only 0.03 ACH greater than the blower door estimate. Combined effective ACH does not account for 1) duct leakage induced infiltration while HVAC is operating and 2) uncontrolled ventilation on intake duct systems that also ventilate during normal heating and cooling duty cycles when ventilation demand is not required.

Impacts of ductwork Research conducted in these and other Pacific Northwest homes found typical "leaky" HVAC ductwork located outside the home pressure envelope significantly increases the ACH of a home while the HVAC system is operating (Palmiter 1989). When HVAC systems are not operating this duct leakage is in effect contributing to the natural infiltration rate. When the HVAC system is running these duct leaks impact the ACH due to HVAC duct leakage induced infiltration. The annual impact of this duct leakage can be similar in magnitude to that contributed by natural ventilation, and greater than the mechanical ventilation systems as operated in VIAQ homes. The author believes that to properly address duct leakage, hourly simulation programs are required. However these hourly simulations programs require input values not available in this research study. ASHRAE 136 estimation of combined effective ventilation rates accounts for the interaction of the unbalanced flow caused by the ventilation system and it's impact on stack infiltration when the mechanical ventilation system is operating. While ASHRAE 136 provides a way to account for mechanical ventilation, it does not account for duct leakage system interactions, unless the ductwork supply and return leakage rates are both known.

Other Analysis

Many comparisons were made between various parameters. In the following cases, however, the number of possible variables overwhelms the small sample size. While trends may have been identified, no firm conclusions should be drawn without further study.

- No relationship between daily hours of ventilation system use and system airflow rate was found.
- The more pets in a household, the more the ventilation system were utilized.
- Those who believe their home has good IAQ use their ventilation systems less.
- No relationship between natural air change rate and hours of ventilation system use was found.
- No relationship between an occupant's perception of home IAQ and natural air change rate was found.
- No evidence was found to show that installers tested systems to ensure airflow. Where these tests were required, calculations and "tested flows" were sometimes found, but the best results were not similar to measurements conducted through this survey.

Conclusions

The field research data reveal that the technical details of the whole house ventilation requirements are widely misunderstood. Only 32% of all systems surveyed met VIAQ performance requirements. Exhaust systems not integrated with central heating were more compliant than other systems, complying with the code 71% (10/14) of the time (all prescriptively). Only 60% of those also met the performance airflow targets of the code. Only 29% (5/17) of the systems integrated with central heating systems complied with either the prescriptive or performance requirements of the code.

Occupants surveyed in this study believe ventilation is important for health and use their systems. However, due to inadequate occupant education and poorly designed/installed ventilation systems, energy is wasted and indoor air quality is compromised. Due to the limited ventilation system operation during mild weather many homes were under ventilated, and did not provide controlled ventilation that was significantly greater than natural ventilation.

The winter use of continuous whole house ventilation in many homes evaluated in this study may result in over-ventilation and wasted energy. Systems utilizing HVAC (non-ECM type) blowers that are not equipped with automatic fresh air dampers (1/3 of all integrated systems) consume the most energy, and do not allow occupants control.

Ventilation system operation is problematic in typical homes with leaky ductwork and building envelopes, due to the dynamic interaction of weather and HVAC operation.

Recommendations

Problems identified in this study can be addressed through occupant education, improved code language, and education of builders, contractors and building officials.

- Code language can be improved by providing simpler, clearer specifications for each system type. The study reveals that many installed systems are not described in the code. Often, components from several system types are mixed and matched. By eliminating the two options that do not require automatic dampers for integrated systems, energy will be saved and the code will be simplified.
- Occupants can be provided with information on how to adjust their systems and when to use automatic ventilation. Occupants should be made aware of energy and health issues related to whole house ventilation systems. Information can be distributed through building departments, utilities, builders and others through a public outreach campaign directed at new homebuyers. New code language should require that user instructions be provided with the HVAC information. Occupants should be instructed on the use of ventilation systems to provide good IAQ and reduce energy waste. Controls should be labeled and ventilation instructions should address control operation.
- Training and performance testing should be provided to builders and code enforcers, and should emphasize energy implications as well as health concerns. Builders, HVAC subcontractors and code officials must better understand the impacts of leaky envelopes, ductwork and poorly installed/commissioned HVAC systems.

- A new direction in marketing ultra (beyond code) energy efficient homes should be implemented. Ventilation requirements for Energy Star Homes and other efficiency programs may help raise consumer IAQ awareness, and reduce IAQ problems and/or energy use liabilities to these programs. New innovative control systems are needed to optimize ventilation rates. These controls must account for variations in weather induced natural ventilation and HVAC induced infiltration. Controls that rely less on occupant perceptions of IAQ for operation may improve IAQ while minimizing energy use.
- Additional modeling research and field validations should be conducted to explore issues of temporal and spatial ventilation effectiveness, energy use, pollutant concentrations and occupant exposures. Computer simulations such as CONTAM may be applicable in evaluating ventilation effectiveness of various ventilation systems, in terms of energy and indoor air quality (Persily 2000).

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