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Are Residential Whole-House Mechanical Ventilation Systems Reliable Enough to Mandate Tight Homes?

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Are Residential Whole-House Mechanical Ventilation Systems Reliable Enough to Mandate Tight Homes?

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ABSTRACT

As residential building codes and above-code programs move toward tighter homes with whole-house mechanical ventilation, the reliability and homeowner use of ventilation systems become extremely important. What happens when a system fails? Do occupants repair it? Are failures a common enough problem that this is a concern? If failures are a problem, are there steps code bodies can take to minimize risk to health and safety?

A 21-home field study was conducted investigating the failure rates of whole-house mechanical ventilation systems installed in Florida homes over the last 15 years (12 of the 21 systems were installed in the last 3 years). Researchers conducted a survey to assess homeowner ventilation system awareness and maintenance practices, and inspected and tested ventilation systems to assess operational status, level of ventilation provided, and identify performance issues. Homeowners surveyed felt ventilation was important for health, but many were unaware of how their ventilation system operated.

Testing found only 3 of the 21 study homes (14.3%) had ventilation air flow close to the design level. Two of the ventilation systems were turned off by the homeowner, so only one of 21 homes (4.8%) was actually receiving the expected ventilation. Only 12 of the 21 homes (57.1%) were capable of operating. Issues identified included failed controllers and dampers, partially disconnected or crushed ducts, dirty filters, and poor outdoor air intake locations.

INTRODUCTION

As residential building codes and above-code programs move toward requiring tighter homes with whole-house mechanical ventilation, the reliability and homeowner use of ventilation systems become extremely important. An example of building code direction and concerns is the Florida legislature delayed implementation of the 2014 Florida Building Code whole-house mechanical ventilation requirement for any home with tested air leakage of < 5, expressed in air changes per hour at 50 Pascals (0.20 in wc) (ACH50), which is also the air leakage upper limit (5 ACH50).

Similar International Code Council (ICC) code airtightness and mechanical ventilation requirements are being implemented in other states (air tightness requirements are stricter in cooler climates). What happens when a system fails? Do occupants repair it? Are failures common enough that this is a concern? If failures are a problem, are there steps code bodies can take to minimize risk to health and safety? This paper will summarize the findings of the Florida Solar Energy Center's (FSEC) investigation of these questions originally reported to the Florida Building Commission.

Health and Safety Concerns

While the 2014 Florida code's residential airtightness requirement of ACH50 <=5 is only slightly tighter than typical new construction in the state (Withers et al. 2012 and Cummings et. al. 2003), an established tightness limit is anticipated to result in tighter Florida home construction. Serious concerns related to mechanical ventilation failure in

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very tight houses include deceased indoor air quality, moisture problems and mold growth during cold winters, and combustion safety problems from unbalanced air flow depressurizing spaces (Sonne and Vieira 2014).

A Canadian field study (Hill 1999) provides an example of the combustion safety problems that may occur in very tight homes due to specific mechanical ventilation failures. In this case owners heard the exhaust fan operation of their heat recovery ventilator so were not aware that the supply air delivery had failed. The dominant exhaust flow caused backdrafting of the fireplace and potential backdrafting of other atmospherically vented appliances.

While sealed combustion equipment is gaining popularity in northern states, mild Florida winters make high efficiency sealed combustion furnaces less cost effective here, so the state is likely to continue to see significant use of atmospherically vented combustion equipment and potential depressurization issues (Sonne and Vieira 2014).

Ventilation System Failure Rates

Limited available research raises concerns about mechanical ventilation system failure rates. A 2002 Washington State study (Lubliner et al. 2002) included a survey which found that occupants in homes with mechanical ventilation believe ventilation is important for health, however testing found that only 32% of the systems met ventilation and indoor air quality requirements. The Canadian study noted above (Hill 1999) found 12% of the 60 heat recovery ventilators inspected for the project to be non-operational because of component failure. It also identified air balance, installation faults, and homeowner understanding as issues.

A more recent study involving 29 Washington State homes (Eklund et al. 2014) found that significant mechanical ventilation problems continue. Fourteen of the 29 ventilation systems were found to have control issues, eight had dirty components, and six had installation issues.

RESEARCH APPROACH

A field research study was undertaken to investigate the effectiveness of systems to deliver desired flows and proper functioning of whole-house mechanical ventilation systems installed in Florida over the last 15 years. The study approach included two primary efforts: 1) A survey to assess homeowner awareness of the ventilation system and its purpose and maintenance practices; and 2) Inspection and testing of each home's ventilation system(s) to assess operational status, level of ventilation provided, and likely reason(s) for any issues discovered.

Participants were recruited via a post card mailing to 937 Florida addresses at which a registered energy rating indicated the presence of a mechanical ventilation system capable of meeting the energy code in terms of system type (so runtime ventilation without controller was not included). Most rating registrations in the state have occurred over the past two years, so in an effort to make sure that older homes were well represented in the study and increase overall participation, a second postcard mailing was made to 264 of the older homes in the original mailing.

A total of 47 mailing responses was received, but only 21 homes could be included due to funding limitations. Homes were selected to limit potential bias. Staff worked to limit the number of homes in the study built by any specific builder and to include different ventilation system types.

TEST PROTOCOL

Each house in the study was visited by research staff who administered the survey, inspected the mechanical ventilation system, and measured the ventilation system flow rate(s). Owners were asked to show or indicate where central ducted space conditioning equipment and its controls were located. They were also asked to show or indicate where the mechanical ventilation system and its controls were located.

The primary focus of ventilation system inspection and measurement was to assess:

- Type of mechanical ventilation system and control(s)
- Location of system components and controls

- Control operational status as found (enabled or disabled)
- Functional status (operable or inoperable)
- Measured air flow rate(s) of the ventilation system
- Maintenance or performance issues
- Evidence of occupant alteration or damage to system.

Evaluation of the mechanical ventilation system involved inspection of all accessible components of the system including intake and discharge grilles, ductwork, dampers, control modules, and powered fan units.

Airflow measurements were typically taken at intake grilles located outside (see Figure 1a) and, if applicable, at outdoor air supply discharge or exhaust intakes located indoors. A fan-powered flow hood was the preferred instrument for measuring outdoor air flow rates due to its accuracy and ease of use. When airflow measurements had to be taken outside during windy conditions, the measurement period was prolonged. In some cases, airflow measurements were made by duct traverse method.

FINDINGS

House Characteristics

A total of 21 central and north Florida houses were included in the study ranging from 1,251 square feet to 5,014 square feet in size, with ages ranging from 1 to 28 years old, with 16 homes built in the past three years, when ventilation systems became more common in Florida. The average ACH50 for the group is 3.8.

Survey Responses

A 27-question homeowner survey was completed for each of the 21 study homes. Owners were often not aware where the ventilation system or controls were located or how they operated, and on a number of occasions needed guidance to help them differentiate their space cooling and heating system from their ventilation system.

Overall, homeowners felt ventilation is important for health, but indicated mixed knowledge about their ventilation system and its operation. Survey results include:

- Nineteen out of 21 homeowners answered affirmatively when asked "Do you feel ventilation is important for health?" with one respondent being unsure and another unclear
- One homeowner had removed their ventilation system and one disconnected the ducts to the system (noting indoor air quality and odor issues and cost concerns respectively); in a third case, a runtime ventilation system was still connected, but the homeowner had not used it in the last 2 ½ years out of cost concerns and because they do not like air conditioning or heat (they do however open windows on a regular basis)
- Eighteen out of 21 homeowners were aware that they had a mechanical ventilation system (including the two who had them disconnected); three were unsure
- When asked, "What is the purpose of the ventilation system/why was it installed?" 11 homeowners noted health, fresh air or similar, three said it came with the house or similar, and four indicated they did not know. The remaining answers included “being energy smart,” durability, and to provide positive pressure
- When asked if they set the ventilation system's operation times and/or adjust the system's air flow rates or just allowed it to run "hands-off" as it was originally set-up, 15 homeowners responded “hands off” or similar; two homeowners indicated they just turn it on and off, and one stated that they typically keep their energy recovery ventilator (ERV) on low but “kick it up to high” if someone burns something cooking
- When asked, “What do you do, if anything, to maintain the ventilation system?,” three homeowners stated they have service contracts, and of the 14 homes with runtime ventilation systems, nine owners answered that they clean or change the filter, and of the four homes with ERVs, three owners answered that they clean or change the filters; one homeowner with exhaust fan ventilation stated that they clean the vent in the bathroom but

none indicated they maintain or inspect the outdoor air grilles or vent caps

- When asked, "Overall, how knowledgeable would you say you are about the ventilation system and its operation?" six responded "not at all" or similar, 11 responded "somewhat" or similar and 4 responded "very"
- When asked if they are satisfied with the overall performance of the ventilation system, 10 homeowners replied "yes," two replied "I guess," eight replied "I don't know" or similar and one, "no" (humidity concerns)

Testing Results

Table 1 compares the type of ventilation system and air flow rates we expected to the type of ventilation system and air flow rates we measured. "Expected" values were based on the rating database and "As-found" based on research inspection and measurement. An "Operational Status" column indicates whether the ventilation system was capable of operation or not. Multiple results within a specific field such as "on/off" indicate status of two separate systems. Ventilation system types in Table 1 include:

- Fans = exhaust-only ventilation
- ERV = energy recovery ventilaton
- Min. RTV = runtime ventilation with electronic control or logic designed to provide some minimum level of ventilation regardless of space conditioning load
- "Runtime Vent w/o Min" = runtime ventilation with no electronic control or logic; ventilation only occurs when cooling/heating or thermostat fan set "on"

Table 1. Expected vs. As-found Mechanical Ventilation System Types and Flow Rates

	Expected			As-found					
House #	Ventilation System Type	Supply Rate (cfm / L/s)	Exhaust Rate cfm / L/s)	Ventilation System Type	Capable of Operating?	Supply Rate (cfm / L/s)	Exhaust Rate (cfm / L/s)	Switched on or off?	Approximately Meets Design?
1	Min. RTV	297/140	--	Min. RTV	No	N/A	--	Off	No
2	ERV	70/33	70/33	ERV	Yes	59/28	91/43	On	Yes
3	Min. RTV	246/116	--	Min. RTV	Yes	83/39	--	Off	No
4	Min. RTV	374/177	--	Min. RTV	1 of 2	75/35 (sys 1)	--	Off/ Off	No
5	Min. RTV	262/124	--	Min. RTV	2 of 2	97/115	--	Off/ Off	Yes
6	Min. RTV	246/116	--	Min. RTV	Yes	55/26	--	On	No
7	Min. RTV	191/90	--	Min. RTV	Yes	65/31	--	Off	No
8	Min. RTV	110/52	--	Non-existent	N/A	N/A	--	N/A	No
9	Fans	--	88/42	Runtime Vent w/o Min	Yes; manual damper found closed	21/10	Not meas-ured*	Off	No
10	Fans	--	44/21	Runtime Vent w/o Min	Yes; not controllable	19/9	Not meas-ured*	When air handler runs	No
11	Min. RTV	59/28	--	Min. RTV	No	N/A	--	On	No
12	ERV	120/57	120/57	Removed	N/A	N/A	N/A	N/A	No
13	ERV	30/14	40/19	ERVs (2)	No	N/A	N/A	On/Off	No
14	ERV	200/94	200/94	ERV capable of 4 speeds	Operates with powder room exhaust switch	76/36 104/49 129/61 150/71	45/21 62/29 78/37 94/44	Off	No
15	Min. RTV	42/20	--	Min. RTV	No; not controllable	46/22	--	With air handler	No
16	Min. RTV	42/20	--	Min. RTV	No; not controllable	34/16	--	With air handler	No

17	ERV	43/20	43/20	ERV	Yes (high / low)	35/26	56/43	Off	Yes
18	Fans	--	71/34	Runtime Vent w/o Min	Yes; manual damper found closed	46/22	Not meas-ured*	Off	No
19	Fans	--	51/24	Runtime Vent w/o Min	Yes; manual damper found closed	27/13	100/47*	Off	No
20	ERV	50/24	0/0	ERV (dis-connected ductwork)	No (4 speeds)	137/65 177/84 204/96 207/98	75/35 101/48 119/56 119/56	Off	No
21	Min. RTV	100/47	--	Min. RTV	Yes	46/22	--	Off	No

* A bathroom exhaust fan noted here was indicated as an optional mechanical ventilation system that could be controlled by either the bathroom wall switch or a remotely located switch in a mechanical closet. These fans were only operated by occupants as local bathroom ventilation control, not whole-house ventilation.

Only three houses, 2, 5, and 17 (14.3%) were found to be delivering flow close to the design level with the type of ventilation system specified. Two of these had been turned off by the owner, so only one of the 21 homes (4.8%) was actually delivering the expected ventilation. Only 12 of the 21 houses (57.1%) had systems capable of operating.

The "Capable of Operating?" column in Table 1 indicates whether the ventilation system was operational or not at the time of the study. It does not, however, indicate if the homeowner utilized it adequately. It also does not indicate if the system operates as expected over long term periods. For example, a runtime vent with minimum ventilation control may be noted as being operational, but may have been found with the control set to off. This study also was not designed to be able to determine how well the "runtime vent with minimum" systems provide ventilation expectations over long periods of time.

Of the 12 homes listed in Table 1 as capable of operating, some had issues. Two homes had fully operational mechanical ventilation systems without any significant issues. Five homes had systems which were operational but had the following performance issues:

- Houses 2 and 17: very dirty filters and House 2 had a dirty outdoor intake mesh screen
- House 5: significant air leakage into the outdoor air duct from attic/soffit
- Houses 3 and 6: outdoor air intake above or near the air conditioner condenser (under low wind conditions at one home, tissue was used to verify that air discharging from the condenser was reaching the inlet grille)

House 14 has an ERV which can be controlled via one of two bathroom exhaust fan switches. Turning on one of these switches turns on both the ERV and bathroom exhaust fan. While the ERV on its own would provide slight positive pressure in the house with respect to outside, coupling it with the exhaust fan makes the system exhaust dominant (creating negative pressure in the house with respect to outside); while the system is operational as intended, due to moisture concerns, coupling ERV control with a bathroom exhaust fan is not recommended in Florida.

Four other homes (19%) (Houses 9, 10, 18 and 19) had what appeared to be two different ventilation options; however the options were either not utilized or not designed to be able to provide adequate ventilation based upon stated design targets. As such these could be considered potentially operational with limited ventilation capacity.

Finally nine (43%) of the 21 study homes were determined to be "not operational" for the following reasons:

- Houses 1 and 11: unable to turn on the ventilation system due to controller failure
- House 4: one of two ventilation systems was inoperable due to failure of damper to open
- House 8: a runtime ventilation system with control was shown on the energy rating, but no ventilation system was present at house (only standard bath fans controlled by simple on/off switches)
- Houses 12 and 20: ERV removed (House 12) or ERV ducts disconnected (House 20) by homeowner
- House 13: both ERV units had 120v service and breakers were on, but were not functional; the filters and cores

were so clean they may have never operated (the owners were unaware of these units)

- House 15: could not be operated as intended; ventilation only occurs when air handler is on
- House 16: ventilation only occurs when air handler is on, damper fixed 100% open

Figure 1. Study findings included: a) airflows often fell short of design values, b) outdoor air duct with hard kinked turn at plenum as shown, c) outdoor air intake duct disconnected from grille collar, resulting in over 40% of the "outdoor air" coming from the attic/soffit area.

In addition to the issues noted above in the operational assessment, several others were identified during testing. The number of occurrences of each issue between the 21 study homes is indicated in brackets:

- Reduced air flow due to crushed or kinked ducts—at outside soffit or at return plenum (Figure 1b) (4)
- Outdoor air ducts slipping off of soffit intake grille collars -- likely due to very short collar height of about 1 inch at the intake grille and installation difficulty at restricted wall edge/roof junction space, causing outdoor air to be drawn from soffit/attic as shown in Figure 1c (2)
- Difficult access to ventilation system control located in attic (1)
- Uninsulated outdoor air duct in unconditioned attic (2)
- Rooftop air intake terminations where residents may not be aware of location and air may be hotter (3)
- Second floor soffit or wall intakes-- requiring a tall ladder to measure or service (8).

DISCUSSION

The mechanical ventilation systems in our 21 Florida study homes fell far short of providing intended ventilation. In all but one of the 21 study homes they were either not being turned on, had been disabled, had malfunctioned, or were delivering ventilation significantly short of design or specification. Only one of the 21 homes had a ventilation system that was capable of operation, achieved the intended air flow rates, and was operated continuously. Nine of 21 mechanical ventilation systems in this study (43%) were not operational for various reasons, including two of the systems having been disconnected. Of those that were functional, another five were deemed to have significant performance issues. An additional system (and likely three others) relied on a three way switch configuration with one switch located in an air handler closet and the other on/off switch located in the master bathroom where an exhaust fan was located and intended to provide continuous whole-house ventilation. The problem with this configuration is that the fan can simply be turned on and off in the bathroom just like any other bathroom exhaust fan and if occupants do not understand the significance of this, the home will not receive adequate ventilation.

Of homes with switch controllable ventilation systems, 15 of 19 systems were found to be in the off position. This finding as well as survey results provide strong evidence for the likelihood that mechanical ventilation systems are not used as intended by a majority of occupants. While the home visit only provides a "snapshot" of the home on the day of the visit, survey responses generally supported a strong case that ventilation systems were underutilized.

Access to ventilation equipment and controls is also an issue. If equipment is difficult to access, it is more likely to be poorly maintained. Difficulty or inability for occupants to determine if the system is functioning properly was found to be another problem.

There were two cases where significant air leakage occurred at outdoor air duct terminal connections in unconditioned space. An example of this can be seen in Figure 1c where an outdoor air duct has partially slipped off an intake grille collar. Collar connections within vented soffits have tight clearance with the roof deck requiring tight turns, putting additional mechanical stress on the duct and connection. This highlights the importance of adequate collar height, good mechanical fastening, and secure sealing.

Homeowner and contractor education is also needed. In a few cases owners were told by their builder to turn systems off. The full report provides detailed suggestions (Sonne et al. 2015). This study's findings are consistent with a Washington State ventilation study where even though 90% of occupants surveyed were satisfied with indoor air quality, more than half of them did not know how to properly operate and maintain the system (Hales et al. 2014).

Due to the ventilation system reliability issues found in these studies, code bodies should consider the energy savings of extremely tight air leakage limits versus slightly looser limits that might be healthier when whole-house mechanical ventilation systems are not operating. In Florida's mild climate the simulated savings of tighter requirements are relatively low and offset by the energy use of the ventilation system if an ERV at 1 Watt/cfm is used as shown in Table 2 from Sonne et al. 2015.

Table 2. *EnergyGauge* modeled energy use comparison for no ventilation, 2014 FL Code ventilation and ASHRAE 62.2-2013 ventilation for sample, single story, 2000 sq. ft., 3 bedroom, 2014 FL Code house in Tampa

ACH50	No ventilation		2014 FL Code Ventilation Requirement		ASHRAE 62.2-2013 Ventilation Requirement	
	cfm	kWh	cfm	kWh	cfm	kWh
3	0	10241	60	10898	71.9	11027
5	0	10368	60	11009	59.9	11009
7	0	10474	60	11112	47.9	10985

RECOMMENDATIONS

Based on the findings of this field study, specific code-related recommendations include:

- Setting required air tightness levels in homes that are more forgiving when a whole-house mechanical ventilation system is not operating; until the ventilation issues identified in this paper are resolved, there needs to be a balance between mandatory very low air change rates for reducing energy use and a higher level that may lessen the severity of underventilation if mechanical ventilation does not operate
- Requiring labeling that indicates a home has a ventilation system and place labels on key components of the ventilation system (including ducts, grilles, dampers and controllers)
- Requiring general summary documentation written for occupants and service personnel that describes the ventilation system, its purpose, the location of system components, how to tell if the system is operable, and how frequently to check and provide maintenance
- Requiring alarm(s) indicating failure of every component of the ventilation system; alarms could be visual, audio or both and should signal on the event of fan or damper failure, or when loss of control or communication occurs
- Requiring intake grille or other vent collar heights to be at least 2 inches, mechanically attached to grille or vents, with seams and joints sealed with mastic or other code approved duct sealant

- Disallowing filter locations that require ladders to access; consider exception to this if an alarm feature is implemented indicating a need for service

CONCLUSION

Although this study was limited to a relatively small sample size, the results suggest that whole-house mechanical ventilation in Florida is currently not well understood by homeowners, and that for a variety of reasons a majority of these systems are not providing design outdoor airflows. Considering the number of installation and maintenance issues identified, the researchers conclude that homeowner education, improved installation practices, and improved fault detection are all needed. These actions are needed to improve the likelihood that tight homes will receive intended ventilation. Code bodies should consider setting required air tightness levels in homes that are more forgiving when a whole house mechanical ventilation system is not operating. Given the results of other studies outside of Florida cited in this paper, other states or local code jurisdictions should consider recommendations stated here.

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REFERENCES

Cummings, J., Withers, C.R., McIlvaine, J., Sonne, J.K., and M. Lombardi. 2003. Air Handler Leakage: Field Testing Results in Residences. FSEC-RR-138-03. Florida Solar Energy Center, Cocoa, FL.

Eklund, K., Kunkle, R., Banks, A., and D. Hales. 2014. Ventilation Effectiveness Study Final Report. Portland, OR. Northwest Energy Efficiency Alliance.

Hill, D. 1999. Field Survey of Heat Recovery Ventilation Systems. Canada Mortgage and Housing Corporation (CMHC) Technical Series 96-215.

Hales, D., Eklund, K., Kunkle, R., Lubliner, M., and A. Banks. 2014. A Field Study of Ventilation System Effectiveness in Low Air Leakage Residences. 2014 ACEEE Summer Study on Energy Efficiency in Buildings; August 2014, Washington, D.C. American Council for an Energy Efficient Economy.

Lubliner, M., Kunkle, R., Devine, J., and A. Gordon. 2002. Washington State Residential and Indoor Air Quality Code (VIAQ): Whole House Ventilation Systems Field Research Report. Residential Buildings: Technologies, Design, Performance Analysis, and Building Industry Trends 1:115-130.

Sonne, J.K., and R.K. Vieira. 2014. A Review of Home Airtightness and Ventilation Approaches for Florida Building Commission Research. FSEC-CR-1977-14, Florida Solar Energy Center, Cocoa, FL.

Sonne, J.K., C. Withers, and R.K. Vieira. 2015. Investigation of the Effectiveness and Failure Rates of Whole-house Mechanical Ventilation Systems in Florida. FSEC-CR-2002-15. Florida Solar Energy Center, Cocoa FL.

Withers, C.R., Cummings, J., Nelson, J., and R.K. Vieira. 2012. A Comparison of Homes Built to the 2009 and 1984 Florida Energy Codes. FSEC-CR-1934-12. Florida Solar Energy Center, Cocoa, FL.