Characterization of Mechanical Ventilation Systems in New US Homes: What types of systems are out there and are they functioning as intended?

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ABSTRACT

As the airtightness of homes improves to meet energy efficiency goals, it becomes more important for mechanical ventilation systems to help maintain a comfortable and healthy indoor air environment. ASHRAE Standard 62.2 provides national guidance for mechanical ventilation system design and installation, however adoption of those guidelines into local building codes has occurred at different rates. Once provisions for mechanical ventilation are adopted in a local code, are mechanical ventilation systems properly designed, installed, commissioned and operated according to code or above-code program requirements?

This paper presents results from field studies that include characterization of whole house mechanical ventilation (WHMV) systems in 150 occupied homes in CA, CO, FL, GA, OR, and SC built between 2011 and 2018. In each of the study homes, homeowners were asked how they operate the system, system airflow was measured, and operation of the system was monitored for one week. Resulting installed performance was compared to inferred design intent.

Results show that the installed performance of WHMV systems is related to complexity of the system itself, with systems that are simpler to install and operate more likely to be capable of meeting ASHRAE 62.2-2010. The frequency that systems were operating *as found* did vary regionally, and was related to the presence of clear labeling, and complexity of system controls. Results show there is a need for further homeowner and industry education to ensure behavior that results in operation of WHMV systems as intended.

Introduction

Whole building air exchange is an important element to maintain healthy indoor air quality (IAQ) in residential buildings. Air exchange acts to dilute concentrations of indoor air pollutants with outdoor air. In older homes, air exchange occurs in cracks and other openings in the envelope, but in newer buildings with tighter envelopes, mechanical means for ensuring air exchange is necessary. Other components that make up a comprehensive strategy for IAQ include limiting materials and activities providing the source of pollutants, and employing local exhaust in bathrooms and kitchens where intermittent odors and high concentrations of contaminants are likely to occur.

Following the guidance provided by national model codes and standards, local building codes are updated over time to require progressively more energy efficiency in new residential construction, which often includes requirements for tighter building enclosures. To maintain adequate air exchange, requirements for whole house mechanical ventilation (WHMV) systems are also often included. Adoption of these specific provisions into local building codes has occurred at different rates. For example, Washington State has required WHMV in its residential building code since 1991, while Florida has required WHMV only since 2017, and some states still do not require WHMV.

For WHMV systems to perform as intended, they need to be adequately designed, installed, commissioned, and maintained. In addition, homeowners need to be aware of the existence of the system, its purpose, and be educated on proper operation. Ignoring or overlooking any of these fundamental activities may result in failure of the WHMV system to perform as intended. Failure of a WHMV system may result in degraded IAQ and/or comfort. More serious concerns related to WHMV failure arise in cases of very tight houses and include moisture problems during cold winters, and combustion safety problems from unbalanced airflow depressurizing spaces (Sonne 2014). WHMV failure can also result from intentional actions on the part of a contractor or homeowner who disables all or part of a system. This action often results from real or perceived impacts of the WHMV on comfort and energy use, especially in extreme cold and hot humid climates.

This paper presents results from field studies that include characterization of WHMV systems in 150 occupied, single family attached and detached homes in CA, CO, FL, GA, OR, and SC built between 2011 and 2018. Installed performance is compared to inferred design intent. As code and above-code programs result in WHMV systems becoming commonplace, results of field characterization are expected to 1) inform local jurisdictions, above-code programs, national standards, ventilation equipment manufacturers, and contractors if improvements are required to ensure proper design, installation, and commissioning of residential WHMV systems, and 2) identify if homeowner educational and behavioral changes are required to ensure proper operation and maintenance of WHMV systems.

Background

ASHRAE standard 62.2, "Ventilation and Indoor Air Quality in Low-Rise Buildings" is the most commonly referenced residential ventilation standard in the United States. The 2010 version of the standard (ASHRAE 62.2-2010) is currently required by ENERGY STAR® for Homes Version 3, the U.S. Department of Energy's (DOE's) Zero Energy Ready Home Criteria, state Weatherization programs, and other home performance programs. The current, 2019 version of the standard (ASHRAE 62.2-2019) is generally available as an alternative option, and contains several additional provisions, giving ventilation system designers more flexibility and providing more energy efficient ventilation solutions.

Since 2012, the International Energy Efficiency Code (IECC) and the International Residential Code (IRC) permit a maximum measured building air leakage of 3-5 air changes per hour at 50 Pa (ACH50), depending on climate. For homes tighter than the maximum allowable leakage, these codes require or at least define WHMV based on ASHRAE 62.2-2010. Many local jurisdictions base their local codes on these model codes, with some early adopters, such as Washington State including required provisions for WHMV long before model codes, and others continuing to not adopt provisions. Martin (2014) provides a review of mechanical ventilation in residential codes and standards, and according to market research conducted by Washington State University, at least 23 states have adopted the 2012 IRC and built roughly 500,000 new units in 2014 where whole-house ventilation system installations were required (Martin 2018). As shown in Figure 1, many state codes are still not deemed equivalent to 2012 IECC, and requirements for WHMV may be lacking in states colored orange, red, or white. Red circles indicate states where WHMV systems were characterized for this paper.

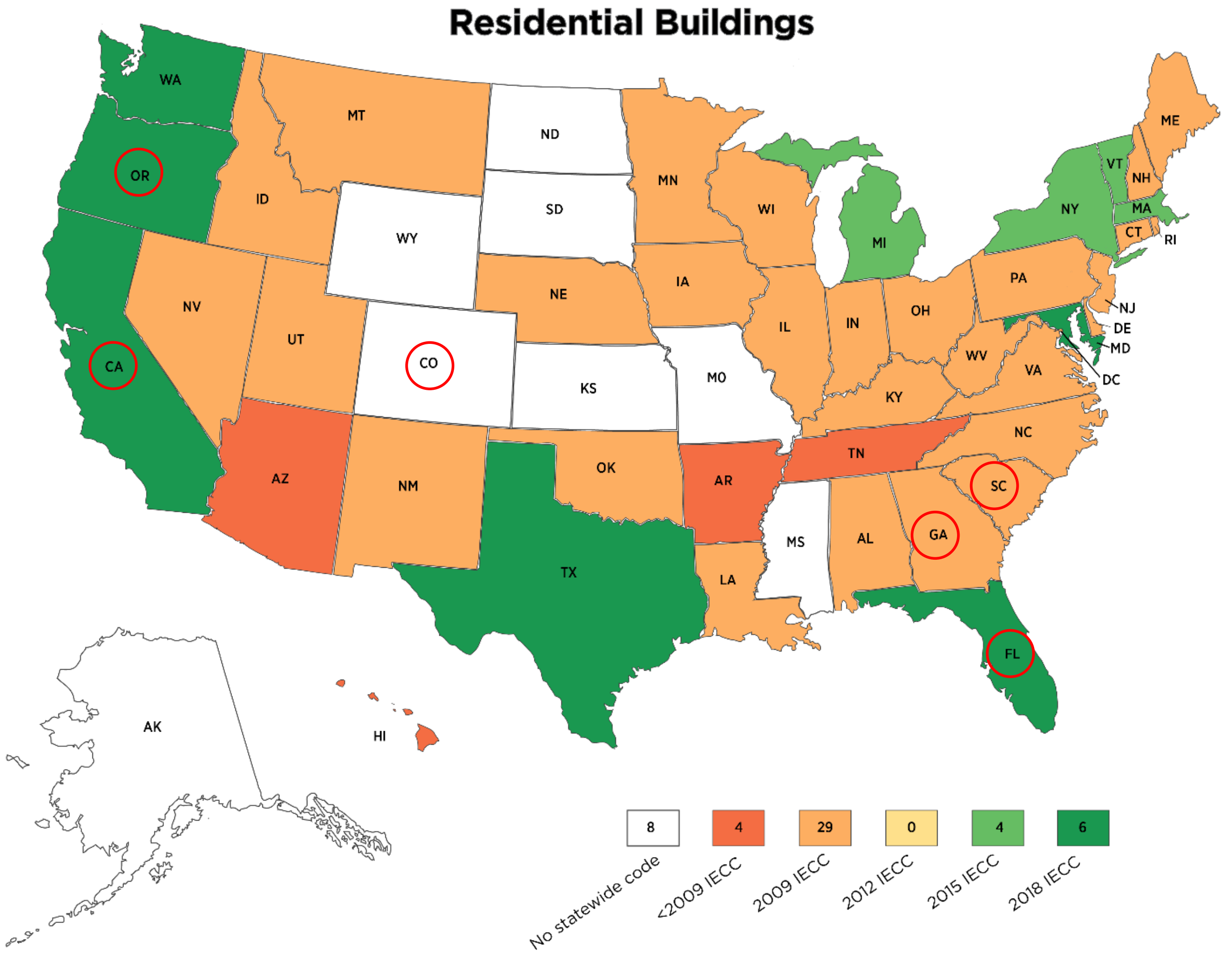

Figure 1. IECC equivalencey of state and local codes. https://www.energycodes.gov/adoption/states, current as of 3/31/2020. Red circles indicate states where WHMV systems were characterized for this paper.

Sonne (2014) conducted a literature search and found that limited past research is available investigating whether WHMV systems are operating as intended. One Canadian study determined 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 (Hill 1999). A 2002 Washington State study 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 (Lubliner 2002). A more recent study involving 29 Washington State homes found that significant WHMV problems continue; fourteen of the 29 ventilation systems were found to have control issues, eight had dirty components, and six had installation issues (Eklund 2014).

In CA, research studies found: (a) a majority of households in new CA homes reported not opening windows regularly for ventilation in some seasons; and (b) that actual, measured ventilation rates in many homes were below target minimum levels (Price 2007 and Offermann 2009).

While FL only recently began requiring WHMV in all new residential construction, successful penetration of ENERGY STAR® Homes and other above-code programs have resulted in a significant number of homes incorporating WHMV prior to the required code. In 2014, a 21-home field study was conducted by the Florida Solar Energy Center investigating mechanical ventilation systems installed in FL homes since 1999, with over half installed since 2011 (Sonne 2015). The 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 airflow close to the design level. Two of the ventilation systems were turned off by the homeowner, so only 1 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.

Methodology

Using a similar study protocol, two recent field research studies were designed to gather information on measured IAQ in occupied, new U.S. homes built since 2011. The Healthy Efficient New Gas Homes (HENGH) project analyzed 70 homes in CA built since 2011 (Chan et al. 2020, Singer et al. 2020), representing mostly IECC climate zones 3B (dry) and a few in 3C (marine), and the Building America New Home IAQ (BAIAQ) study, which is ongoing, is collecting data from homes with WHMV built since 2013 with a target of 20-30 each in some of the other major US regions, including OR, representing zone 4C (marine), CO, representing zone 5B (cold dry), FL, representing zone 2A (hot humid), and GA and SC, representing zone 3A (mixed humid). WHMV system performance data from both studies are presented here to gain insight into residential WHMV system functionality and operation in newer homes. Different teams led the data collection efforts in different regions, but all teams are following the same data collection protocol. Lawrence Berkeley National Laboratory led data collection in CA, Pacific Northwest National Laboratory led data collection in OR and CO, and the Florida Solar Energy Center (FSEC), a research institute of the University of Central Florida, led data collection in the southeastern US. The BAIAQ study includes an additional team, the University of Illinois, but data collection in that region is just underway, and results of that effort will be included in future publications.

Source records used for recruitment purposes differ from region to region, and are discussed in the following sections. A field team visited each participating home to characterize the WHMV system, find out if homeowners were aware of the system, and learn how they operated the system. In each of the study homes, airflow of the WHMV systems were measured, and operation of the systems was monitored for one week in each home. Monitoring took place during different seasons for different homes, however as most of the systems encountered were designed to be operated continuously or on a timed cycle, one week of monitoring was sufficient to capture typical operation. Airflow was measured with a powered flow hood, or in the case of some exhaust systems, with a passive exhaust flow meter. The maximum error is <10% of the metered flow. Except in the case of a few systems integrated with multi- or variable speed heat pumps, all WHMV systems deliver a constant amount of airflow during operation, and therefore a single airflow measurement is sufficient for flow characterization. For WHMV systems that deliver variable flow, the field teams tested the system as it was expected to operate during the testing week. Frequency of WHMV fan operation was monitored with a data logging anemometer placed in the flow stream, or by monitoring fan energy. It is important to note that differing ventilation systems are compared on the basis of whether they were operating as found, if they were capable of operating, and if operation achieved the design intent purely on the basis of airflow and runtime, not on the basis of ventilation effectiveness, or achieving a target level of pollutant concentration.

Results and Discussion

Types of WHMV Encountered

In general, three common types of WHMV were encountered. The most common approach to providing WHMV is to use an exhaust fan capable of continuous operation. These fans are also often used for local exhaust in bathrooms, or laundry rooms. New fans are generally quieter and more energy efficient than traditional exhaust fans, and are seen by many builders and contractors as the easiest way to add WHMV to a home. They are also easier to commission because the air intake is often readily accessible. This type of exhaust WHMV system was found in the vast majority of the CA study homes.

Some homes use their central forced air heating and cooling systems to temper and distribute outdoor air that is pulled in through a ducted connection from outside to the return side of the forced air system. This supply-based WHMV system may be set up to pull outdoor air through the system using the negative return side pressure when the forced air system fan operates, or set up to use a supplemental supply fan to ensure consistent airflow. These central fan integrated supply (CFIS) ventilation systems are generally harder to commission than exhaust systems because the outdoor air inlets and ducting are typically difficult to access. The challenge of commissioning CFIS systems is greater with variable speed air handler fans, since they result in variable outdoor airflow rates. Passive CFIS systems that are "uncontrolled" (U-CFIS) rely exclusively on the heating/cooling runtime of the forced air system and thus are not ASHRAE 62.2 compliant. Some manufacturers package control and damper systems that invoke additional air handler fan runtime to meet flow targets on an hourly basis. These "controlled" CFIS systems (C-CFIS) may be programmed by a thermostat or a separate controller that connects to the thermostat. In cases where a dedicated outdoor air supply fan is present, controls are integrated such that they operate the dedicated fan outside of calls for heating and cooling to maintain desired flow targets, with such fans generally consuming much less energy than an air handler/furnace fan. Some of these controlled systems also contain customizable settings that limit outside air from being introduced when outdoor temperature, or indoor relative humidity, reach certain thresholds, which may save energy or improve comfort, but generally result in operation that is not compliant with code or industry standards. There is some regional variability in the use of exhaust and supply systems, with supply systems being more common in southern/humid climates, where the supply systems sometimes include supplemental dehumidification.

Balanced ventilation systems combine supply and exhaust fans that are set to operate in unison, balancing pressure between indoors and outdoors. Most common are energy recovery ventilators (ERVs) or heat recovery ventilators (HRVs). Balanced ventilation systems are more common in colder climates where there are more energy-related advantages to using heat recovery, but in general, such systems are installed less frequently than exhaust or supply systems, mostly due to added cost and complexity.

Southeastern US (FL, GA, SC)

Historically, the FL Building Code has referenced provisions for WHMV, but those provisions were not enforced, in part due to uncertainty in how building enclosure leakage contributes to whole house air exchange. The current, 6th edition of the FL Building Code, which applies to homes permitted after July 1, 2017, instituted mandatory enclosure leakage testing and permits a maximum enclosure leakage rate of 7 ACH50. This is slightly leakier than what past studies have found to be typical in new construction in the state (Withers 2012 and Cummings 2003). Rather than triggering IRC WHMV requirements for building enclosure leakage at less than 5 ACH50, the FL code triggers WHMV for enclosure leakages at less than 3 ACH50. While bathroom and kitchen ventilation is required at a minimum of 50 cfm and 100 cfm respectively, kitchen ventilation is not required to exhaust to the outdoors and recirculating type range hoods and over the range microwaves are allowed. As previously mentioned, successful penetration of ENERGY STAR® Homes and other above-code programs have resulted in a significant number of homes built since 2012 that incorporate ASHRAE 62.2-2010 guidelines, and all FL homes characterized as part of this study fall into this category.

All homes in this study from SC and GA also fall into the above-code category. GA has required mandatory enclosure leakage testing since 2010, and until recently, had the same state energy code since January 2011, which references IECC 2009. While that code referenced IRC 2012 requiring WHMV for homes with air exchange less than 5 ACH50, local amendments permitted a maximum enclosure leakage of 7 ACH50. Beginning January 2020, a new code took effect that lowered the maximum allowed enclosure leakage to less than 5 ACH50, effectively triggering WHMV for all new homes. SC also requires mandatory enclosure leakage testing, with a maximum permitted leakage of 7 ACH50. However, they do not reference WHMV provisions of the IRC.

Home Summary. Homes with WHMV systems were identified by querying records from the Residential Energy Services Network (RESNET), which maintains a database of characteristics for homes that have undergone an energy audit and received a Home Energy Rating System (HERS) Index. Twenty-five homes which were indicated as having a WHMV system were recruited, and applicable characteristics are summarized in Table 1. Sixteen of the homes are in FL, five are in GA, and four in SC.

Table 1. Summary of home characteristics for 25 southeastern US homes.

Parameter	Median	Range
Conditioned Area (sqft)	1967	1095-3869
Year Built	2017	2013-2018
Number of Occupants	2	1-6
Enclosure Leakage (ACH50)	3.6	1.5-5.9

Ventilation System Characterization Results. Figure 2 shows the measured average ventilation rate in each home for the week, expressed as a percentage of ASHRAE 62.2-2010. This version of the standard is chosen as the reference design intent because it is the version referenced by the codes and above code programs the homes are built to. The percentage takes into account both the WHMV system airflow and runtime. Two results are shown for each home. The "as found" results are shown with blue bars and represent the WHMV system operation for the week had the system been left as found when the study team arrived at the home. The "capable" results are shown with orange bars and represent the capability of the WHMV system to meet ASHRAE 62.2-2010 for the testing week if a simple control modification had been performed, like turning a switch from "off" to "on" or adjusting a timer. In some cases, as-found operation exceeding ASHRAE 62.2-2010 could be dialed down to meet the target, either by adjusting flow or runtime. In other cases, operation could be increased to meet the target. Some systems had limited capacity or control functionality that did not allow for adjustment.

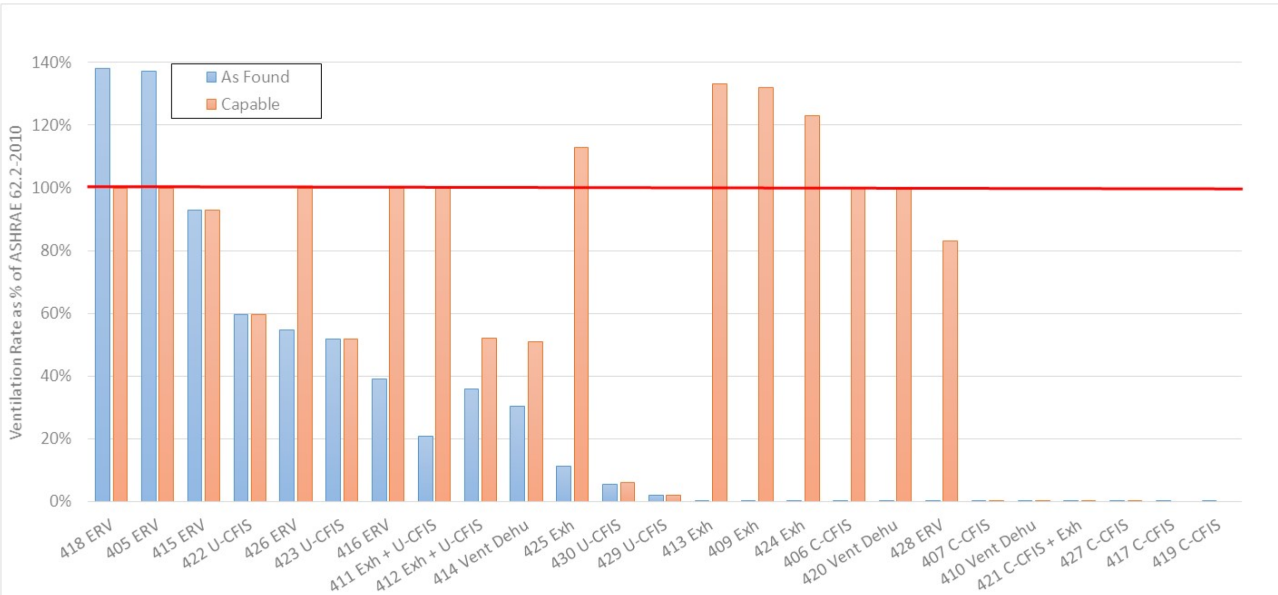

Figure 2. WHMV performance in homes in select southeastern states as a percentage of ASHRAE 62.2-2010 guideline.

Discussion. As seen in Figure 2, approximately half of the systems (12 of 25) were not operating upon arrival at the homes for the inspection visit, and approximately half of the systems (11 of 25) were capable of operating per ASHRAE 62.2-2010. Six homes were recruited with ERVs and they are the one system type that was almost always operating upon arrival at the home. There were some ERV installation and maintenance issues, but homeowners always were aware of the systems and what they were for, and the units were "on" upon arrival. Filters in the ERV in house 428 were heavily clogged and no flow could be measured until they were cleaned by the research team, with that flow represented by the orange bar. The filters for the ERV in house 405 were also very dirty, and the unit was incorrectly ducted, resulting in it acting as a supply ventilator with no capacity for heat or moisture exchange. This unit was operating continuously, with a flow that caused it to exceed ASHRAE 62.2-2010, but the control had an intermittent timer option that would have enabled a reduced air exchange target if desired. The same ERV was in house 416, only operating at 10 minutes/hour, but was correctly ducted. The ERVs in houses 418 and 426 operated continuously but had controls that allowed for flow adjustment.

All six homes listed as having exhaust systems in the RESNET database (Exh and Exh + U-CFIS) were bathroom fans with simple on/off switches without any sort of advanced controls or switch labeling, that were always found "off" upon arrival. In general, homeowners were not informed of these fans serving as WHMV, and were not aware of why or how they should be operated as such. As a result, none were operated to achieve the design intent. Orange bars in Figure 2 represent operation had the switch been left "on" for the entire week. Blue bars are generated by reviewing actual operational data from the week and revealed that in one case (412), significant runtime was achieved by the homeowner who sometimes left the fan running. In general, most exhaust systems were capable of meeting ASHRAE 62.2-2010 had they been left on, and often would have exceeded 100% of ASHRAE 62.2-2010 since no controls for flow adjustment or intermittent operation were present, even though many had been listed as having a fractional runtime in the RESNET database. A few homes labeled as having an exhaust system in the RESNET database were found to also have an uncontrolled CFIS duct present (Exh + U-CFIS). The team generally could not get the U-CFIS system to deliver any flow. Anecdotally, FSEC has learned that some contractors consider an exhaust system + U-CFIS system operating together as "balanced". Another possibility for this system combination is that low wattage exhaust fans provide a better HERS Index than a CFIS system that relies on a high power air handler fan. However, never intending the exhaust system to be operated like a WHMV, a U-CFIS system is installed to provide some means for partial WHMV in the event it is deemed necessary by a homeowner or mechanical contractor.

As previously discussed, U-CFIS systems are not capable of providing ASHRAE 62.2-2010 consistently as they are dependent on heating/cooling runtime. While it is possible that an air handler could be operated with continuous fan, it is assumed that U-CFIS systems are not designed to operate in that manner, in part due to the large energy consumption of the air handler fan. Both the blue and orange bars for U-CFIS systems in Figure 2 are based on runtime during the one week of testing. For these four U-CFIS systems it is possible that a controller was present at one time, and later removed – otherwise the homes should not have qualified as meeting ASHRAE 62.2-2010. None of the six CFIS systems that were found to actually have controls present (C-CFIS) were functioning upon arrival, two as a result of component failure. One (406) was capable of operating, but flow was largely locked out by temperature and humidity threshold controls. Systems in 417 and 419 were off upon arrival and controls were not attempted to be enabled by the field team to see if they worked, so actual capability is unknown. One home (421) had an integrated, pre-packaged CFIS + bathroom exhaust system controls, enabling the bath fan to function as the WHMV outside of calls for cooling and heating. However, the field team could only get limited functionality with this system even after calling the manufacturer. A few owners of homes with CFIS systems were aware that their home had a system for "fresh air" that could be controlled through the thermostat, but in general most were not aware of these systems or how they functioned.

The three ventilating dehumidifiers encountered act like C-CFIS systems with flow supplied by a dedicated fan, in line with the outside air duct. It is unclear whether control of the dehumidification compressor is based on a humidistat in the space, or in the outdoor air stream. While all owners of homes with ventilating dehumidifiers were aware of the existence and purpose of these system, two of these systems were found "off" upon arrival. One could be made to operate by the field team while the other could not. The third system in house 414 was found "on" but had generally low flow, and a wiring issue that seemingly only allowed the unit to ventilate when it sensed high humidity.

Western United States (CO, OR)

OR's Residential Specialty Code 2014 and 2017 similarly define specific prescriptive requirements which new residential buildings must meet, as well as a list of additional measures such as high efficiency walls, high-efficiency thermal envelope, WHMV, ductless heat pumps, and more, from which two must be selected. There is no defined level of air leakage required by OR residential building codes. 2014 and 2017 OR Residential Specialty Codes require all joints and penetrations in the exterior envelope to be sealed in a manner approved by the building official. One of the optional additional measures is enhanced envelope air sealing, which in addition to the base prescriptive requirements includes a continuous air barrier with sealing at wall to top-plate intersection and wall covering to structural members, with specific sealant requirements. OR does not require WHMV, but if a builder chooses to install it as one of the optional additional measures (likely driven by cost of a WHMV system vs. other options), it must be supplied at a continuous rate that is equivalent to ASHRAE 62.2-2010. In addition, certain builders pursue certification by above-code programs that require WHMV in accordance with ASHRAE 62.2-2010.

All types of exhaust ventilation are defined by OR's Residential Specialty Code 2017, and every mechanical exhaust system is required to discharge air to the outdoors, except for cases in which whole house ventilation-type attic fans may discharge into private attic space. Range hoods and downdraft exhaust systems must have a minimum flow of 150 cfm intermittent, full bathrooms must have a minimum of 80 cfm intermittent or 20 cfm continuous, and toilet rooms must have a minimum of 50 cfm intermittent flow.

The state of CO is a home-rule state, where each jurisdiction decides which code to implement. This makes characterization of CO building codes more complicated, but all counties which were studied utilized IECC from 2006, 2009, or 2015 for building energy codes and IRC from 2006, 2012, or 2015 for building codes. 2006 IECC provides a prescriptive requirement that the building thermal envelope must be sealed durably to limit infiltration. 2009 IECC requires the same as 2006, with an additional option of air-barrier testing, which when carried out requires air leakage to be less than 7 ACH50. 2015 IECC requires testing with a maximum ACH50 of no more than 3 in CO climate zones (4b, 5b, 6b, 7). IRC 2006 does not require or define WHMV, IRC 2012 and IRC 2015 do not require WHMV but define ventilation rates for cases where whole-house mechanical ventilation is provided which are equivalent to ASHRAE 62.2-2010.

The International Residential Code, as followed by the studied CO counties, also requires specifications for spot mechanical ventilation. According to IRC 2006, 2012, and 2015, mechanical ventilation must exhaust air directly to the outside, including bathrooms, clothes dryers, and kitchen ventilation. The rate of this ventilation is consistent between IRC 2006, 2012 and 2015, and the ventilation rate must be at least 100 cfm intermittent or 25 cfm continuous for kitchen exhaust, and 50 cfm intermittent or 20 cfm continuous for all bathrooms.

Home Summary. Fifty five homes were studied in the western United States, including 26 homes in CO and 29 homes in OR. In OR, homes were recruited using a database provided by a local non-profit organization called Earth Advantage that certifies home to an above-code standard. Those homes should meet ASHRAE 62.2-2010. In CO, recruitment leveraged a pre-existing relationship with Thrive Home Builders, an above-code home builder that incorporates WHMV in all new homes. In both locations, PNNL's team also purchased new-home addresses from a large online real estate website. This strategy ensured that both code-level and above-code homes were recruited. Characteristics from these homes are shown in Table 2.

Table 2. Summary characteristics for 55 western US homes.

Parameter	Median	Range
Conditioned Area (sqft)	2825	1166 - 6000
Year Built	2015.5	2013 - 2018
Number of Occupants	2	2-6
Enclosure Leakage (ACH50)	3	1.2 - 5.8

Ventilation System Characterization Results. Figures 3 and 4 show the measured average ventilation rate in each home for the week, expressed as a percentage of ASHRAE 62.2-2010, for OR and CO homes, respectively. The charts are constructed identically to that described for Figure 2**.**

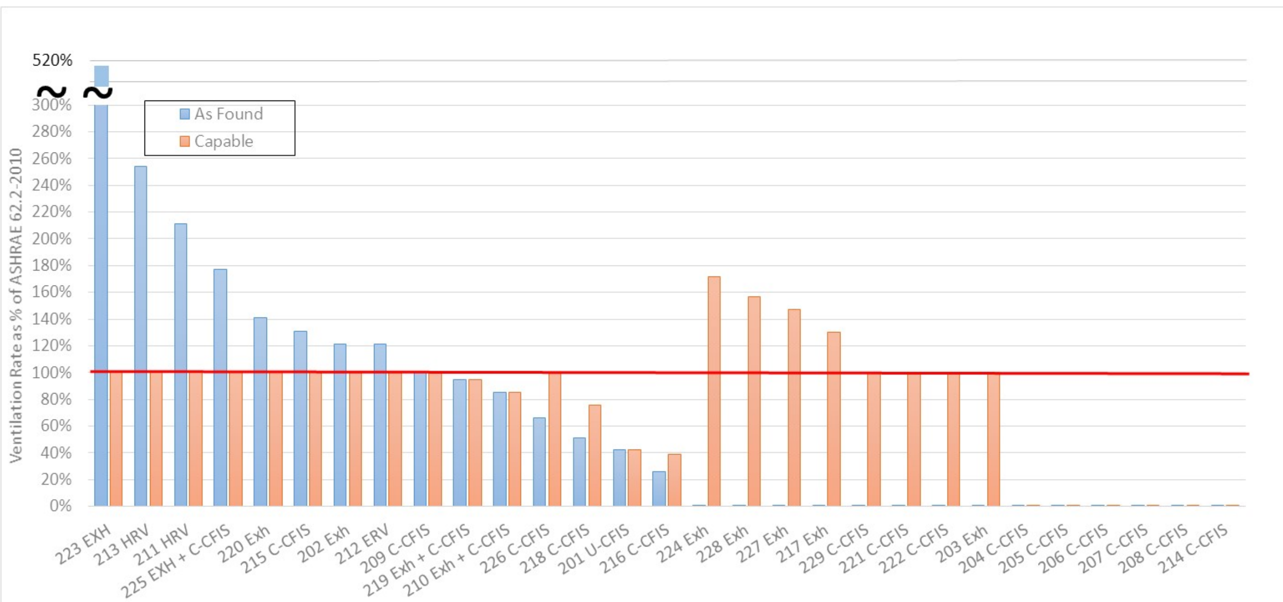

Figure 3. WHMV performance in homes in OR as a percentage of ASHRAE 62.2-2010 guideline.

Discussion. As seen in Figure 3 slightly more than half of the systems (15 of 29) in OR were operating as found, and 2/3 of those systems (10 of 15) were capable of meeting ASHRAE 62.2-2010, or being reasonably close. Overall, nearly half of the systems (15 of 29) were not operating as found, could not be operated, or were otherwise not capable of meeting ASHRAE 62.2-2010. In CO (Figure 4), a much higher percentage of homes were found with WHMV systems operating (19 of 26), also with 2/3 of those systems (12) operating at rates near-to or meeting ASHRAE 62.2-2010. Only one system was not capable of operating, seemingly due to an installation error.

In general, exhaust and balanced systems were found to be working. A few homes had multiple exhaust fans operating simultaneously, including house 324 which had five exhaust fans linked together. In contrast to the southeastern US most exhaust fans were found to have controls

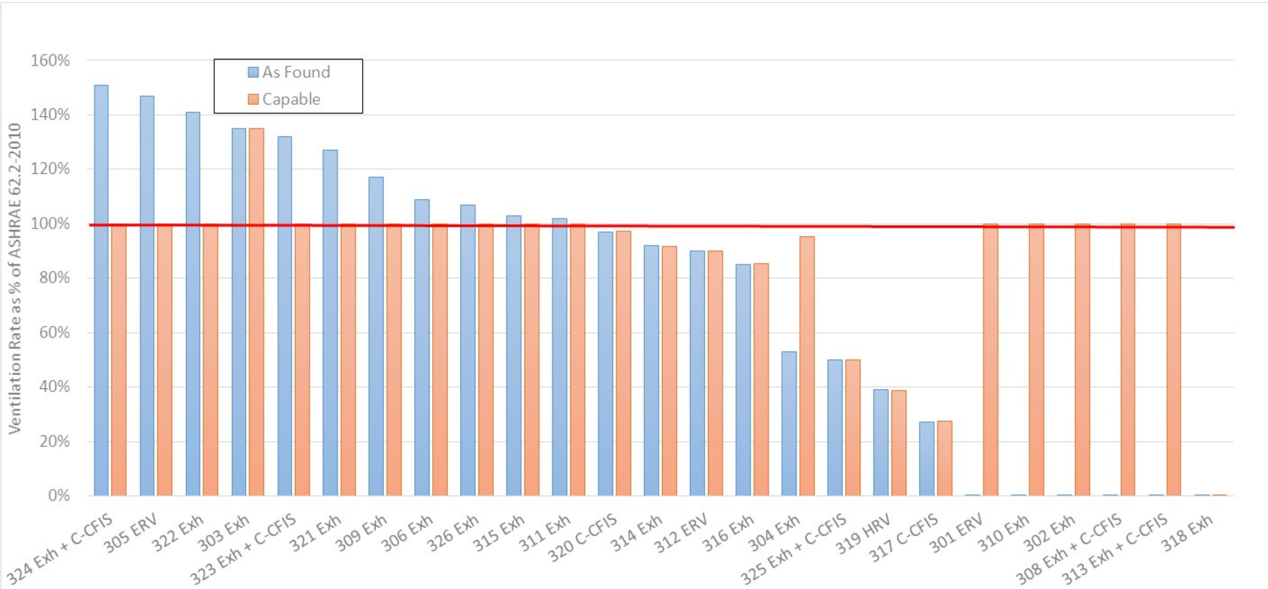

Figure 4. WHMV performance in homes in CO as a percentage of ASHRAE 62.2-2010 guideline.

built into them that allowed for either continuous or timed operation. Similar to the issues found with CFIS systems in the southeast, several of these systems across OR and CO were not working properly. In many instances, the damper did not appear to open, even when the air handler was on. In other cases, the damper position was unknown, however, when the airflow was attempted to be measured, the flow was too low to measure.

In contrast to what was found in the southeast, many of the homeowners in the western US were aware their home had a ventilation system. In OR 21 of 29 homeowners indicated that they had a ventilation system, and 19 of 26 in CO. However, only about half of those homeowners indicated they knew how the controls worked: 11 in OR and 10 in CO. At least two homeowners in CO (310 and 313) disabled their systems in the winter because it made the house too dry, and one (314) disabled their system at night due to excessive noise.

California

In 2008, ventilation requirements were added to the CA Title 24 Building Energy Efficiency Standards (Title 24). The CA Energy Commission added the ventilation requirements to address adverse impacts that could potentially result from air sealing envelopes to reduce air infiltration, based on research studies (Price 2007 and Offermann 2009). The 2008 Title 24 ventilation requirement was based on a 2007 version of ASHRAE Standard 62.2 specifically developed for CA and set a minimum continuous mechanical airflow along with an option to ventilate intermittently at rates providing equivalent dilution of indoor sources. While not explicitly stated in Title 24, a 5 to 7 ACH50 range of airtightness is assumed. The standards also include requirements for kitchen and bathroom ventilation.

Home Summary. HENGH recruited 70 homes with WHMV to participate in the field study. Homes were split between Northern and Southern CA. All homes have natural gas appliances and service provided by one of CA’s investor-owned gas utilities. Each home received a standard gas appliance safety inspection by a utility field service technician. Three homes failed the inspection because of a venting non-conformity identified for a fireplace or water heater. In addition, three homes had problems with WHMV (e.g., inoperable fan, fan not powered). All problems were corrected prior to monitoring. Table 3 presents summary of the characteristics of 70 CA homes; see Singer et al. (2020) for more detailed discussions.

Table 3. Summary of characteristics for 70 California homes.

Parameter	Median	Range
Conditioned Area (sqft)	2621	675-4995
Year Built	2014	2011-2017
Number of Occupants	3	1-9
Enclosure Leakage (ACH50)	4.4	1.5-9.6

Ventilation System Characterization Results. WHMV was provided by an exhaust system in 64 homes and by a supply system in six homes. Fifty-five of the exhaust systems used a continuous fan and the remaining nine had a programmable switch for intermittent operation. Forty three of the exhaust systems exhausted air from the laundry room, the others exhausted from bathroom(s). Three of the exhaust systems had remote fans located in the attic. All supply systems were integrated into the central forced air heating and cooling system. Four had inline fans, three of which were operating continuously, and two relied on the central system fan operating on a timer to pull in outdoor air through a duct connecting the return to outdoors. Even though the 70 homes is a sample of convenience, our observation that exhaust systems are the dominant type of WHMV is likely true in other parts of CA where majority of new houses are built.

Only the airflow of exhaust systems was measured because none of the supply systems could be safely accessed for measurements. The continuous measured flow values for these systems are shown in Figure 5, representing maximum capability at 100% runtime. In all but two of the homes with measured airflow, the continuous flow exceeded the code minimum requirement. In many homes, the “extra” airflow could be explained by use of a common exhaust fan size set to maximum capacity, i.e. not adjusted down to meet minimum requirements. The three homes with the most “extra” airflow in Figure 5 had multiple intermittent bathroom exhaust fans, so actual as-use ventilation will be lower. However, WHMV was running in only 18 of the 70 homes as found. Systems with understandable signage at the power switch for the system were much more likely to be operating (7 of 9).

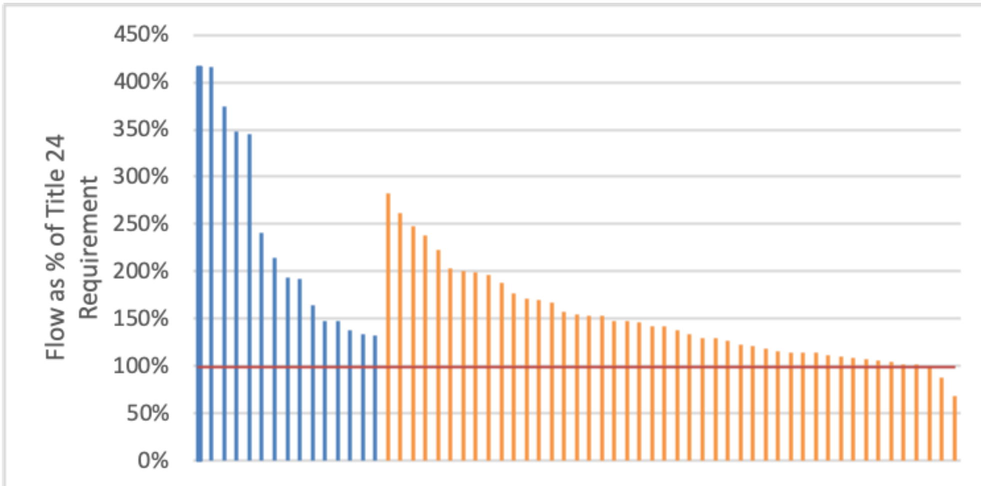

Figure 5. Ventilation rate for 61 of 64 exhaust systems as a percentage of Title 24 ventilation requirement. Color of the bar indicates whether the WHMV was on as found (blue) or if it was turned off as found (orange).

Discussion. On average, HENGH found that the WHMV moved 50% more airflow than the minimum code requirement in new CA homes. A key predictor of whether the system was running as found appears to be whether the system control switch was labeled, and how clear the signage was. Programmable controllers, either as a dedicated WHMV control or as part of the thermostat, were confusing to homeowners, resulting in the system not set to run in 7 out of 12.

Conclusions

Two recent field research studies designed to gather information regarding measured IAQ in occupied, new U.S. homes built since 2011 are revealing regional variations in how residential WHMV systems are designed and installed, as well as how they are operating. The Healthy Efficient New Gas Homes (HENGH) project analyzed 70 homes in CA built since 2011, and the Building America New Home IAQ (BAIAQ) study, which is ongoing, is collecting data from homes with WHMV built since 2013 with a target of 20-30 each in some of the other major US regions. In each of the study homes, homeowners were asked how they operated the WHMV system, airflow was characterized, and operation of the system was monitored for one week. Achievement of design intent is purely based on airflow and runtime, and not on ventilation effectiveness.

In CA, where WHMV has been required by code since 2008, all but 2 of 61 systems where WMHV flow was measured were determined capable of meeting the design intent. This is likely due to the ease of installation and commissioning of the single point exhaust systems used, which are also seen as cost effective, rather than the relatively long history of code requirements for WHMV. Even in states where WHMV has historically not been required or enforced by code, exhaust systems were also found to be mostly capable of functioning and delivering design intent. The bulk of homes in CO, OR, FL, GA, and SC that have WHMV had it incorporated as part of requirements for voluntary, above-code program certification. Such activity has occurred for quite some time, almost as long as CA code requirements have existed, but overall it has resulted in a much smaller fraction of new homes built with WHMV. Exhaust systems are the predominant system in the CO home sample, but a much smaller fraction of the sample in OR and in the Southeastern US, in part due to the regional preference for supply systems. In CA and in the southeastern states, most of the exhaust systems lacked flow and/or timer controls, and could only be operated continuously, resulting in capable flows exceeding minimum requirements, while in CO and OR, timer and flow controls were more common.

While some maintenance issues were encountered, balanced ERV and HRV systems were also generally found to be capable of meeting design intent. These systems appear to be less common, especially in mild climates like CA, likely due to installation cost factors. However, added first cost may be justified not only by the additional comfort and energy savings such systems can provide, but potentially also from an improved ventilation effectiveness that may exist due to better distribution over single point exhaust systems. Additional data collection and analysis in process by the BAIAQ and other studies may shed more light on this issue.

CFIS systems tended to be the most likely to have operational issues in all states. Common problems encountered included non-functioning electronic dampers and missing or improperly programmed controls. It is unclear if non-functioning systems worked at one time, or never worked, and in some cases how it was ever possible to commission an outdoor airflow in the first place.

While the ability of WHMV systems to meet design intent was similar across all states, and seemingly a function of the system type, the frequency that systems were operating *as found* did vary regionally. In CO, nearly all WHMV systems inspected (22 of 26) were found operating, with 2/3 found to deliver flows meeting ASHRAE 62.2-2010. In OR and the southeastern states, only about 1/2 of the systems were found operating upon arrival, and in CA only 1/4. While two thirds of the OR systems were found to be capable of meeting ASHRAE 62.2-2010, only about half of the southeastern homes were found similarly capable, and only two homes were meeting ASHRAE 62.2-2010 as found. This seems to be largely related to the lack of clear labeling of ventilation controls and their complexity of operation, along with general homeowner awareness of the existence of a ventilation systems.

In the southeastern US homeowners generally recognized the presence and purpose of visible WHMV systems such as ERVs, HRVs, but were generally unaware of exhaust and CFIS systems serving as WHMV. In contrast, many homeowners in the western US were aware their home had a ventilation system, regardless of type. In OR 21 of 29 homeowners indicated that they had a ventilation system, and 19 of 26 in CO. However, only about half of those homeowners indicated they knew how the controls worked.

Similar to findings from past studies, these new studies illustrate barriers that still need to be overcome with regard to residential WHMV systems. The findings of both the HENGH and BA IAQ studies suggest that proper training of HVAC technicians, electricians, code inspectors and home energy auditors around installation and commissioning is critical to ensuring the IAQ benefits of WHMV are realized, enabling the industry to continue to build energy efficient homes with tight building enclosures. In particular the industry needs systems with performance that is easy to verify, including easier access to air inlets and outlets or built-in flow measurement, along with on board fault detection systems that alert homeowners to non-functioning systems. An urgent matter is improved labeling and training on identification of controls for homeowners to overcome the issue of non-operating systems. Examples of such solutions are described in Lubliner (2020), and include Home Ventilation Institute (HVI) proposed labeling to be provided with HVI certified WHMV equipment, and additions to the 2020 Washington state energy code that require WHMV commissioning data to be displayed on the compliance certificate.

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