

Study Shows Mechanical Outdoor Ventilation Necessary

IAQ in Airtight Homes

By Francis (Bud) J. Offermann, P.E., Member ASHRAE

Homes are being constructed and retrofitted to make them more airtight for energy conservation purposes. In addition, many homeowners report never opening windows for ventilation. As a result, these airtight homes with closed windows have very low outdoor air exchange rates, which can result in elevated concentrations of indoor air contaminants with indoor sources. In recognition of this trend, ASHRAE Standard 62.2, *Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings*, has required mechanical outdoor air ventilation in residences since 2003.

To address this concern regarding residential ventilation, a multi-season field study of ventilation and indoor air quality was conducted in 108 new single-family, detached homes in California.¹ While most new homes are built without a mechanical outdoor air system, this study searched and recruited 26 homes with a mechanical outdoor air system.

In this study the field teams measured indoor and outdoor air concentrations of 22 volatile organic compounds (VOCs), including formaldehyde and acetaldehyde, PM_{2.5} particulate matter, nitrogen dioxide, carbon monoxide, and carbon dioxide over 24-hour periods. The outdoor air ventilation rates were determined concurrent with the air contaminant measurements using passive perfluorocarbon tracer (PFT) gas measurements.

The final report¹ describes the details of the home selection, measurement methods, results, and conclusions. Here we report the findings related to the performance of the mechanical outdoor air systems.

Most homes were single or two-story, slab-on-grade, stucco exterior, with an attached garage, and a forced air heating/cooling unit (FAU) in the attic. Two types

of mechanical outdoor air systems were encountered in this field study: ducted outdoor air to the return side of the home FAU (DOA systems) and heat recovery ventilators (HRV systems). The HRVs were independent systems that exhausted air from the bathrooms and utility room and supplied outdoor air, pre-cooled/heated by the exhaust air in an air-to-air heat exchanger, to the hallway near the return for the FAU. There were a total of 26 homes with mechanical outdoor air systems: 17 DOA systems and nine HRV systems.

The blower door measurements of the airtightness of these new homes indicated that the homes were relatively airtight. The median ACH₅₀ was 4.8, and ranged from 2.8 to 8.4.

A total of 32% of the homes did not use their windows during the 24-hour Test Day, and 15% of the homes did not use their windows during the entire preceding week. The median 24-hour outdoor air exchange rate was 0.26 air changes per hour (ach); 57% of the homes were below 0.30 air changes per hour and 25% were less than 0.18 ach.

Of the indoor air contaminants measured, only formaldehyde and PM_{2.5}

particulate matter exceeded recommended non-cancer and non-reproductive exposure guidelines. For formaldehyde (24-hour measurements), 98% of the homes exceeded the California Office of Environmental Health Hazard Assessment (OEHHA) Chronic and 8-hour reference exposure levels (RELs) of 9 µg/m³, and 28% exceeded the OEHHA Acute REL of 55 µg/m³. For PM_{2.5}, only one home, with an indoor concentration of 36 µg/m³, exceeded the EPA PM_{2.5} 24-hour ambient air quality standard of 35 µg/m³.

Most new homes had indoor concentrations of formaldehyde that exceeded recommended non-cancer irritant guidelines. The primary source of formaldehyde in homes is composite wood products; particleboard was used in 99% of the kitchen and bathroom cabinetry, as well as many pieces of furniture. Other sources of composite wood include plywood and oriented strand board in walls, subfloors, and attics, and medium density fiberboard in baseboards, window shades, interior doors, and window/door trims.

Figure 1 is a scatter plot of the indoor concentrations of formaldehyde and the outdoor air exchange rates, depicting a significant ($p < 0.0001$) inverse correlation (i.e., higher indoor formaldehyde concentrations correlated with lower outdoor air exchange rates). The only other significant correlation between indoor formaldehyde concentrations was indoor air temperature, which was found to correlate positively (i.e., higher indoor air temperatures correlated with higher indoor formaldehyde concentrations).

As depicted in *Figure 1*, homes with low air exchange rates have a higher frequency of exceeding the formaldehyde acute one hour irritant guideline of 55 µg/m³. The median Standard 62.2 recommended minimum outdoor air exchange rate for the homes in this study was 0.30 ach (i.e.,

0.16 ach mechanical plus 0.14 ach assumed infiltration). In homes with air exchange rates less than the ASHRAE 0.30 ach minimum, there were 37% (22 of 59) exceedences of the acute formaldehyde irritant guideline, while in homes with rates greater than 0.30 ach, there were only 14% (6 of 44) exceedences, and for homes with rates greater than 0.50 ach there were no exceedences (0 of 24).

The mean indoor concentration of formaldehyde and acetaldehyde was significantly higher in the homes with intermittently operated DOA mechanical outdoor air systems than in non-mechanically ventilated homes, while the mean outdoor air exchange rate was significantly higher in homes with continuously operated HRV systems than in homes with DOA systems.

When comparing the performance of the DOA and HRV ventilation systems to the recommended Standard 62.2-2010 recommendations, none of the 14 operational DOA systems met the Standard 62.2 requirement, while all eight of the operational HRV systems met the requirement.

The poor performance of the DOA systems is a result of the combination of low outdoor airflow rates and low fractional on-times. The HRV systems, all provided outdoor airflow rates that exceeded the Standard 62.2 requirements, and typically operated continuously.

The low outdoor airflow rates of the DOA systems were the result of the connection location of the outdoor air duct, which typically had a diameter of 5 in. or 6 in. (125 mm or 150 mm). The most common connection of the outdoor air duct was to a sheet metal box just above the hallway return air inlet grille, which contains the air filter. As this air filter is typically a low efficiency/low pressure drop filter, there is little negative air pressure to draw in outdoor air.

The low fractional on-times of the DOA systems are the result of the FAU fan control, which typically was controlled by the FAU thermostat fan switch and always set in the “auto” position. Therefore, the fan only operated when the thermostat called for heating or cooling. As these new homes are built to be energy efficient, the median operating time of the FAUs was just 1.1 hours per day.

Standard 62.2 does allow for residential outdoor air ventilation systems to be operated intermittently, provided the outdoor airflow rates are increased according to Section 4.4. In addition, Standard 62.2 requires that intermittent ventilation systems have a fan cyclers, which can be set up to provide periodic delivery of outdoor air. Of the 14 operational DOA systems only four had fan cyclers, and only three of these were operational. Of the three DOA systems with operational fan cyclers, none provided the outdoor airflow rate required by Standard 62.2 Section 4.4; the actual outdoor flow rates ranged from just 3% to 8% of the required airflow rates. We note that Standard 62.2 requires verification of the required outdoor airflow rates during the installation of all mechanical outdoor air systems.

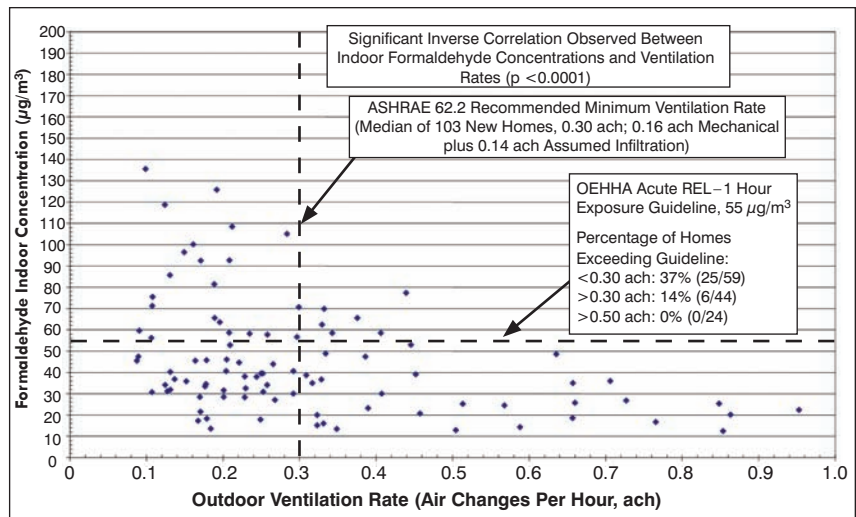


Figure 1: Indoor formaldehyde concentrations and outdoor air exchange rates.

However, intermittent systems, even if operated according to Standard 62.2 requirements, cannot perform equivalently to continuous systems with respect to controlling short-term exposures to indoor air contaminants, especially if the cycle times are long. During off-times, intermittent systems allow for indoor concentrations of air contaminants with indoor sources to increase substantially.

To compare indoor air contaminant control performance of continuous and intermittent ventilation systems, we used a well-mixed single-zone computer model with constant contaminant emission rates to simulate indoor residential air contaminant concentrations each minute for a 24-hour period.² We modeled the indoor concentrations of formaldehyde, carbon dioxide (surrogate for body odor), and airborne infectious disease organisms according to 62.2 continuous and intermittent ventilation rates. For emission rates we used the median emission rate of formaldehyde observed in the 108 home study, the human sedentary emission rate for CO₂ cited in 62.1, and one infected occupant generating two infectious doses (i.e., quanta) per hour.

With an intermittent system, having a 24-hour cycle time with a 0.40 fractional on-time, there were 5.6 hours per day that the indoor formaldehyde concentration exceeded the acute one-hour irritation guideline of 55 µg/m³, as compared to zero exceedences for a continuous system. For carbon dioxide, the indoor concentrations exceeded the ASHRAE Standard 62.1 body odor guideline of 700 ppm over outdoors for 9.4 hours per day, with no exceedences for a continuous system. Therefore, operation of intermittent systems results in periods during the off-cycles where indoor concentrations of human bioeffluents exceed the body odor threshold for visitors of the residence.

With respect to airborne infectious disease, the risk of a person becoming infected while visiting a home with an infected person for a three-hour period, is up to two times higher for an intermittent system with a 24-hour cycle time as compared to a home with a continuous system.

For the air contaminants modeled, only a cycle time of less than two hours provides indoor concentrations of formaldehyde less than the acute one hour guideline, concentrations of carbon dioxide

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below the 62.1 body odor guideline, and a risk of infectious disease that is not significantly higher than that for continuous ventilation.

While the higher ventilation rates specified for intermittent systems in Standard 62.2, provide for rates that result in corresponding time averaged 24-hour indoor air concentrations that are approximately equivalent to those of continuous systems, the peak concentrations are substantially higher during the off periods.

We conclude that new homes are being built more airtight for energy conservation purposes, and this combined with the fact that many people never open windows for ventilation, results in very low outdoor air exchange rates and elevated indoor concentration of air contaminants with indoor sources.

We note that the Standard 62.2 ventilation rates are insufficient to control formaldehyde concentrations below the eight hour and chronic OEHHA guidelines of $9 \mu\text{g}/\text{m}^3$ and a reduction of the emission rates of formaldehyde from indoor building materials and furnishings, in combination with ventilation, will be required to reduce concentrations below this level.

Therefore, it is important that airtight energy-efficient homes be provided with mechanical outdoor ventilation that is at least that prescribed by Standard 62.2. For a 1,764 ft² (164 m²) home with an 8 ft (2 m) ceiling and three bedrooms, this translates into just 48 cfm (23 L/s), which depending on climate and utility rates, costs between \$100 to \$300/year for the fan power and energy to heat/cool/dehumidify the outdoor air.

Residential intermittent ventilation systems, as operated ac-

ording to Standard 62.2 recommendations, allow for periods where indoor air contaminant concentrations can increase and exceed short-term exposure guidelines, causing odors, irritation, and increased exposure to airborne infectious disease organisms. This is especially true for intermittent ventilation systems with long cycle times (e.g., greater than two hours). To minimize periods of poor indoor air quality, intermittent ventilation systems should be operated with cycle times no greater than two hours.

What we must always remember is that buildings are for people, and thus health must trump energy. When concerns for energy costs exist because of cold or hot climatic conditions, the response should not be to reduce the outdoor air ventilation, but rather to pursue energy conservation measures. Similarly, when concerns are present for high outdoor air contaminant concentrations, then air cleaning measures should be pursued.

The home ventilation mantra remains; build tight, but ventilate right.

References

1. Offermann, F.J. 2009. "Ventilation and Indoor Air Quality in New Homes." California Air Resources Board and California Energy Commission, PIER Energy-Related Environmental Research Program.
2. Offermann, F.J. 2010. "Standard 62.2 Intermittent Residential Ventilation: What's It Good For, Intermittently Poor IAQ?" Ventilation and Indoor Air Quality and Energy Conservation Conference.

Francis (Bud) J. Offermann, P.E., is president of Indoor Environmental Engineering in San Francisco. ●

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