Mechanical Outdoor Air Ventilation Systems and IAQ in New Homes

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- B.S. (Rensselaer) and M.S. (Stanford) in Mechanical Engineering
- Staff Scientist: IAQ Program, Lawrence Berkeley Laboratory
- Member of USBGC LEED EQ Technical Advisory Group
- Co-Chair ISIAQ HVAC Hygiene Task Force
- Member of ASHRAE Standard 62 Ventilation for Acceptable IAQ
- Member of ACGIH Bioaerosols Committee
- Member of the Cal-OSHA IAQ Advisory Committee
- Published 26 Peer-Reviewed Studies on Building Air Quality
- IAQ Diagnostics/Mitigation in over 2,000 Buildings (25 years - 2009)
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Acknowledgements

Study Sponsors

• California Energy Commission
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This Report was submitted in fulfillment of ARB Agreement #04-310.
• Many homeowners never or rarely open their windows.

• As a result, outdoor air exchange rates in these homes are very low (e.g. 0.1 - 0.2 ach)

• These low air exchange rates result in elevated indoor concentrations of air contaminants such as formaldehyde, which is both a potent irritant and a known human carcinogen.
Study Design

- Recruit 108 home
  - 54 each from Northern and Southern California
  - 20 homes with mechanical outside air ventilation systems.
- Summer and Winter Field Sessions (20 home seasonal crossover)
- Measure window/door opening, outdoor air exchange rates, air contaminant concentrations, house characteristics, source activities, and occupant perceptions.
Recruitment

• We utilized a recent mail survey by UCB on window use in new single family homes (random stratified).

• A total of 965 of the 1,515 UCB Mail Survey respondents indicated an interest in participating in the follow up field study.

• We mailed out recruitment letters to the 965 interested UCB Mail Survey participants, as well as 1,798 additional nearby new homes.
Ventilation Measurements
7 Day Monitoring Period

• **Window/door openings**
  - electronic loggers and occupant logs.

• **Exhaust fan usage**
  - electronic loggers, occupant logs, and flowhood measurements.

• **Mechanical outside air and FAU fan usages**
  - electronic loggers and flowhood measurements.

• **Building envelope air leakage**
  - multi-point fan depressurization
Outdoor Air Exchange Rate Measurements - 24 hour

- **Passive tracer gas technique (PFT)**
  - 4-8 tracer gas sources deployed one week in advance to allow for the emission rates to equilibrate.
  - tracer sampler deployed in home for 24 hour period
  - a subset of 30 homes also deployed samplers for a 2 week period
Quiet Active Indoor Air Sampler

- HCHO
- VOC’s
- PM$_{2.5}$
- CO$_2$
- CO
- T
- RH
- Flow Control
- Power Surveillance
Field Session Recruits

- 108 homes primarily from tract developments
- built 2002 or later, and have been owner-occupied for at least one year (median age 3.4 years)
- typically stucco and slab on grade with attached garages.
- all homes had forced air unit heating systems (94% with AC)
- 35 homes with some type of mechanical outdoor air ventilation system
Heat Recovery Ventilator (HRV) System (9 homes)

Balanced 2 fan system independent of FAU
Ducted Outdoor Air (DOA) System (17 homes)

Unbalanced - single fan system – integrated with FAU

Also called Central Fan Integrated (CFI) systems and “passive inlets”.

FAU
• 32% of the homes never opened windows or doors during the test day and 15% never during the previous week.

• most of the homes with zero window/door usage were in the Winter field session (85%)
RESULTS - Building Envelope Leakage

- ACH 50 (N=106)
- SLA (N=107)

Median (50%)
SLA = 2.9

Median (50%)
ACH50 = 4.8
RESULTS - Outdoor Air Exchange Rates - PFT Measurements

67% of homes are below the 2001 CBC 1205 Code Requirement of 0.35 ach

Median (50%) Outdoor Air Exchange Rate = 0.26 ach

Median (50%) Outdoor Air Exchange Rate = 0.26 ach

Cumulative Frequency (%) vs. Outdoor Air Exchange Rate (ach)
RESULTS - Outdoor Air Exchange Rates - PFT Measurements

Window/Door Opening Impact on Outdoor Air Exchange Rates
41 Homes Without Mechanical Outdoor Air Ventilation
2006 - Summer Field Sessions - Northern and Southern California

\[
y = 0.0495x - 0.1169
\]
\[
R^2 = 0.3813
\]
### RESULTS - 24-hour Average Outdoor Air Exchange Rates

<table>
<thead>
<tr>
<th></th>
<th>Number of Homes Tested</th>
<th>Minimum (ach)</th>
<th>Median (ach)</th>
<th>Maximum (ach)</th>
<th>Percentage of Homes Below CBC Code Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-mechanically Ventilated Homes</td>
<td>73</td>
<td>0.09</td>
<td>0.25</td>
<td>5.3</td>
<td>75</td>
</tr>
<tr>
<td>DOA-mechanically Ventilated Homes</td>
<td>14</td>
<td>0.10</td>
<td>0.20</td>
<td>0.60</td>
<td>64</td>
</tr>
<tr>
<td>HRV-mechanically Ventilated Homes</td>
<td>5</td>
<td>0.33</td>
<td>0.71 *</td>
<td>4.3</td>
<td>64</td>
</tr>
</tbody>
</table>

- 0.35 ach; 2001 California Building Code (CBC), Appendix Chapter 12, Interior Environment, Division 1-Ventilation, Table A-12-A, Outdoor Air Requirements for Ventilation, Living
- * statistically significantly higher mean ach (t-test, p<0.05)
## RESULTS - Mechanical Outdoor Air System Performance

<table>
<thead>
<tr>
<th>Quartiles</th>
<th>DOA Mechanical Outdoor Air Homes (n=14)</th>
<th>HRV Mechanical Outdoor Air Homes (n=8)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ach (h⁻¹) % on time cfm</td>
<td>Ach (h⁻¹) % on time cfm</td>
</tr>
<tr>
<td>Minimum</td>
<td>0 0 9</td>
<td>0.12 32 66</td>
</tr>
<tr>
<td>Median</td>
<td>0.01 10 38</td>
<td>0.30 100 128</td>
</tr>
<tr>
<td>Maximum</td>
<td>0.08 75 355</td>
<td>0.47 100 159</td>
</tr>
</tbody>
</table>
RESULTS - Formaldehyde Concentration Guidelines

- Proposition 65 (cancer):
  - NSRL (cancer) - 2 µg/m³

- OEHHA Reference Exposure Levels (non-cancer, irritant effects)
  - CREL - 9 µg/m³
  - 8 hour REL - 9 µg/m³
  - AREL - 94 µg/m³

- California Air Resources Board
  - Indoor Air Guideline - 33 µg/m³
RESULTS – Formaldehyde Concentrations

Formaldehyde Concentration Cumulative Frequency Distribution

- 59% of indoor and 0% of outdoor samples above the CARB IAQ Guideline of 33 µg/m$^3$ (27 ppb)
- Median (50%) Indoor Concentration = 36 µg/m$^3$ (29 ppb)
- 100% of indoor and 58% of outdoor samples above the NSRL (cancer) of 2 µg/m$^3$ (1.6 ppb)
- 28% of indoor and 0% of outdoor samples above the OEHHA Acute Reference Exposure Level of 55 µg/m$^3$ (45 ppb)

Indoor (N=105)  Outdoor (N=39)
## RESULTS - Indoor Concentrations of Formaldehyde

<table>
<thead>
<tr>
<th></th>
<th>Number of Homes Tested</th>
<th>Minimum (µg/m³)</th>
<th>Median (µg/m³)</th>
<th>Maximum (µg/m³)</th>
<th>Percentage of Homes Above ARB Indoor Air Guideline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-mechanically Ventilated Homes</td>
<td>72</td>
<td>8</td>
<td>35</td>
<td>126</td>
<td>57</td>
</tr>
<tr>
<td>DOA-mechanically Ventilated Homes</td>
<td>14</td>
<td>34</td>
<td>68*</td>
<td>136</td>
<td>93</td>
</tr>
<tr>
<td>HRV-mechanically Ventilated Homes</td>
<td>5</td>
<td>8</td>
<td>37</td>
<td>63</td>
<td>60</td>
</tr>
</tbody>
</table>

a.) 2005 California Air Resources Board – 33 µg/m³.  
* statistically significantly higher mean concentration (t-test, p<0.05)
RESULTS - Formaldehyde Concentrations and Ventilation

Formaldehyde Concentration and Outdoor Air Exchange Rate
84 Homes Without and 38 With Mechanical Outdoor Air Ventilation
2006 and 2007 - Summer and Winter Field Session - Northern and Southern California

California Title 24 ACM - 2001
Minimum mechanical outdoor air for homes built tight (SLA < 3.0).
Median 0.30 ach for this sample of homes.

ASHRAE 62.2-2004
(Proposed 2008 California Title 24 Standard)
Minimum mechanical outdoor air.
Median of 0.15 ach for this sample of homes.

\[ y = 19.914x^{-0.4854} \]
\[ R^2 = 0.4088 \]

ARB IAQ Guideline - 33 \( \mu \)g/m\(^3\)

Non-Mechanical Winter (N=43)
DOA Mechanical Winter (N=10)
HRV Mechanical Winter (N=3)
Other Mechanical Winter (N=8)
Non-Mechanical Summer (N=41)
DOA Mechanica Summer (N=7)
HRV Mechanical Summer (N=3)
Other Mechanical Summer (N=7)
RESULTS - Intermittent vs. Continuous Outdoor Air Ventilation

ASHRAE 62.2-2007 (addenda "b")
Continuous and Intermittent Ventilation- Fractional On Time (Cycle Hours)
Continuous Indoor Air Contaminant Source

- On continuous - TWA = 70, Max = 70 - 60 cfm
- On 0.3/1 - TWA = 70 (1.0x), Max = 76 (1.1x) - 200 cfm
- On 0.3/2 - TWA = 70 (1.0x), Max = 86 (1.2x) - 200 cfm
- On 0.3/4 - TWA = 73 (1.1x), Max = 105 (1.5x) - 200 cfm
- On 0.3/8 - TWA = 81 (1.2x), Max = 146 (2.1x) - 215 cfm
- On 0.3/12 - TWA = 92 (1.3x), Max = 195 (2.8x) - 241 cfm
- On 0.1/12 - TWA = 111 (1.6x), Max = 231 (3.3x) - 923 cfm
- On 0.4/24 - TWA = 111 (1.6x), Max = 314 (4.5x) - 326 cfm
RESULTS - Intermittent vs. Continuous Outdoor Air Ventilation

ASHRAE 62.2-2007 (addenda "b")
Continuous and Intermittent Ventilation - On Time Ratio (Cycle Hours)
Intermittent Indoor Air Contaminant Source (2 minutes at start of ventilation off period)

- On Continuous - TWA = 10 - 60 cfm
- On 0.3/1 - TWA = 11 (1.1x) - 200 cfm
- On 0.3/2 - TWA = 12 (1.2x) - 200 cfm
- On 0.3/4 - TWA = 14 (1.5x) - 200 cfm
- On 0.3/8 - TWA = 21 (2.2x) - 215 cfm
- On 0.3/12 - TWA = 27 (2.8x) - 241 cfm
- On 0.1/12 - TWA = 32 (3.3x) - 923 cfm
- On 0.4/24 - TWA = 42 (4.3x) - 326 cfm
Conclusions

• We conclude that the new single-family detached homes in California are built relatively tight (i.e. 50% of the homes had an $\text{ACH}_{50} < 4.8$).

• Many homeowners never open their windows (e.g. 32% in the Winter).
Conclusions

• Homes where the windows/doors are not opened, have low outdoor air exchange rates (e.g. 0.1 - 0.2 ach), and indoor concentrations of air contaminants, such as formaldehyde, can be significantly elevated.

• 67% of the homes had outdoor air exchange rates below 0.35 ach (2001 CBC 1205 code requirement).

• 59% of the homes had indoor formaldehyde concentrations above 33 µg/m³ (27 ppb), the California ARB indoor guideline.
Conclusions

• The HRV mechanical outdoor air systems performed well in increasing the home outdoor air exchange rates and reducing indoor formaldehyde concentrations.

• The DOA systems did NOT perform well as a result of a combination of the low outdoor air flow rates and low fan operation times.
Conclusions

• Intermittent mechanical outdoor air systems, such as the DOA systems in this study, can NOT provide IAQ that is equivalent to continuous systems.

• Especially for long cycle times, the ASHRAE 62.2-2007 ventilation effectiveness factors provide ventilation rates that are too LOW to provide equivalent long term average concentrations, which is important for cancer and cardiovascular diseases.
Conclusions

• In addition, intermittent ventilation systems, especially those with long cycle times, allow for air contaminants with indoor sources to increase substantially during the extended outdoor air ventilation off times.

• For some air contaminants, such as those that cause irritation and/or odor, the effects are initiated by the immediate exposure to the indoor concentration rather than the exposure to a concentration over a period of time.
Recommendations

• Consideration should be given to changing Title 24 and the California Building Code to require installation of mechanical outdoor air ventilation systems in new single-family residences to provide a dependable and continuous supply of outdoor air to the residence.

• Too this end, in 2009, Title 24 was revised to require mechanical outdoor air systems in new single family homes, using ASHRAE 62.2 minimum rates (e.g. typically 0.15 ach mechanical). Additional studies of indoor contaminant concentrations in homes with non-continuous mechanical outdoor air systems (i.e. fan cyclers) should be conducted.
Recommendations

• Consideration should be given to regulating the emissions of air contaminants from building materials. To this end, in April 2007, the California Air Resources Board (2007) adopted an airborne toxics control measure (ATCM) to reduce formaldehyde emissions from composite wood products.

• Emission rate reductions from other indoor sources of formaldehyde will also be needed to provide healthful indoor air quality.
Recommendations

• Conduct further studies in additional homes with mechanical outdoor air ventilation systems to confirm the findings identified in this study and with consideration for other building factors. Evaluate both installation and field performance of the mechanical outdoor air ventilation systems.

• Conduct a similar study in multi-family homes.

• Build it TIGHT but ventilate it RIGHT.
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