A Review of Studies of Ventilation and Indoor Air Quality in New Homes and Impacts of Environmental Factors on Formaldehyde Emission Rates From Composite Wood Products

Francis (Bud) Offermann
Indoor Environmental Engineering

Cheri Marcham
Embry-Riddle Aeronautical University, march617@erau.edu

Follow this and additional works at: https://commons.erau.edu/publication

Part of the Occupational Health and Industrial Hygiene Commons

Scholarly Commons Citation

This Presentation without Video is brought to you for free and open access by Scholarly Commons. It has been accepted for inclusion in Publications by an authorized administrator of Scholarly Commons. For more information, please contact commons@erau.edu.
A Review of Studies of Ventilation and Indoor Air Quality in New Homes and Impacts of Environmental Factors on Formaldehyde Emission Rates From Composite Wood Products

F. (Bud) Offermann PE, CIH
Cheri Marcham, PhD, CIH, CSP, CHMM, FAIHA
This report was prepared as a result of work sponsored by the Air Resources Board (ARB) and the California Energy Commission (Commission, Energy Commission). It does not necessarily represent the views of ARB, the Commission, their employees, or the State of California. The mention of commercial products, their source, or their use in connection with reported material herein is not to be construed as actual or implied endorsement of such products. The ARB, the Commission, the State of California, its employees, contractors, and subcontractors make no warranty, express or implied, and assume no legal liability for the information in this report; nor does any party represent that the use of this information will not infringe upon the privately owned rights. This report has not been approved or disapproved by the ARB or the Commission, nor has the ARB or the Commission passed upon the accuracy or adequacy of this information in this report.
CARB Study Hypothesis

• California residential building code allowance for ventilation only through openable windows may not be sufficient to enable new homes to receive adequate ventilation to control indoor air contaminants

• 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 homes
  - 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
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
• 35 homes with some type of mechanical outdoor air ventilation system
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
Quiet Active Indoor Air Sampler

- HCHO
- VOC’s
- PM$_{2.5}$
- CO$_2$
- CO
- Temp
- RH
- Flow Control
- Power Surveillance

Pathways to Progress
May 21-26, 2016  #AIHce16  AIHce2016.org
RESULTS - Window/Door Usage

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

• New homes in California are built relatively tight, such that outdoor air exchange rates through the building envelope can be very low (e.g., 0.1 air changes per hour)
RESULTS - Outdoor Air Exchange Rates

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

67% of homes are below the CBC 1205 Code Requirement of 0.35 ach
# RESULTS – Formaldehyde Concentrations

<table>
<thead>
<tr>
<th>Compound</th>
<th>Number of Homes Tested</th>
<th>Minimum Concentration (µg/m³)</th>
<th>Median Concentration (µg/m³)</th>
<th>Maximum Concentration (µg/m³)</th>
<th>Indoor Air Guideline (µg/m³)</th>
<th>Percentage Above Indoor Air Guideline (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formaldehyde</td>
<td>105</td>
<td>4.8</td>
<td>36</td>
<td>136</td>
<td>2 a</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9 b</td>
<td>98</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9 c</td>
<td>98</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>33 d</td>
<td>59</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>55 e</td>
<td>28</td>
</tr>
<tr>
<td>Acetaldehyde</td>
<td>105</td>
<td>1.9</td>
<td>20</td>
<td>102</td>
<td>4.5 a</td>
<td>93</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>140 b</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>300 a</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>470 e</td>
<td>0</td>
</tr>
</tbody>
</table>

3.9 – 111 ppb
Median 29 ppb

---

a) Proposition 65 No Significant Risk Level for carcinogens (OEHHA 2008a).
c) OEHHA 8-hour Reference Exposure Levels, 2008 (OEHHA 2008b). Adopted after study completed.
d) *Indoor Air Quality Pollution in California* (California Air Resources Board 2005).
e) OEHHA Acute Reference Exposure Levels, 2008 (OEHHA 2008b). Adopted after study completed.
RESULTS – Formaldehyde Concentrations

Formaldehyde Concentration Cumulative Frequency Distribution
All Home Sample Frame

- 60% of indoor and 0% of outdoor samples above the CARB IAQ Guideline of 33 µg/m³ (27 ppb)
- Median (50%) Indoor Concentration = 36 µg/m³ (29 ppb)
- 100% of indoor and 21% of outdoor samples above the OEHHA Chronic Reference Exposure Level of 3 µg/m³ (2.4 ppb)
- 6% of indoor and 0% of outdoor samples above the OEHHA Acute Reference Exposure Level of 94 µg/m³ (77 ppb)

100% of indoor and 21% of outdoor samples above the OEHHA Chronic Reference Exposure Level of 3 µg/m³ (2.4 ppb)
RESULTS - Formaldehyde Concentrations and Ventilation

ASHRAE 62.2-2003
Median mechanical outdoor air of 0.15 ach for this sample of homes.

California Title 24 - ACM
Median mechanical outdoor 0.30 ach for this sample of homes.

ARB Recommended Maximum - 33 µg/m³

Indoor Concentration - 24 hour average (µg/m³)

Outdoor Air Exchange (1/hr)
Conclusions

- 67% of the homes had outdoor air exchange rates below the minimum CBC 1205 code requirement of 0.35 ach
- In homes where the windows/doors are not opened for ventilation, the outdoor air exchange rates are typically low (e.g. 0.1 - 0.2 ach), and indoor concentrations of air contaminants such as formaldehyde and acetaldehyde can be significantly elevated

Study #2: Emission Rate Dependence on Ventilation Rates

• Engineers typically assume constant indoor emission rates when calculating the change in the concentrations caused by changes in ventilation rates.

• However, mass transfer theory suggests that for some contaminants such as formaldehyde from composite wood products, the emission rates can INCREASE with increased ventilation rates.

• This results in smaller actual decreases of indoor concentrations than those predicted assuming a constant emission rate.
Study Design

• Recruit one fully furnished home from the 108 homes of the California New Homes Study where the occupants are on vacation for a 3 week period (i.e. no occupant activities).

• Install a balanced mechanical outdoor air/exhaust air system

• Measure the impact of outdoor air ventilation rates on the emission rates of VOCs for 3 ventilation rates

• Calculate the ratio of the actual reduction in indoor concentrations for two increases in ventilation rates to those predicted assuming a constant emission rate
Study Design

• Simultaneously measure over a 24 hour period on days 2, 3, and 4 of each four day ventilation rate period:
  - home outdoor air exchange rate
  - temperature and relative humidity in the indoor and outdoor air
  - concentrations of VOCs over a 24 hour period in the indoor and outdoor air
    - EPA Method TO-17
    - Formaldehyde and acetaldehyde by ASTM D5197
RESULTS - 24 Hour Average

• Environmental Conditions
  - Indoor Air Temperature: 23.4 °C – 23.7 °C
  - Indoor Air Relative Humidity: 46.5% – 49.9%

• Outdoor Air Exchange Rates (average of 3 tests)
  - Low 0.21 ach
  - Medium 0.41 ach
  - High 0.64 ach

Relative standard deviation of three test days < 2%.
RESULTS - 24 Hour Average

• Focus on 21 of 48 VOC compounds with minimum indoor concentrations > 1 µg/m³ during the nine measurement periods

• The impact of the ventilation rate on indoor emission rates was calculated as the slope of a linear curve fit of the emission rates and outdoor air ventilation rates

• For 12 of 21 compounds, a linear correlation coefficient (r²) of emission rates as a function of outdoor air ventilation rates was > 0.75
  - 4 VOCs with increasing emission rates
  - 8 VOCs with decreasing emission rates
RESULTS – Ventilation Rate Impact on VOC Emission Rates

- 3 highest emission rate increases
- 2 relatively constant emission rates
- 3 highest emission rate decreases

<table>
<thead>
<tr>
<th>Compound</th>
<th>Low VR</th>
<th>Med. VR</th>
<th>High VR</th>
<th>Linear Slope (µg/m³-h)/ach</th>
<th>r²</th>
<th>R_a/R_p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formaldehyde</td>
<td>16.9</td>
<td>24.4</td>
<td>31.2</td>
<td>32.4</td>
<td>0.96</td>
<td>0.59</td>
</tr>
<tr>
<td>Texanol</td>
<td>5.11</td>
<td>5.55</td>
<td>7.41</td>
<td>5.55</td>
<td>0.92</td>
<td>0.78</td>
</tr>
<tr>
<td>Phenol</td>
<td>1.46</td>
<td>1.87</td>
<td>2.55</td>
<td>2.52</td>
<td>0.98</td>
<td>0.64</td>
</tr>
<tr>
<td>Hexadecane</td>
<td>0.74</td>
<td>0.84</td>
<td>1.10</td>
<td>0.86</td>
<td>0.92</td>
<td>0.76</td>
</tr>
<tr>
<td>Tetradecane</td>
<td>1.99</td>
<td>1.92</td>
<td>2.31</td>
<td>0.84</td>
<td>0.76</td>
<td>0.92</td>
</tr>
<tr>
<td>d-Limonene</td>
<td>3.29</td>
<td>2.01</td>
<td>1.48</td>
<td>-3.95</td>
<td>0.91</td>
<td>1.27</td>
</tr>
<tr>
<td>Dodecane</td>
<td>7.85</td>
<td>6.43</td>
<td>6.18</td>
<td>-3.53</td>
<td>0.78</td>
<td>1.10</td>
</tr>
<tr>
<td>Toluene</td>
<td>2.62</td>
<td>1.84</td>
<td>1.15</td>
<td>-3.31</td>
<td>0.94</td>
<td>1.27</td>
</tr>
</tbody>
</table>
Conclusions

• While increasing outdoor air ventilation rates does reduce the indoor concentrations of air contaminants with indoor sources, the actual reductions in concentrations can differ significantly from those calculated with the assumption of a constant indoor emission rate.

• The ratio of actual to predicted concentration reductions for the low to high outdoor air ventilation modes ranged from 0.59 for formaldehyde to 1.37 for benzaldehyde.
Conclusions

• Increases in emission rates for compounds such as formaldehyde are consistent with mass transfer theory for emissions from materials such as composite wood where mass transfer is limited by gas-phase diffusion across the boundary layer.

• Decreases in emission rates of compounds such as d-limonene were surprising and may be the result of residual emissions of cleaning chemicals which were used by the occupants prior to the tests.
Conclusions and Recommendations

• The results presented here represent the impact on the emission rates from the specific materials in this residence.

• Additional measurements are needed to understand the impact of outdoor air ventilation rates on indoor air contaminant emission rates from materials with different ages and material matrices.

Francis (Bud) J. Offermann PE CIH
Indoor Environmental Engineering
San Francisco, CA
(415)-567-7700
www.IEE-SF.com
Offermann@IEE-SF.com