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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

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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

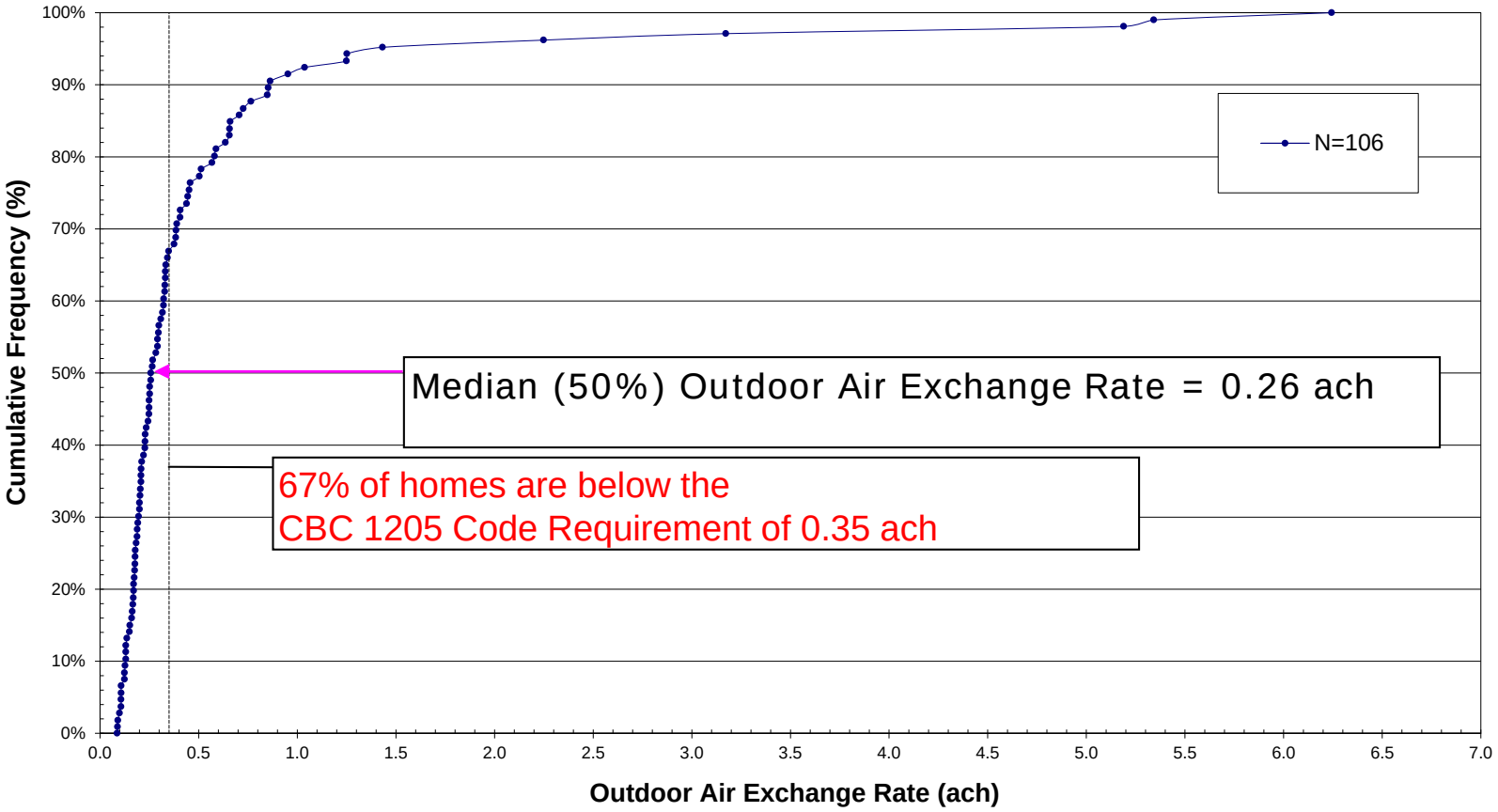
Quiet Active Indoor Air Sampler

- HCHO
- VOC's
- $PM_{2.5}$
- CO_2
- CO
- Temp
- RH
- Flow Control
- Power Surveillance

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



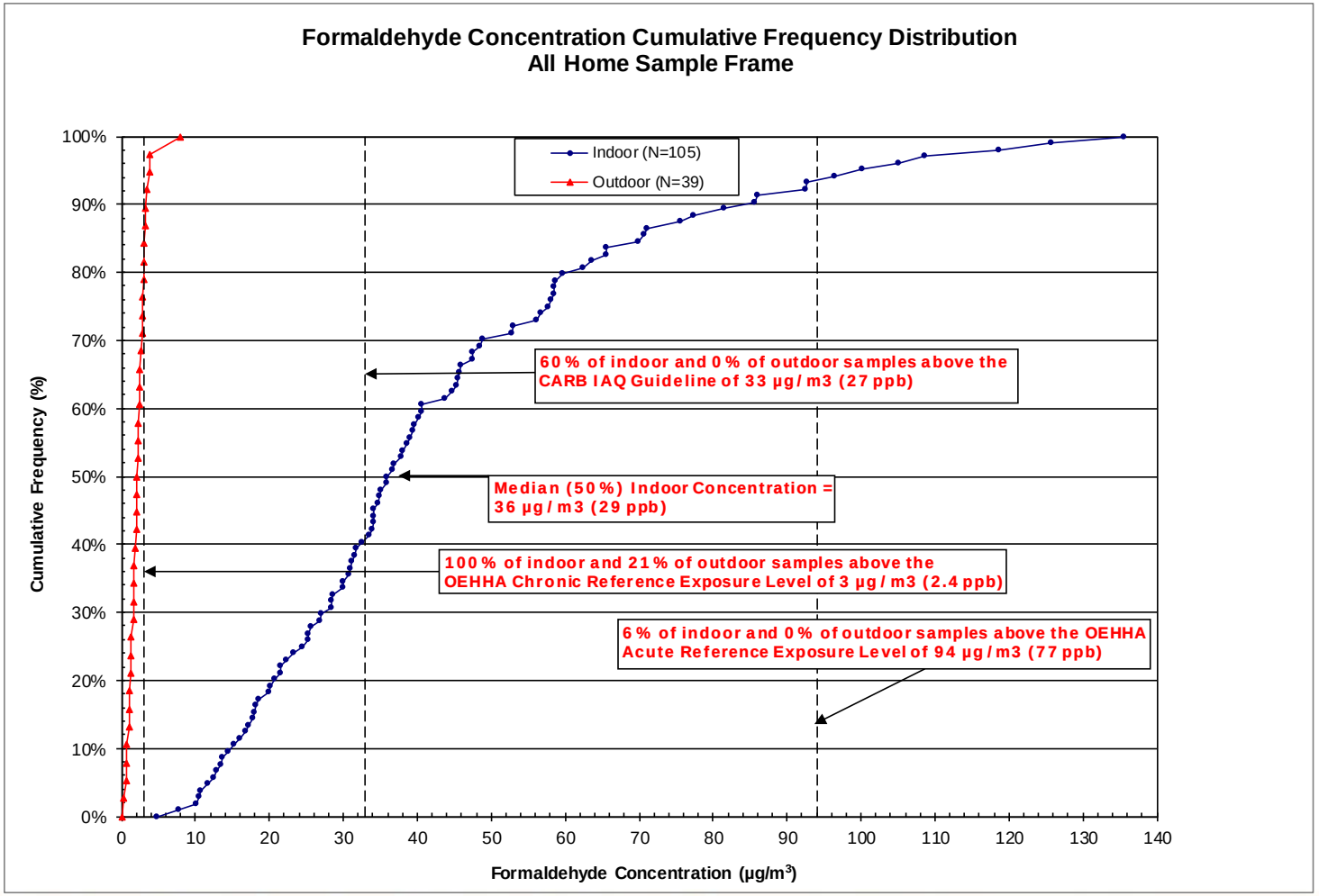
RESULTS – Formaldehyde Concentrations

Compound	Number of Homes Tested	Minimum Concentration ($\mu g/m^3$)	Median Concentration ($\mu g/m^3$)	Maximum Concentration ($\mu g/m^3$)	Indoor Air Guideline ($\mu g/m^3$)	Percentage Above Indoor Air Guideline (%)
Formaldehyde	105	4.8	36	136	2 [a]	100
					9 [b]	98
					9 [c]	98
					33 [d]	59
					55 [e]	28
Acetaldehyde	105	1.9	20	102	4.5 [a]	93
					140 [b]	0
					300 [c]	0
					470 [e]	0

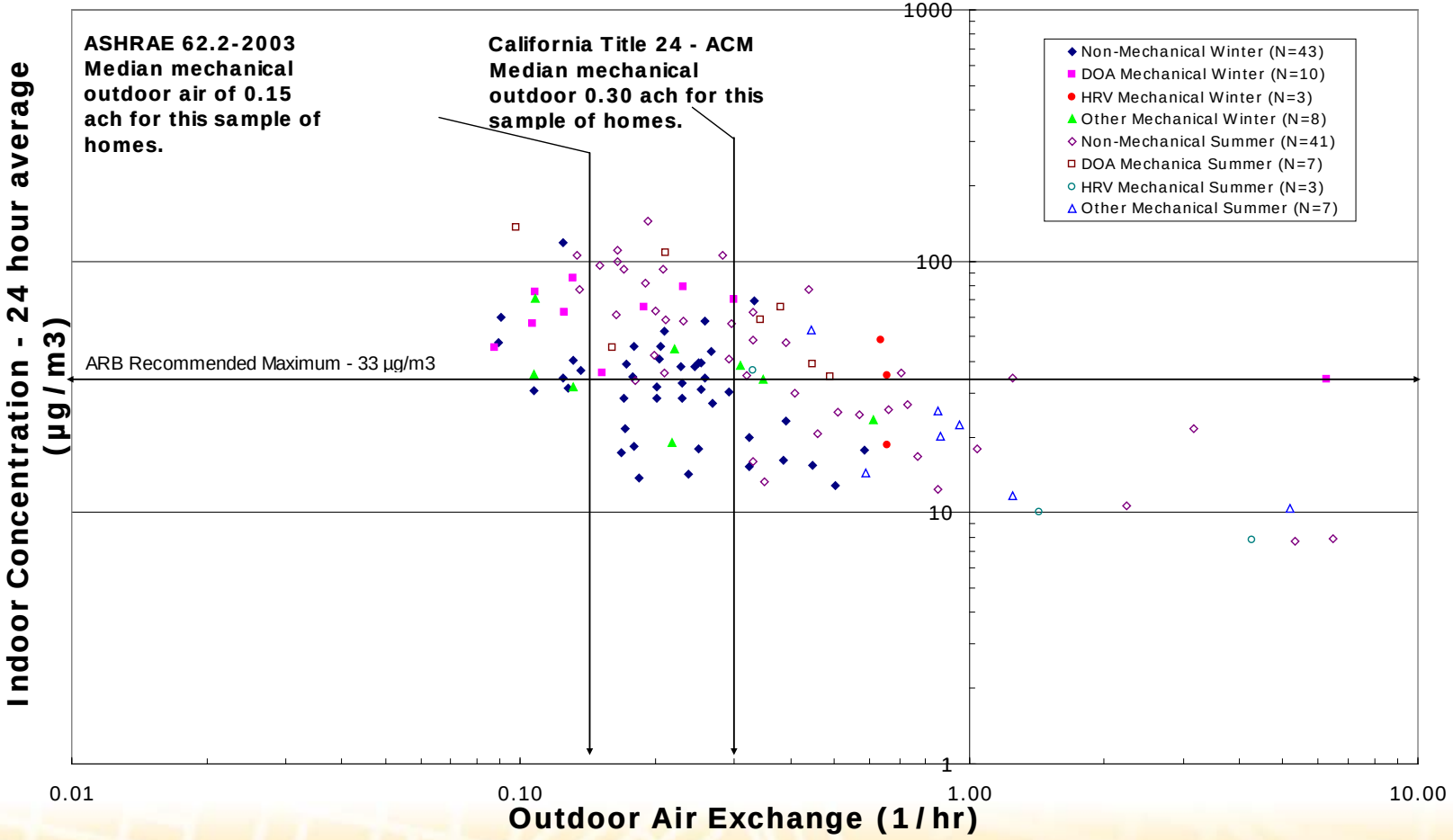
a) Proposition 65 No Significant Risk Level for carcinogens (OEHHA 2008a).
b) Office of Environmental Health Hazard Assessment Chronic Reference Exposure Levels, 2008 (OEHHA 2008b). Adopted after study completed.
c) OEHHA 8-hour Reference Exposure Levels, 2008 (OEHHA 2008b). Adopted after study completed.
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.

3.9 – 111 ppb
Median 29 ppb

RESULTS – Formaldehyde Concentrations



RESULTS - Formaldehyde Concentrations and Ventilation



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

Offerman, F.J. (2009). *Ventilation and indoor air quality in new homes.* Retrieved from California Environmental Protection Agency Air Resources Board website: http://www.arb.ca.gov/research/apr/past/04-310.pdf

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 ^{o}C – 23.7 ^{o}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/m^3 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 (r^2) 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

	Emission Rates ($\mu g/m^3$-h)			Linear Slope		
	Low VR	Med. VR	High VR	($\mu g/m^3$-h)/ach	r^2	R_a/R_p
Formaldehyde	16.9	24.4	31.2	32.4	0.96	0.59
Texanol	5.11	5.55	7.41	5.55	0.92	0.78
Phenol	1.46	1.87	2.55	2.52	0.98	0.64
Hexadecane	0.74	0.84	1.10	0.86	0.92	0.76
Tetradecane	1.99	1.92	2.31	0.84	0.76	0.92
d-Limonene	3.29	2.01	1.48	-3.95	0.91	1.27
Dodecane	7.85	6.43	6.18	-3.53	0.78	1.10
Toluene	2.62	1.84	1.15	-3.31	0.94	1.27

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.

Offermann, F. J., Maddalena R. L., Offermann F. J., Singer B. C., & Willem H. (2012). The impact of ventilation rate on the emission rates of volatile organic compounds in residences. *Healthy Buildings 2012 - 10th International Conference*

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