

Ventilation and Indoor Air Quality in New California Homes

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- **IAQ Diagnostics/Mitigation in over 2000 Buildings (25 years - 2007)**



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HYPOTHESIS

- 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 know 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}

CO₂

CO

T

RH

Flow
Control

Power
Surveillance

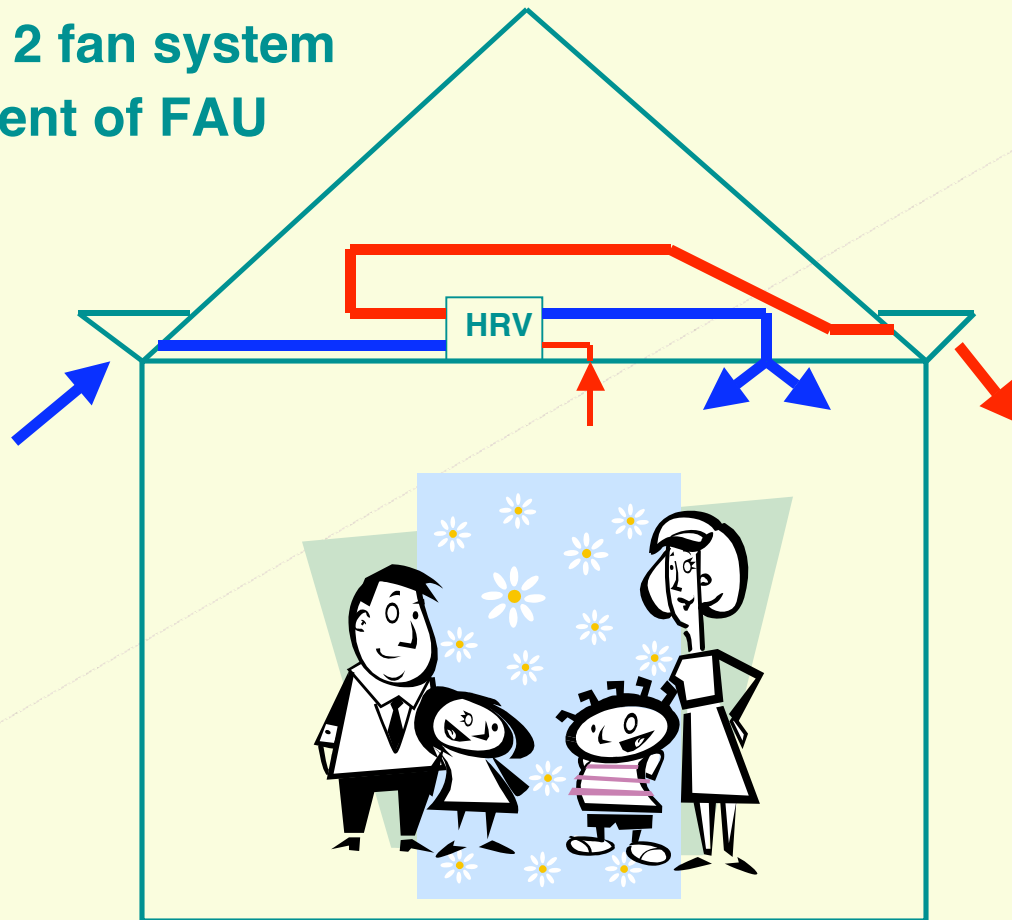


Field Session Recruits

- 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

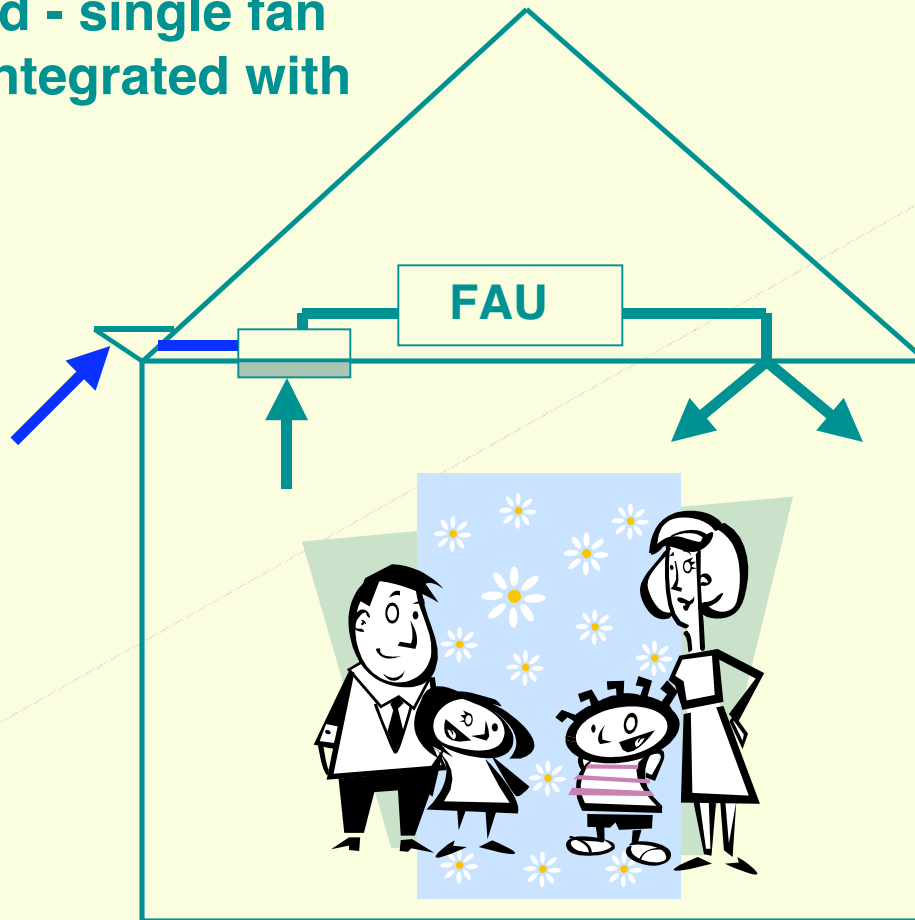
Heat Recovery Ventilator (HRV) System (9 homes)

Balanced 2 fan system
independent of FAU



Ducted Outdoor Air (DOA) System (17 homes)

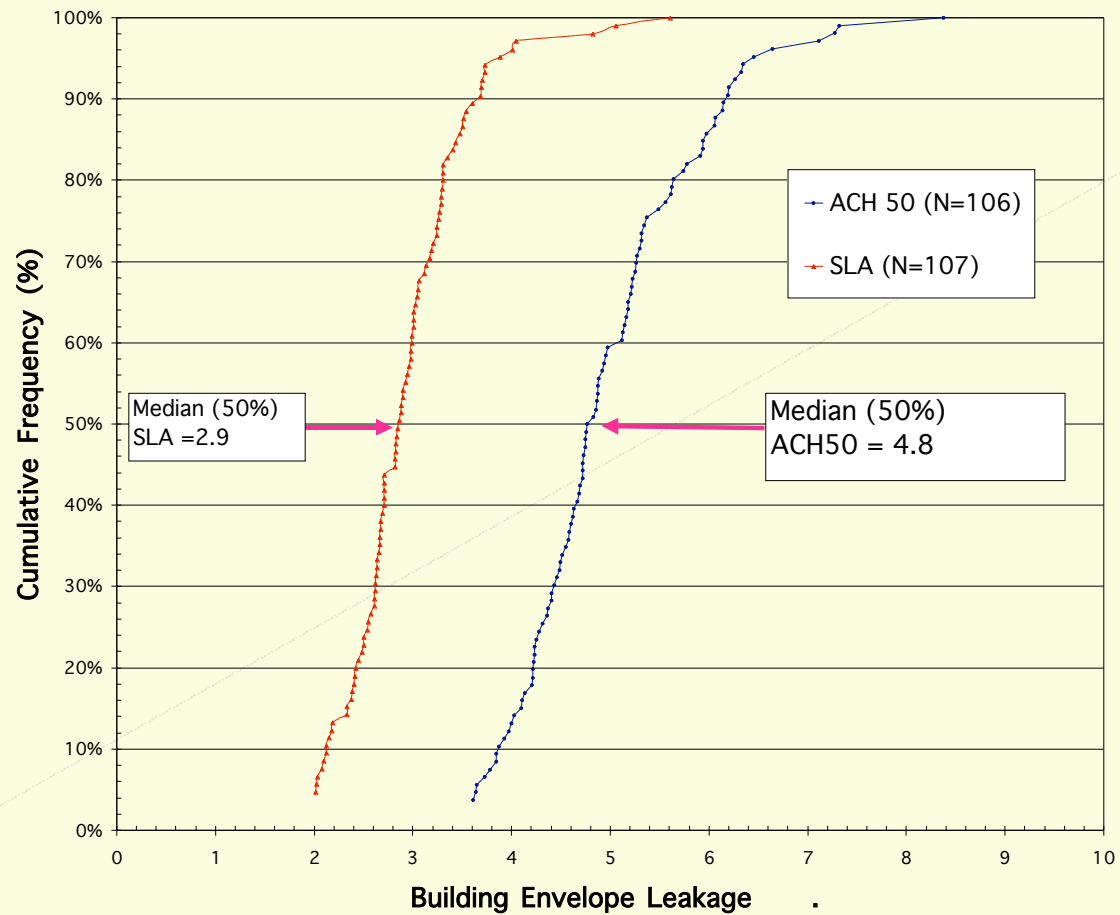
Unbalanced - single fan
system – integrated with
FAU



RESULTS - Window/Door Usage

- 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%)

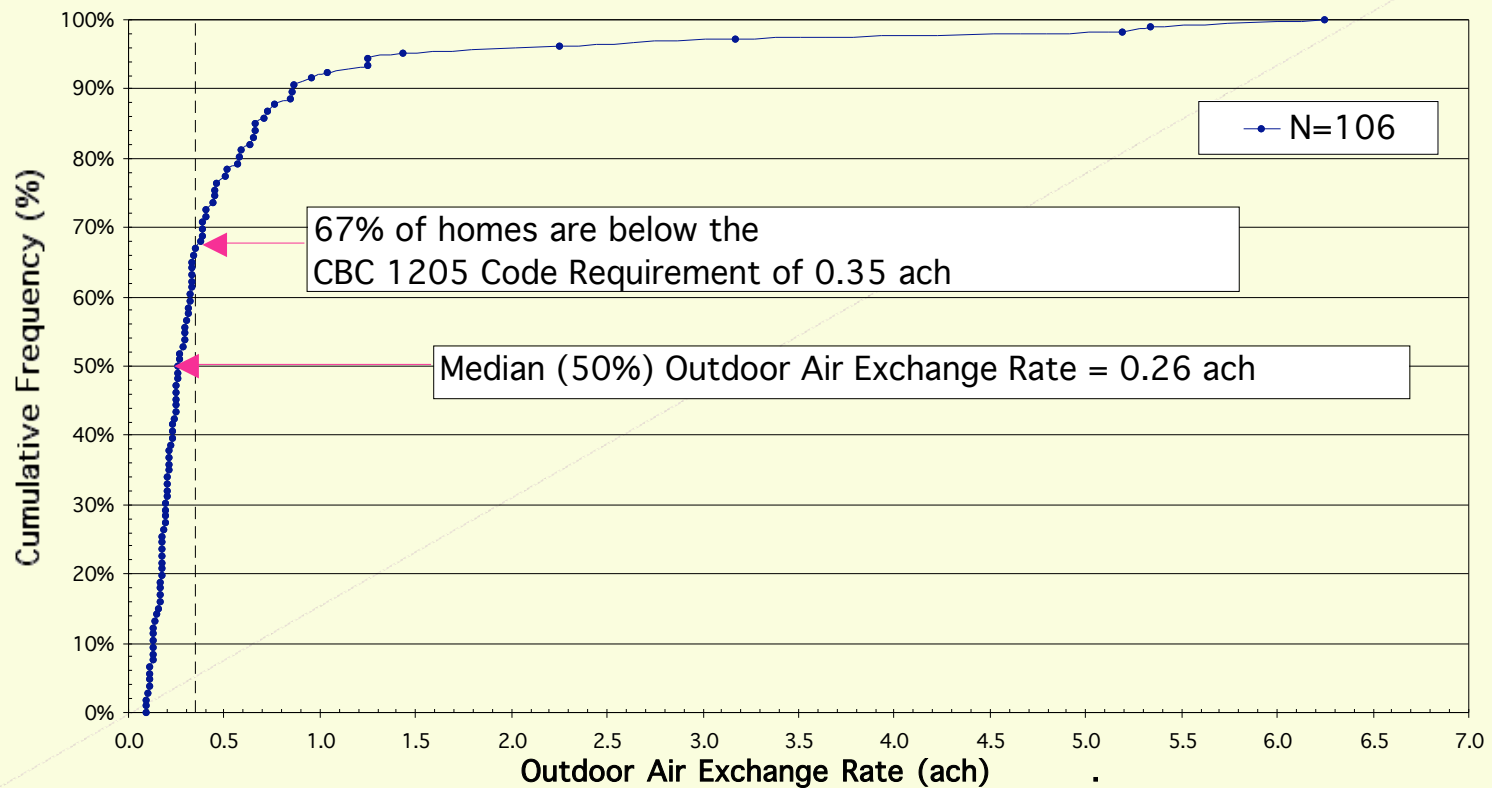
RESULTS - Building Envelope Leakage



RESULTS - Mechanical Outdoor Air System Performance

Quartiles	DOA Mechanical Outdoor Air Homes (n=16)			HRV Mechanical Outdoor Air Homes (n=8)		
	h ⁻¹	% on time	m ³ /hr	h ⁻¹	% on time	m ³ /hr
Minimum	0.00	0	15	0.12	32	112
25%	0.01	1.3	44	0.22	90	192
50%	0.02	8.6	65	0.30	100	218
75%	0.03	25	93	0.44	100	255
Maximum	0.08	90	603	0.47	100	270

RESULTS - Outdoor Air Exchange Rates - PFT Measurements



RESULTS - Indoor Air Contaminant Concentration Guidelines

- ARB Indoor Air Guidelines
- OEHHA Chronic and Acute Reference Exposure Levels
- Proposition 65 Safe harbor Levels
 - No Significant Risk Levels (NSRL)- carcinogenic risk of 1 excess case of cancer / 100,000 population
 - Maximum Allowable Dose Levels (MADL) - reproductive toxicity
- 1/40th the 8-hour occupational health guideline (i.e. Cal/OSHA PEL's, ACGIH TLVs, DFG MAKs).

RESULTS - Indoor Air Contaminant Concentration Guidelines

- 20 Volatile organic compounds: OEHHA Chronic Reference Exposure Levels (CREL) or 1/40th the 8-hour occupational health guidelines (i.e. Cal/OSHA PEL's, ACGIH TLVs, DFG MAKs).
- Acetaldehyde: CREL - 9 $\mu\text{g}/\text{m}^3$
- Formaldehyde:
 - CREL - 3 $\mu\text{g}/\text{m}^3$
 - ARB Indoor Air Guideline - 33 $\mu\text{g}/\text{m}^3$
 - OEHHA Acute Reference Exposure Level (AREL) 94 $\mu\text{g}/\text{m}^3$

RESULTS - Indoor Air Contaminant Concentration Guidelines

- Particulate Matter (PM_{2.5}):
 - ARB Indoor Air Guideline (24 hr) - 65 $\mu\text{g}/\text{m}^3$
 - EPA Outdoor Air Guideline (24 hr) - 35 $\mu\text{g}/\text{m}^3$
- Nitrogen Dioxide:
 - ARB Indoor Air Guideline (24 hr) - 150 $\mu\text{g}/\text{m}^3$
- Carbon Monoxide:
 - ARB Indoor Air Guideline (8 hr) - 9 ppm
 - ARB Indoor Air Guideline (1 hr) - 20 ppm

RESULTS - PM_{2.5}, NO₂, and CO Concentrations

- Particulate Matter (PM_{2.5}):
 - 0 % exceed ARB Indoor Air Guideline (24 hr)
 - 1% exceed EPA Outdoor Air Guideline (24 hr)
- Nitrogen Dioxide:
 - 0% exceed ARB Indoor Air Guideline (24 hr)
- Carbon Monoxide:
 - 0% exceed ARB Indoor Air Guideline (1 hr)
 - 0% exceed ARB Indoor Air Guideline (8 hr)

RESULTS - Volatile Organic Compound Indoor Concentrations

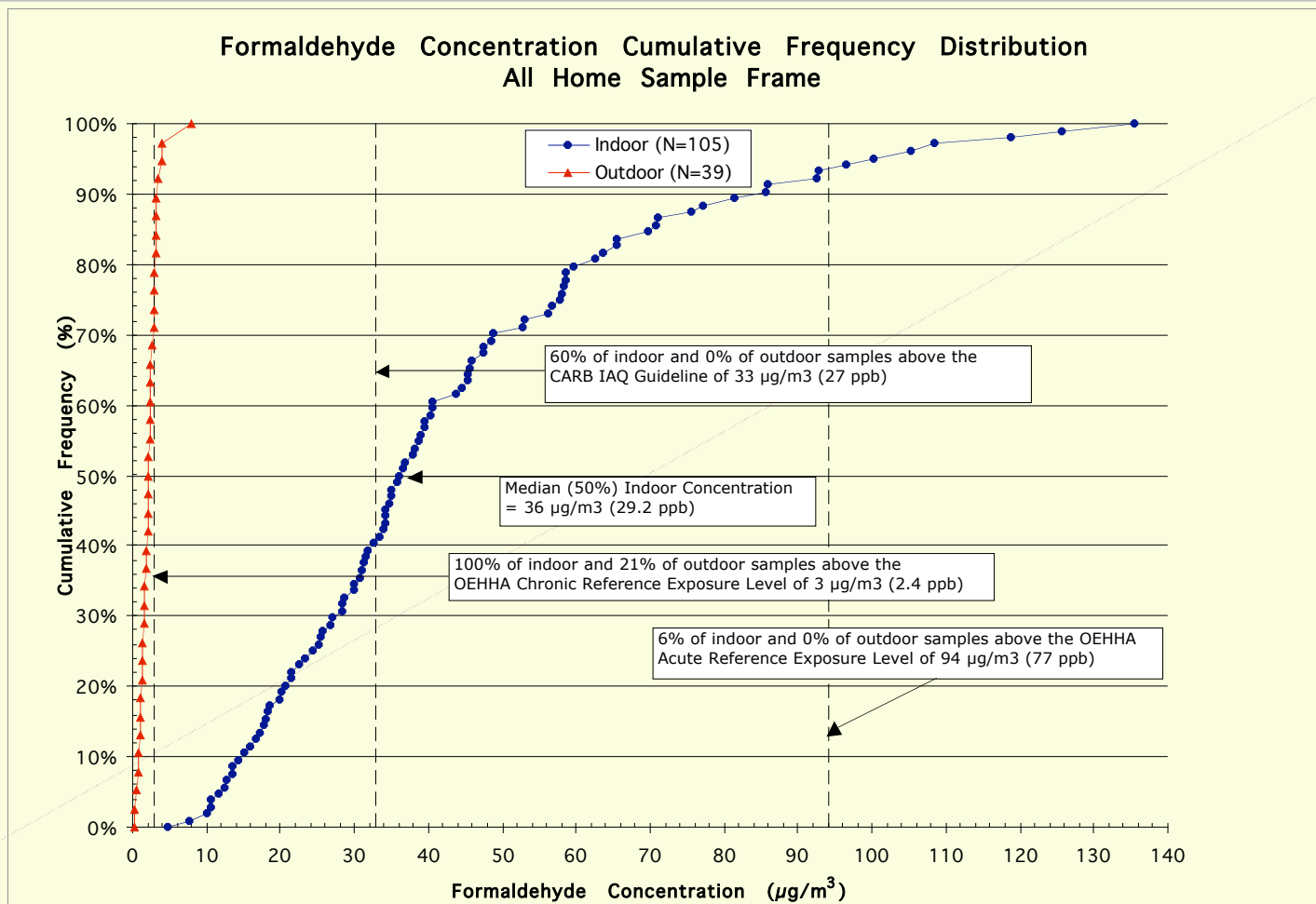
- Volatile Organic Compounds
 - All 20 compounds were below CREL or 1/40th the 8-hour occupational health guidelines
- Acetaldehyde
 - 82 % exceed the CREL ($9 \mu\text{g}/\text{m}^3$)
- Formaldehyde
 - 100 % exceed the CREL ($3 \mu\text{g}/\text{m}^3$)
 - 59 % exceed the ARB Guideline ($33 \mu\text{g}/\text{m}^3$)
 - 6.7% exceed the AREL ($94 \mu\text{g}/\text{m}^3$)

RESULTS - Volatile Organic Compound Indoor Concentrations

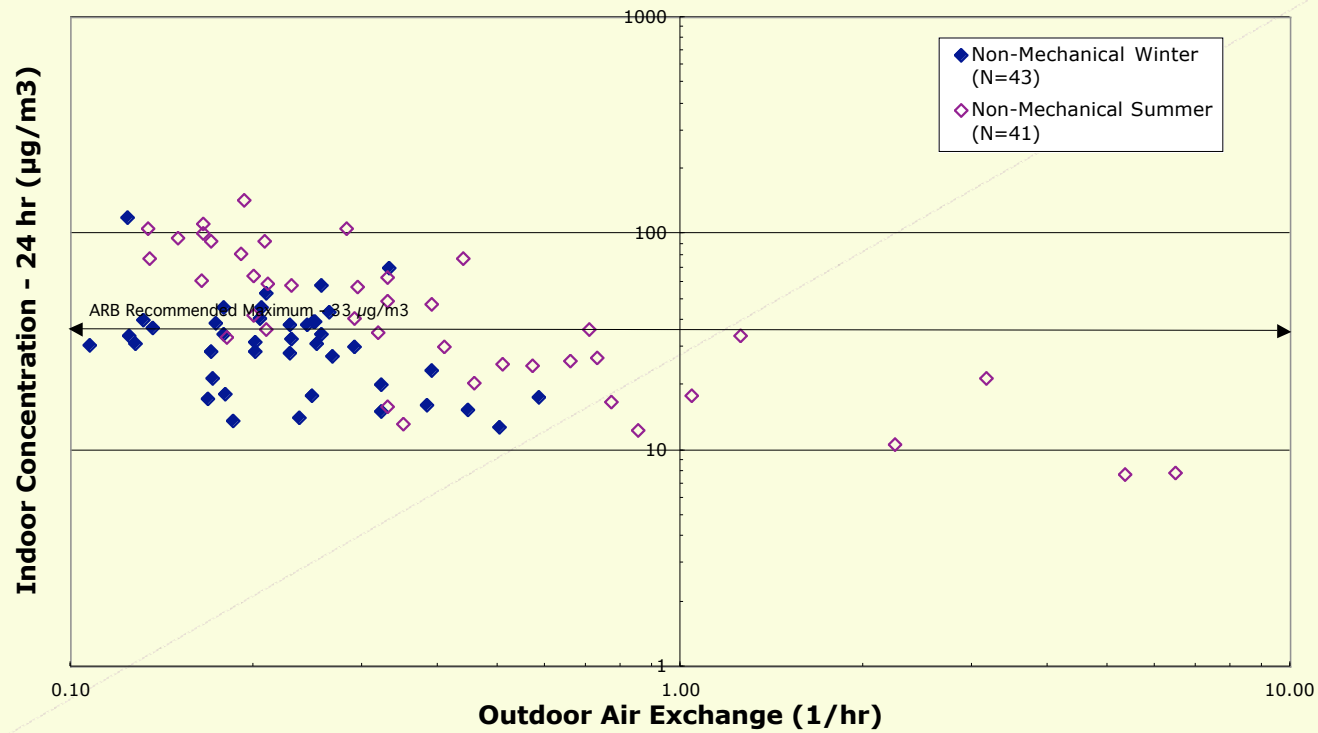
Compound	NSRL Concentration ($\mu\text{g}/\text{m}^3$)	Percentage of Homes Exceeding NSRL	MADL Concentration ($\mu\text{g}/\text{m}^3$)	Percentage of Homes Exceeding MADL
Formaldehyde	2.0	100	-	-
Acetaldehyde	4.5	93	-	-
Benzene	0.7	63	2.5	20
1,4-Dichlorobenzene	1.0	12	-	-
Naphthalene	0.3	27	-	-
Tetrachloroethene	0.70	8	-	-
Toluene	-	-	350	0
Trichloromethane	2.0	8	-	-

Inhalation concentrations calculated from the Proposition 65 NSRL and MADL values of $\mu\text{g}/\text{day}$ divided by $20 \text{ m}^3/\text{day}$ (24 hour respiration volume).

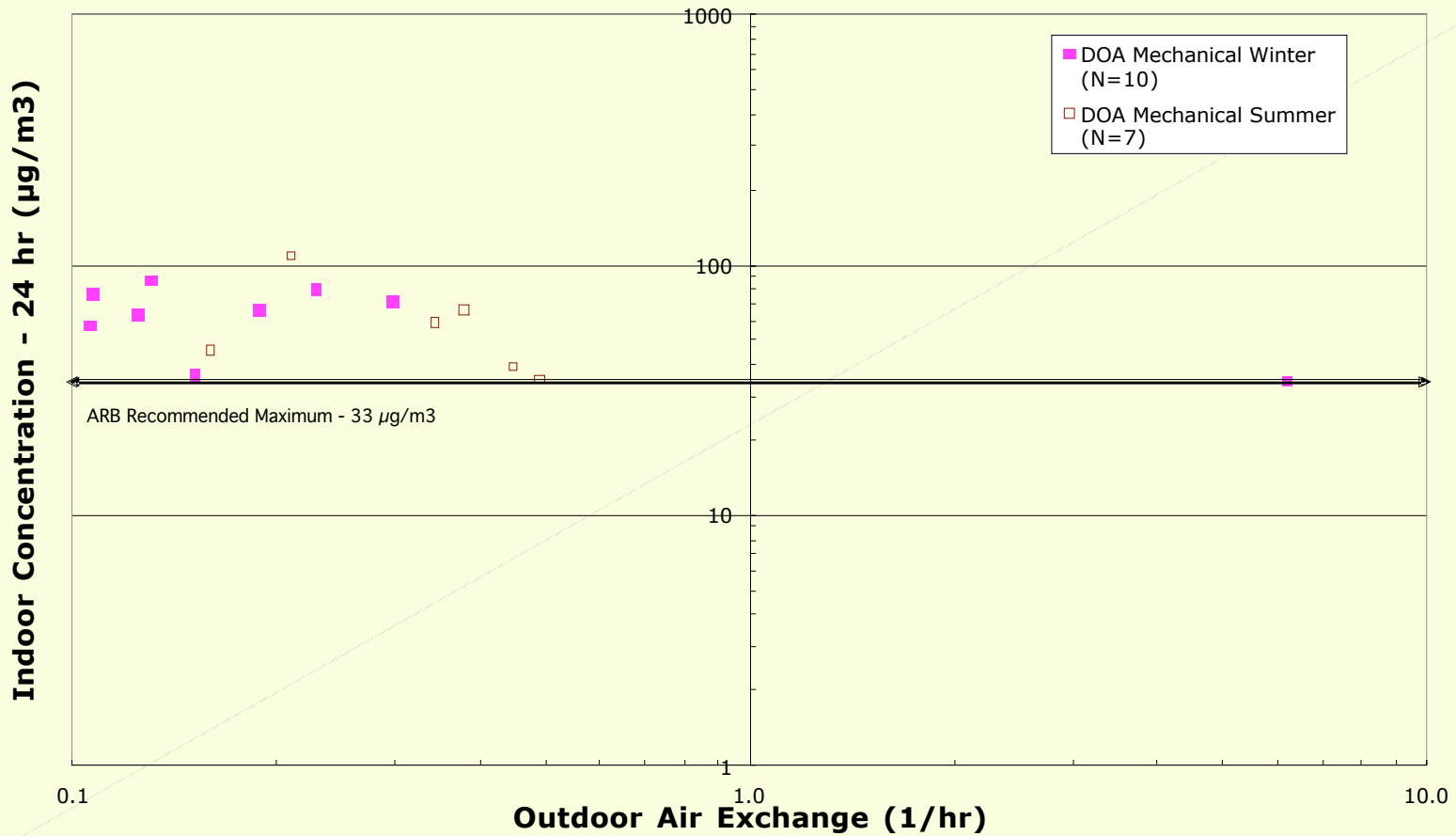
RESULTS – Formaldehyde Concentrations



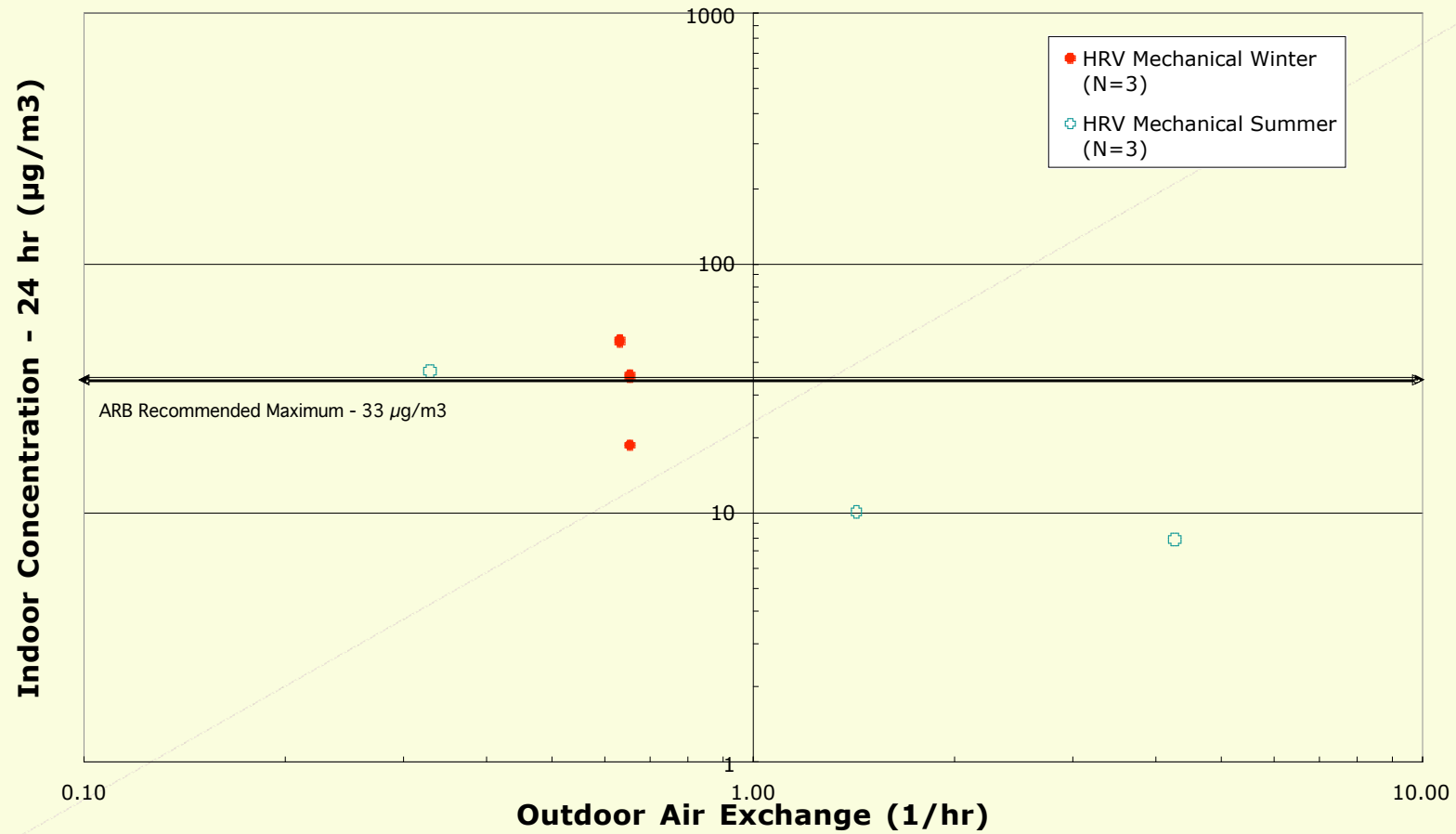
RESULTS - Formaldehyde Concentrations and Ventilation



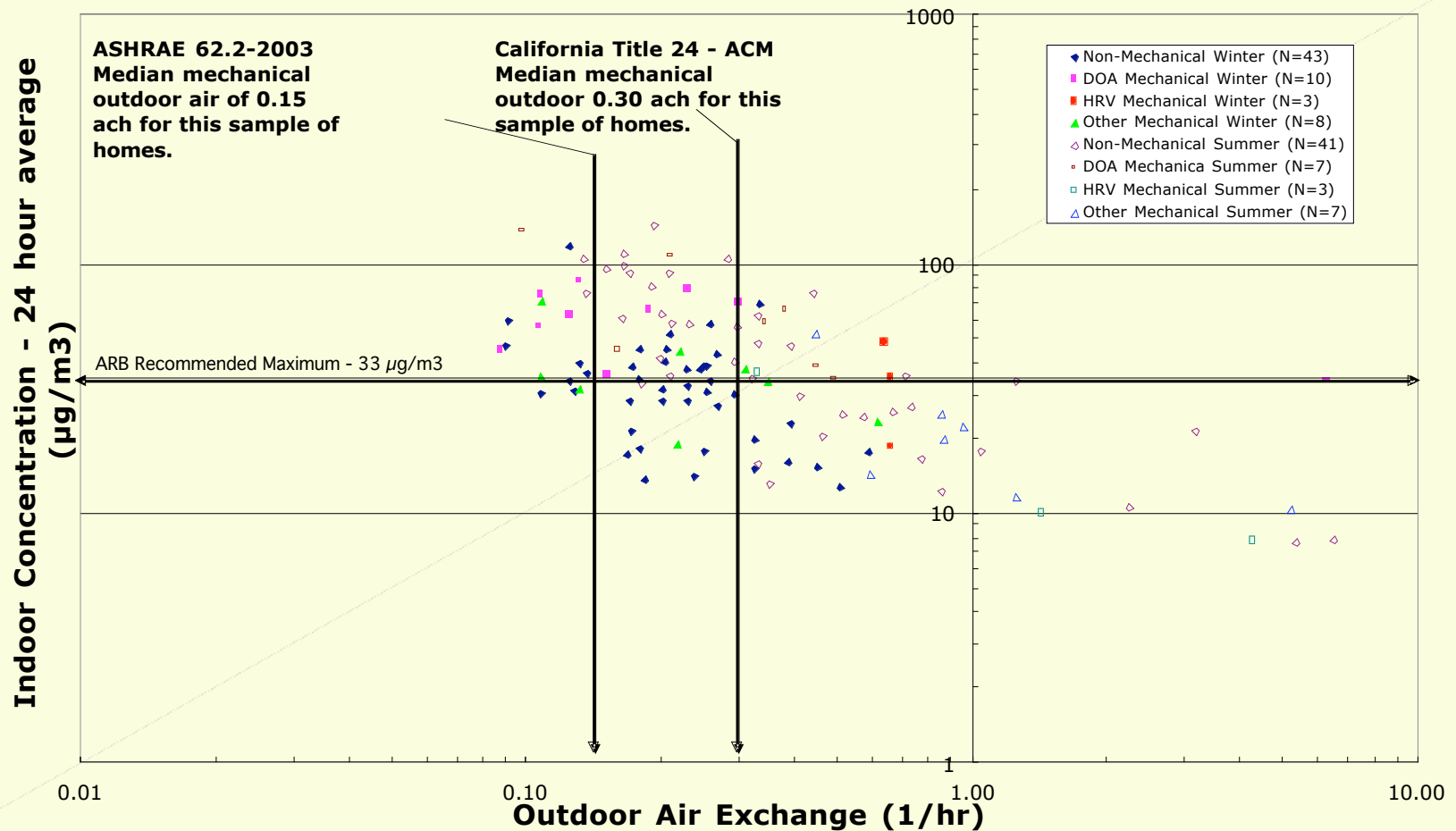
RESULTS - Formaldehyde Concentrations and Ventilation



RESULTS - Formaldehyde Concentrations and Ventilation



RESULTS - Formaldehyde Concentrations and Ventilation



Conclusions

- We conclude that the new single-family detached homes in California are built relatively tight (i.e. 50% of the homes had an $ACH_{50} < 4.8$).
- Many homeowners never open their windows or doors for ventilation, ranging from 6% in the Spring to 29% in the Winter.

Conclusions

- 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.
- 67% of the homes had outdoor air exchange rates below the minimum CBC 1205 code requirement of 0.35 ach.

Conclusions

• Acetaldehyde

- 93 % exceed the cancer NSRL ($4.5 \mu\text{g}/\text{m}^3$)
- 82 % exceed the irritant CREL ($9 \mu\text{g}/\text{m}^3$)

• Formaldehyde

- 100 % exceed the cancer NSRL ($2 \mu\text{g}/\text{m}^3$)
- 100 % exceed the irritant CREL ($3 \mu\text{g}/\text{m}^3$)
- 59 % exceed the ARB Guideline ($33 \mu\text{g}/\text{m}^3$)
- 6.7 % exceed the irritant AREL ($94 \mu\text{g}/\text{m}^3$).

Conclusions

- **Benzene**

- 63 % exceed the cancer NSRL ($0.7 \mu\text{g}/\text{m}^3$)
- 20 % exceed the reproductive toxicity MADL ($2.5 \mu\text{g}/\text{m}^3$)

- **1,4-Dichlorobenzene**

- 12 % exceed the cancer NSRL ($1 \mu\text{g}/\text{m}^3$)

- **Naphthalene**

- 27 % exceed the cancer NSRL ($0.3 \mu\text{g}/\text{m}^3$)

Conclusions

- **Tetrachloroethene**
 - 8 % exceed the cancer NSRL ($0.7 \mu\text{g}/\text{m}^3$)
- **Trichloromethane (chloroform)**
 - 8 % exceed the cancer NSRL ($2 \mu\text{g}/\text{m}^3$)

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.
- The indoor air contaminant measured in this study that most frequently exceeded recommended indoor air quality guidelines was formaldehyde.

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.
- 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

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