Ventilation and Indoor Air Quality in New Homes

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Acknowledgements

Study Sponsors

- California Energy Commission
- Public Interest Environmental Research Program
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Expert Advisory Panel

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- Berkeley Analytical Associates
- Brookhaven National Laboratory
- DataChem
- Chester Labs

Participants

- 108 extremely accommodating homeowners

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 Objectives

- Determine how residents use windows, doors, and mechanical ventilation devices, such as exhaust fans and central heating and air-conditioning systems.
- Measure and characterize indoor air quality (IAQ), ventilation, and the potential sources of indoor pollutants.
- Determine occupant perceptions of, and satisfaction with, the IAQ in their homes.
- Examine the relationships among home ventilation characteristics, measured and perceived IAQ, and house and household characteristics.

Study Objectives

- Identify the incentives and barriers that influence people's use of windows, doors, and mechanical ventilation devices for adequate air exchange.
- Identify the incentives and barriers related to people's purchases and practices that improve IAQ, such as the use of low-emitting building materials and improved air filters.

This presentation will focus on the window and ventilation system usage, envelope tightness, outdoor air exchange rates, mechanical outdoor system performance, and indoor air contaminant concentrations.

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.
- The recruitment rate was 2% from mailers and 13% from phone calls involving 10 communities in Northern, CA and 10 communities in Southern, CA.

Field Team Assignments

- **Field Team 1 (Day 1)**

  - installed PFT sources

  - installed dataloggers on windows and fans

  - administered the Indoor Contaminant Source Activity Sheet and the Occupant Questionnaire.

- **Field Team 2 (Day 7)**

  - installed the air sampling equipment

  - collected information on home construction characteristics and indoor air contaminant sources.

Field Team Assignments

- **Field Team 3 (Day 8)**

  - collected the air sampling equipment, the PFT samplers, and window/door and fan logs and loggers

  - measured building envelope air leakage, garage-home air leakage, duct air leakage, and ventilation system air flow rates.

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.

Ventilation Measurements

Window Opening Data Logger

Ventilation Measurements

Flow Hood Measurement of Air Flow Rates

Building Envelope Air Leakage Measurements

- **Building Envelope Air Leakage**

  - multipoint blower door depressurization test (ASTM E779-03)

- **Garage to Home Air Leakage**

  - blower door tests with and without the garage to home door closed

Building Envelope Air Leakage Measurements

Blower Door with Computer Automated Test System

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

  - outdoor air exchange rate calculated from mass of tracer collected, tracer emission rate, and home air volume (ASTM E741-00)

Volatile Organic Compound Measurements - 24 hour

- A low noise active air sampler was used to collect the integrated 24 hour samples of volatile organic compounds, including formaldehyde/acetaldehyde.
- Formaldehyde/acetaldehyde - ASTM Standard D5197-03 utilizing a solid sorbent cartridge (DNPH).
- Detection limit of 0.7 $\mu g/m^3$.

Volatile Organic Compound Measurements - 24 hour

- 20 additional volatile organic compounds - EPA Method TO-17 using multi-sorbent samplers.
- Detection limit of 0.1 - 0.4 µg/m^3 for most compounds.

Nitrogen Dioxide and PM2.5 Particulate Matter - 24 hour

- Nitrogen dioxide concentrations - NIOSH 6014.
- Particulate matter ($PM_{2.5}$) - NIOSH 500.

Carbon Monoxide - continuous

- Carbon monoxide - real time instrumentation following EPA Method IP-3A.

Quiet Active Indoor Air Sampler

- HCHO
- VOC's
- $PM_{2.5}$
- CO_2
- CO
- T
- RH
- Flow Control
- Power Surveillance

Shielded Outdoor Air Sampler

Rain/Radiation Shield

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

Field Session Recruits

Mechanical Outdoor Air Systems

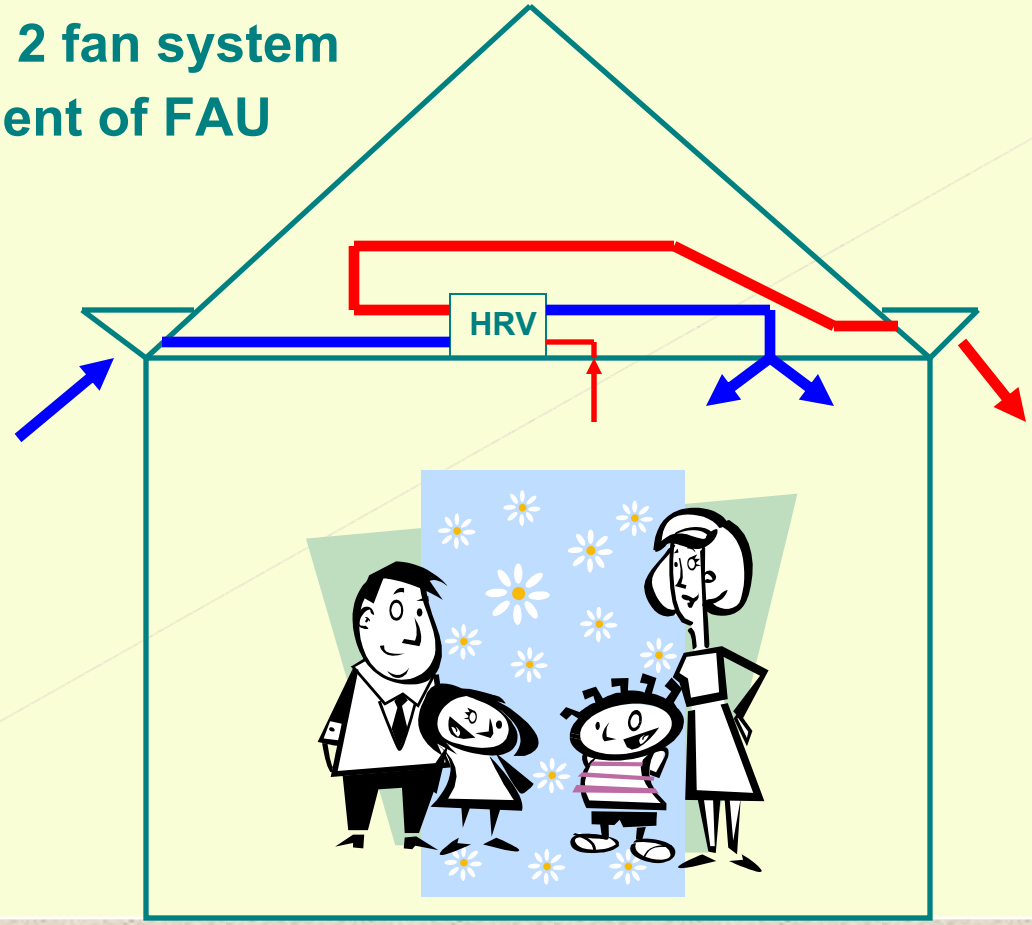
• There were two types of mechanical outdoor air systems:

- Heat Recovery Ventilators (HRV) with fully ducted exhaust air and outdoor air ducts which operated separately from the FAU.

- Ducted outdoor air systems (DOA) with outdoor air ducts connected to the FAU return duct (i.e. the outdoor air duct is typically installed in the hall way central return air inlet filter housing cabinet).

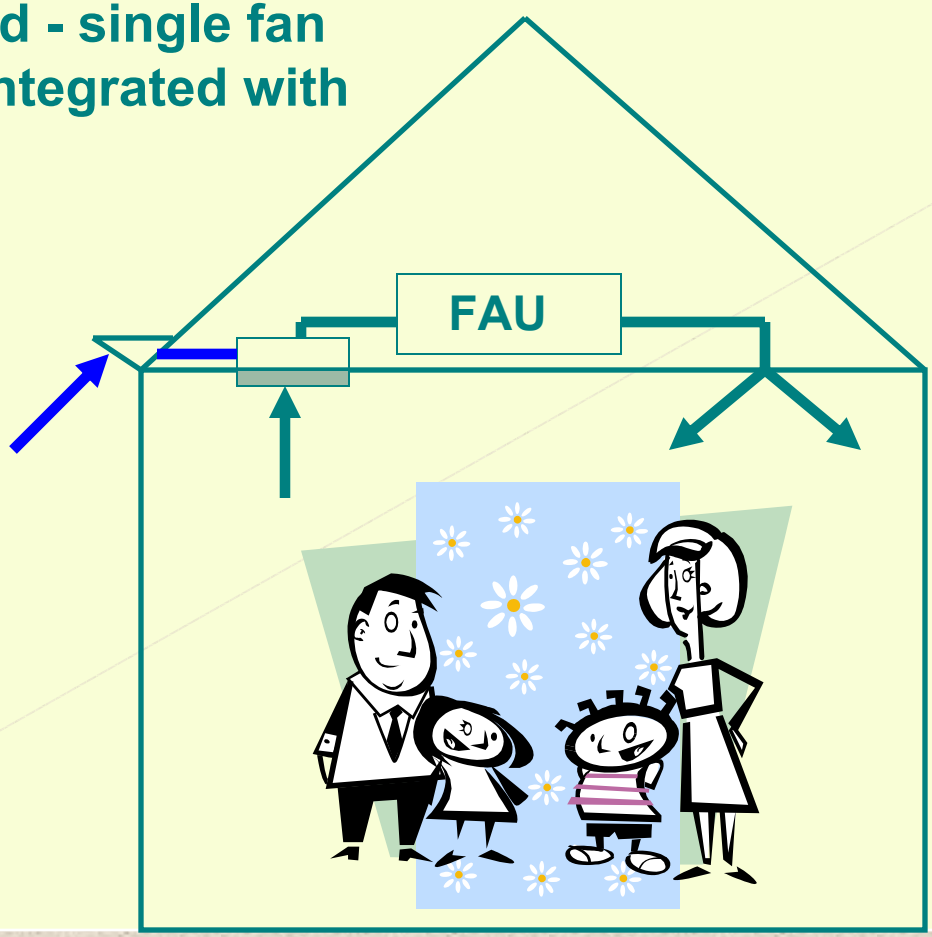
Heat Recovery Ventilator (HRV) System

Balanced 2 fan system independent of FAU



Ducted Outdoor Air (DOA) System

Unbalanced - single fan system – integrated with FAU



Field Session Recruits

HRV Mechanical Outdoor Air Systems

- 9 homes had a Heat Recovery Ventilators (HRVs).
- Of these 9, 6 homes were pure HRV's (without other mechanical outdoor air systems, e.g. nighttime cooling systems, window fans).
- The controls consisted of manual on/off switches.

Field Session Recruits

DOA Mechanical Outdoor Air Systems

- 17 homes with DOA systems.
- These homes were all pure DOA systems (without other mechanical outdoor air systems, e.g. nighttime cooling systems, window fans).

Field Session Recruits

DOA Mechanical Outdoor Air Systems

- 81% controlled by the thermostat fan switch and 19% controlled by a combination of thermostat and a fan cycler.
- Each of the DOA systems controlled by thermostats had the fan switch in the “auto” position with the mode switch in the “cooling/heating/auto” operational mode except for one system where the mode switch was set for “off”.
- With the fan switch in the “auto” position and no fan cycler, outdoor air is introduced into the home only when the thermostat calls for heating or cooling.

Summer Field Session Recruits

Other Mechanical Outdoor Air Systems

- The remaining homes with mechanical outdoor air ventilation systems included:
  - 11 nighttime cooling systems
  - 1 evaporative cooling system, and
  - 1 window fan

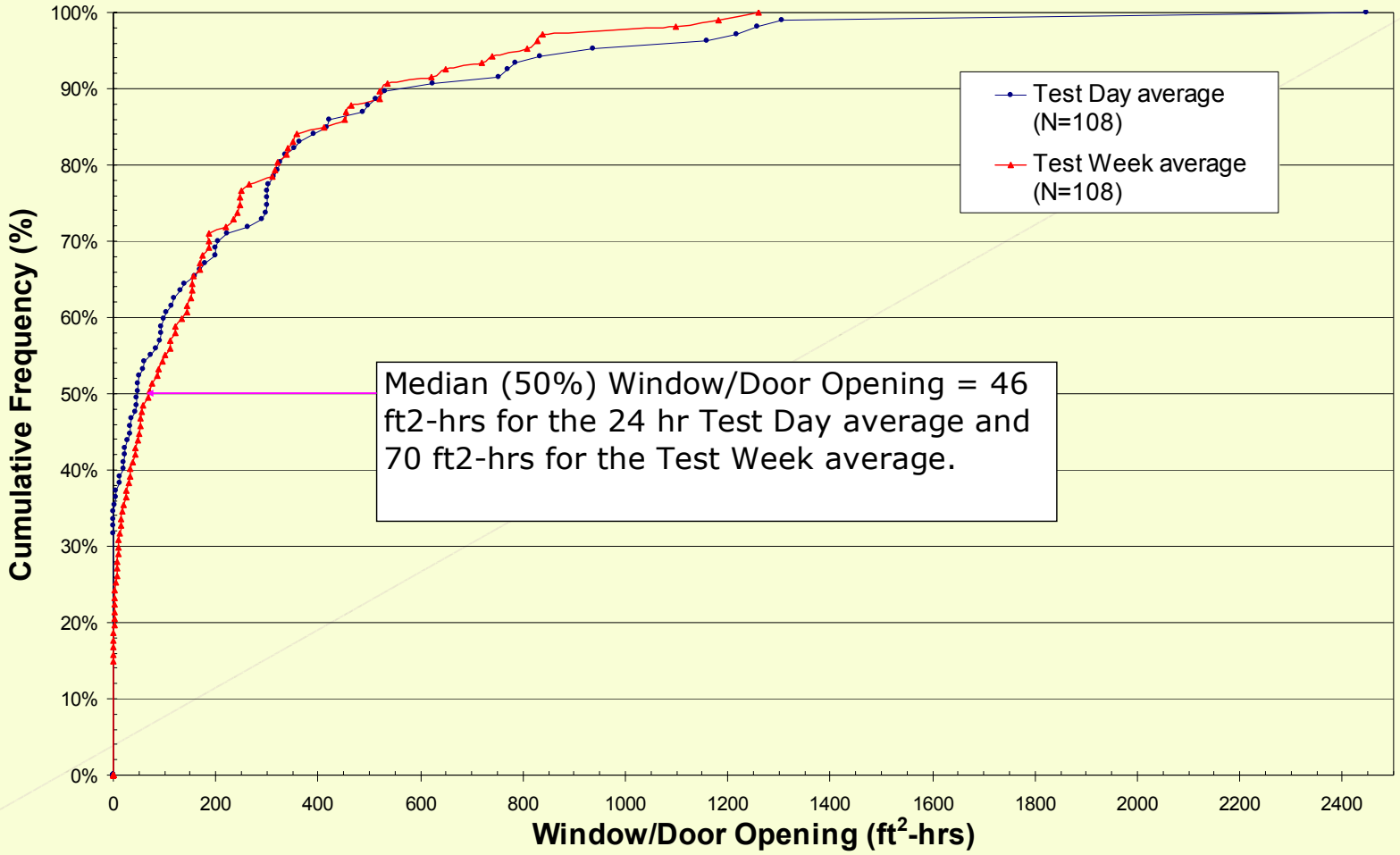
RESULTS – Homes with Low Window/Door Usage

UCB Mail Survey

	Percentage of Homes Surveyed Reporting No Use of Windows for the Indicated Number of Hours per Day (N=1,334)			
	24 hours/day	23 or more hours/day	22 or more hours/day	21 or more hours/day
Summer	7.5	9.1	12	14
Fall	8.6	12	16	18
Winter	29	36	45	47
Spring	5.8	5.8	8.4	12

RESULTS - Window/Door Usage

Field Mail Survey



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 during the test day were in the Winter field session (85%) and all of the homes with zero usage for the preceding week were in the Winter field session.

RESULTS - Exhaust Air System Usage

- Kitchen Range Hood Exhaust

  - median usage was 0.0 hrs (0.0 hrs 25th, 0.0 hrs 75th)

  - 80 % never used their kitchen exhaust fans during the test day

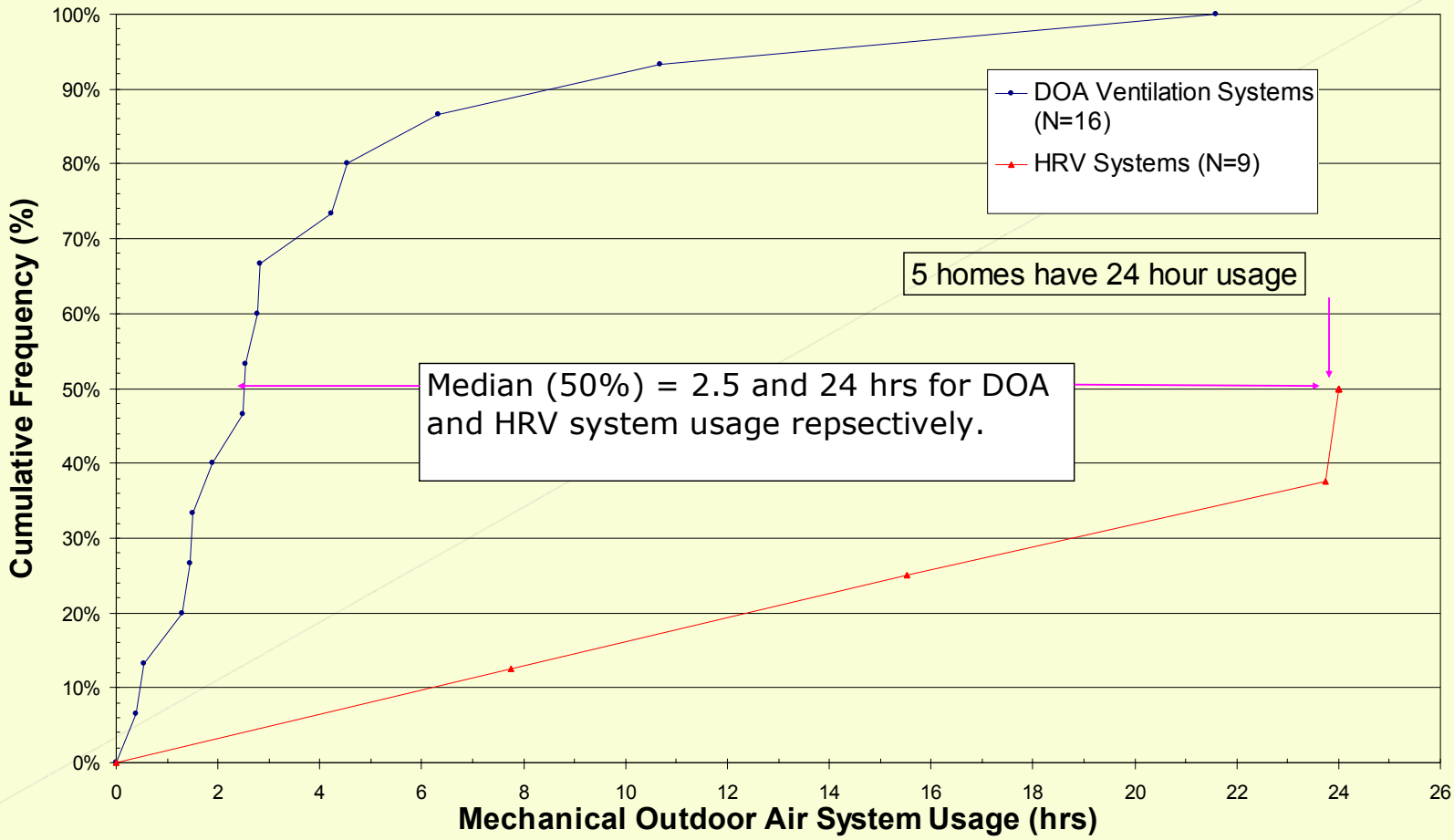
- Bathroom Exhaust

  - median usage was 0.05 hrs (0.0 hrs 25th, 0.7 hrs 75th)

- Other Exhaust Fans (clothes dryer, utility room)

  - median usage was 0.30 hrs (0.0 hrs 25th, 1.5 hrs 75th)

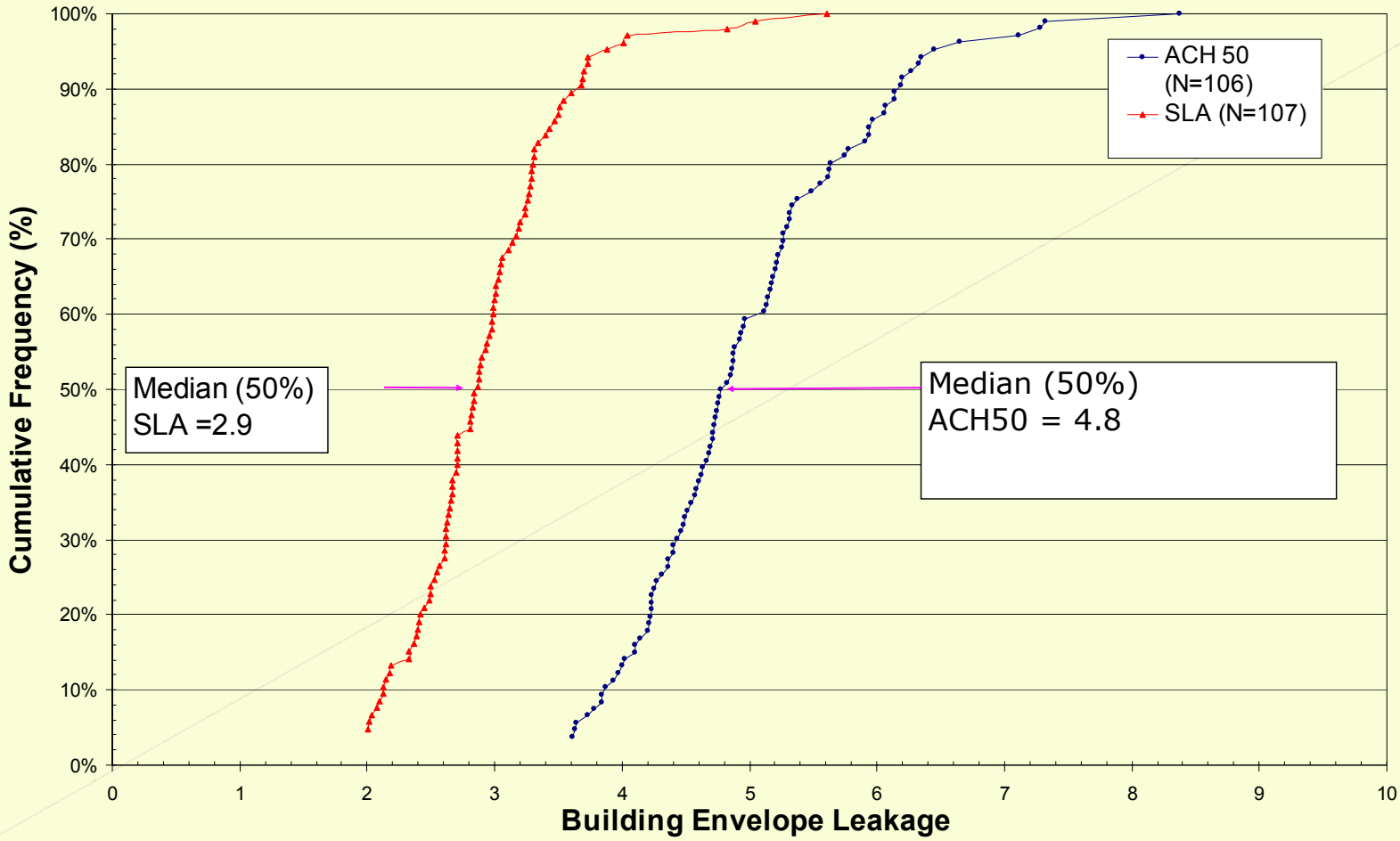
RESULTS - Mechanical Outdoor Air System Usage



RESULTS - Mechanical Outdoor Air System Performance

Variable	Min	50%	Max	% Homes Fail to Meet ASHRAE Guidelines	% Homes Fail to Meet Title 24 ACM Requirements
Ducted Outdoor Air Systems (DOA)				63	81
- 24 hr average outdoor air flowrate (ach)	0.00	0.01	0.08		
- 24 hr average fan ON time (%)	0.00	8.6	90		
- Outdoor air flowrate (cfm)	8.8	38	355		
Heat Recovery Ventilators, (HRV)				0	22
- 24 hr average outdoor air flowrate (ach)	0.12	0.30	0.47		
- 24 hr average fan ON time (%)	32	100	100		
- Outdoor air flowrate (cfm)	66	128	159		

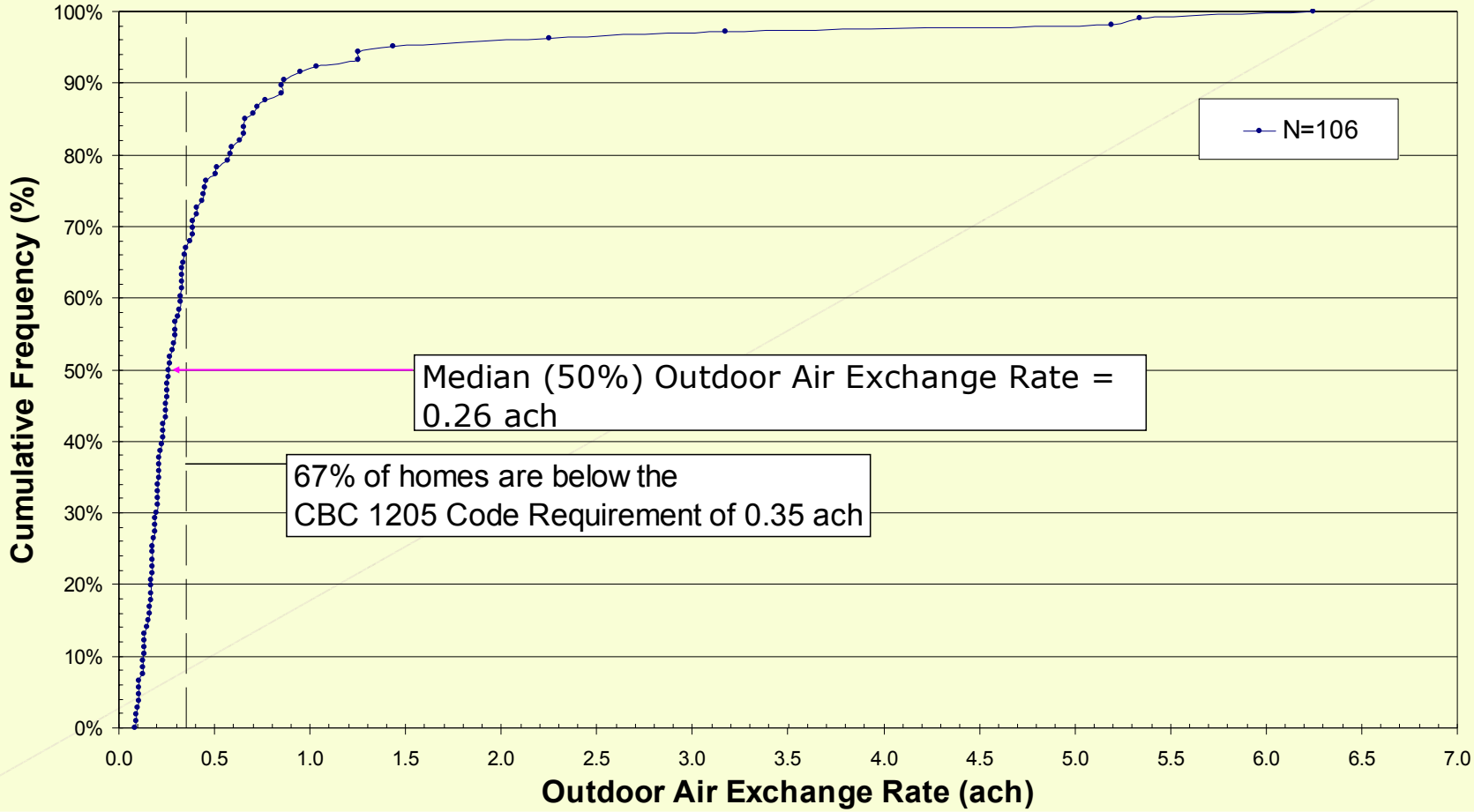
RESULTS - Building Envelope Leakage



RESULTS - Home to Garage Air Leakage

- A total of 65 % of the homes had a home to garage pressure of less then -49 pascals when the home was depressurized to -50 pascals with respect to outdoors (American Lung Association “Health House Builder Guidelines”).
- In the 3 home pilot study we measured with a tracer gas a transport of 4.0%, 7.2% and 11.3% of the garage air into the homes. These homes had home to garage pressures of -49.5, -49.4, and -49.8.

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 (MSDL) - reproductive toxicity
- 1/40th the 8-hour occupational health guideline (I.e. Cal/OSHA PEL's, ACGIH TLVs, DFG MAKs).

RESULTS - $PM_{2.5}$, NO_2, and CO Concentrations

- Particulate Matter ($PM_{2.5}$)
- Nitrogen Dioxide
- Carbon Monoxide

No homes exceeded ARB Indoor Air Guidelines except on home that exceeded the $PM_{2.5}$ guideline.

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 µg/m^3)

- Formaldehyde

  - 100 % exceed the CREL (3 µg/m^3)
  - 59 % exceed the ARB Guideline (33 µg/m^3)
  - 7% exceed the AREL (94 µg/m^3)

RESULTS - Volatile Organic Compound Indoor Concentrations

Compound	NSRL Concentration ($\mu g/m^3$)	Percentage of Homes Exceeding NSRL	MADL Concentration ($\mu g/m^3$)	Percentage of Homes Exceeding MADL
Formaldehyde	2.0	100	-	-
Acetaldehyde	9.0	93	-	-
Benzene	1.3	63	2.5	20
1,4-Dichlorobenzene	1.0	12	-	-
Naphthalene	0.29	27	-	-
Tetrachloroethene	0.70	8.4	-	-
Toluene	-	-	350	0
Trichloromethane	2.0	8.4	-	-
Inhalation concentrations calculated from the Proposition 65 NSRL and MADL values of μg/day divided by 20 m^3/day (24 hour respiration rate)				

California Residential Ventilation Requirements

- **California Building Code Section 1203.3**

- window/door openings greater than 5% of floor area, OR

- 15 cfm mechanical outdoor air per occupant (i.e. median of 0.18 ach in study homes, number of occupants equals # bedrooms)

- **California Building Code Section 1205 (Alternate)**

- 0.35 air changes per hour but not less than 15 cfm mechanical outdoor air per occupant

NOTE: Mechanical ventilation required if interior allowable noise levels require keeping windows closed (CBC Section 1208)

California Residential Ventilation Requirements

- **Title 24 ACM (existing)**

  - 0.047 cfm/ft^2, (i.e. median of 0.30 ach in study homes), required ONLY if taking credit for an SLA < 3.0.

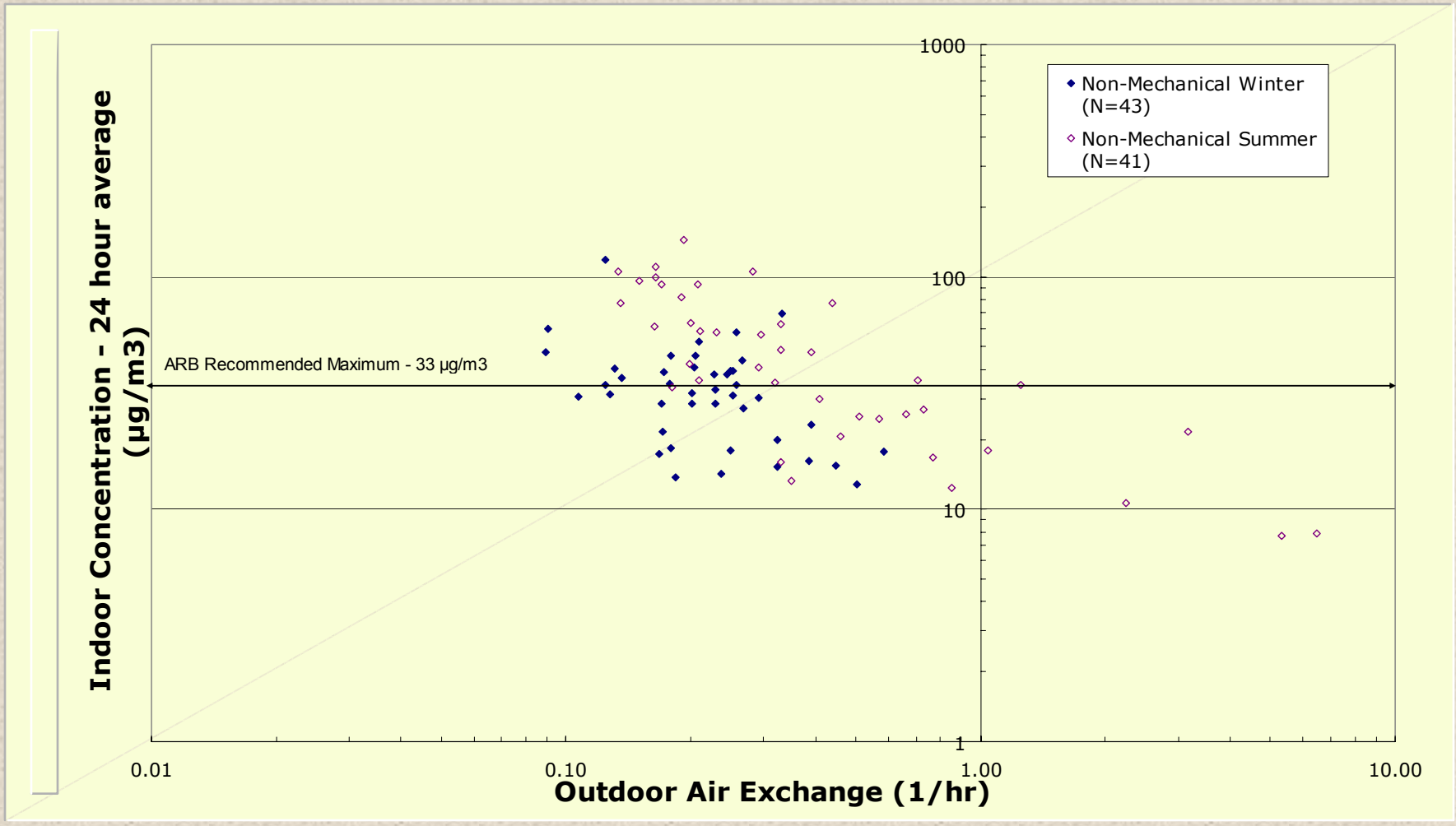
- **Title 24 (proposed 2008)**

  - will adopt ASHRAE 62.2, (i.e. median of 0.15 ach in study homes)

California Residential Ventilation Requirements

- NOTE: these mechanical outdoor air ventilation requirements do not include additional ventilation from natural infiltration.
- ASHRAE 62.2 assumes a natural ventilation rate of 2 cfm/100 ft^2 (i.e. 0.15 ach for homes with 8 ft ceilings).
- For homes with an SLA of 2.9 (median in this study) the infiltration rate for 2 mph wind and 2 ^oF indoor-outdoor temperature difference is just 0.08 ach.
- Furthermore, if a continuous unbalanced mechanical outdoor air system is used then the natural infiltration is reduced to less than 0.01 ach.

RESULTS - Formaldehyde Concentrations and Ventilation



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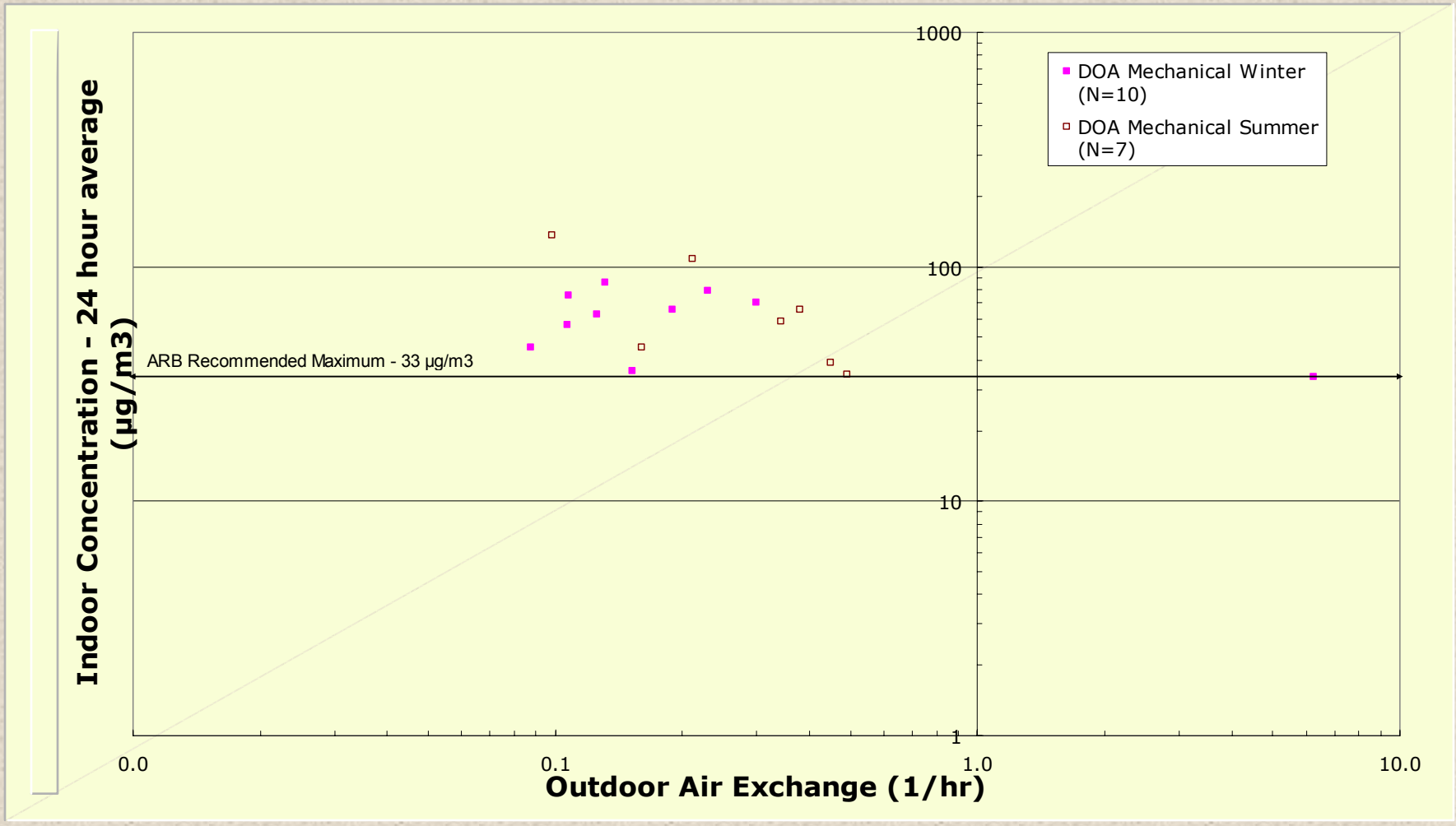

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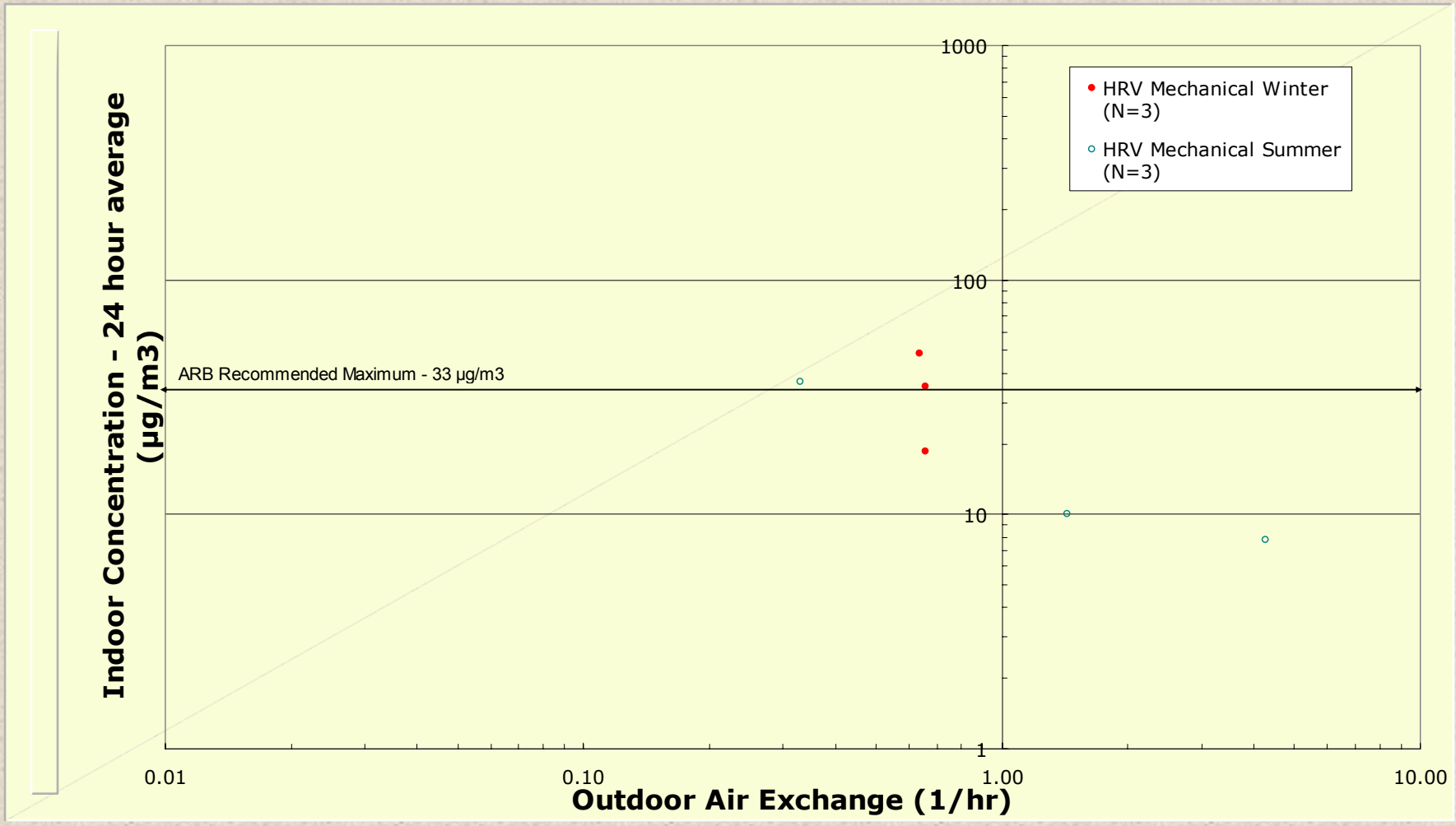

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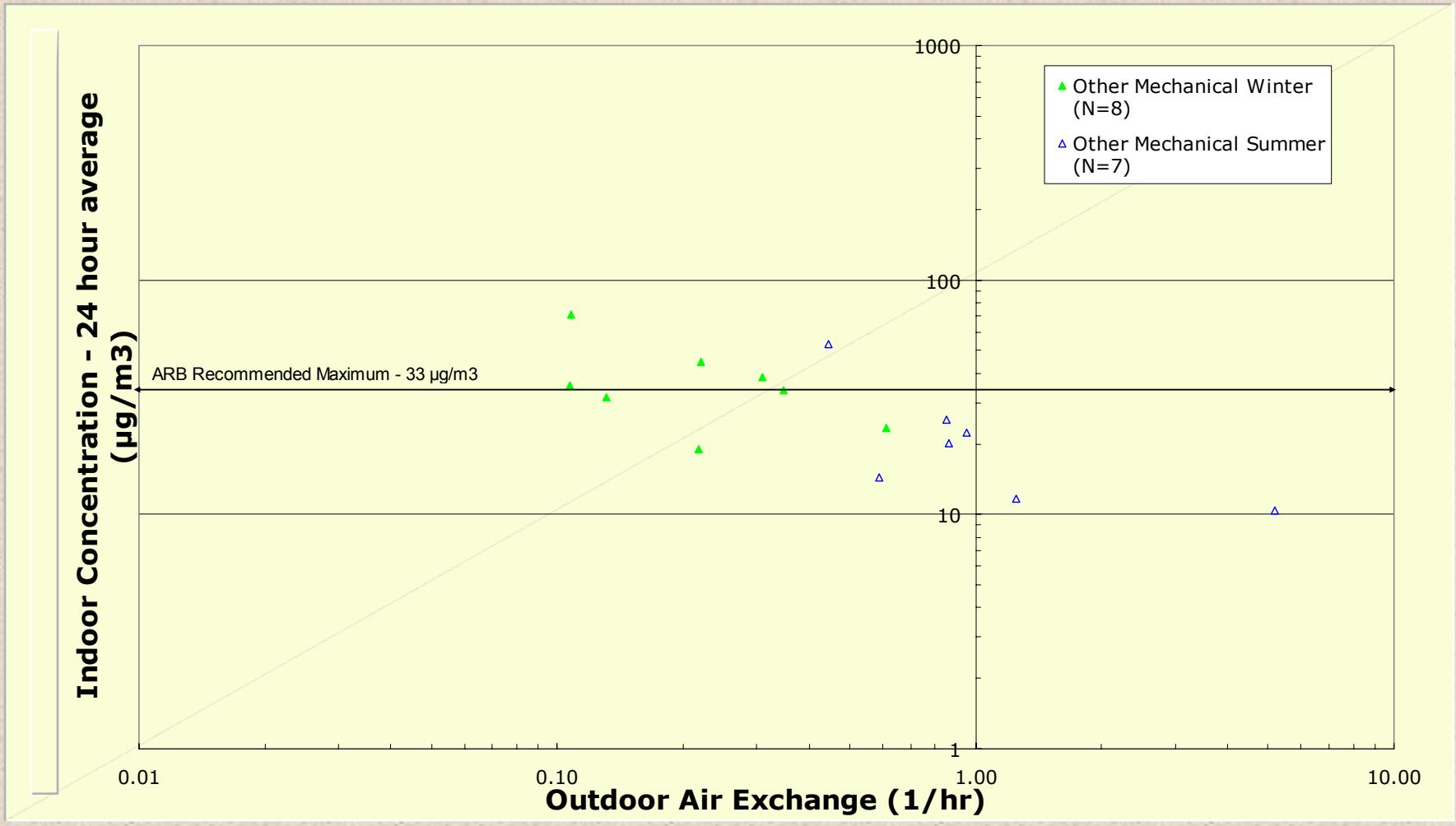

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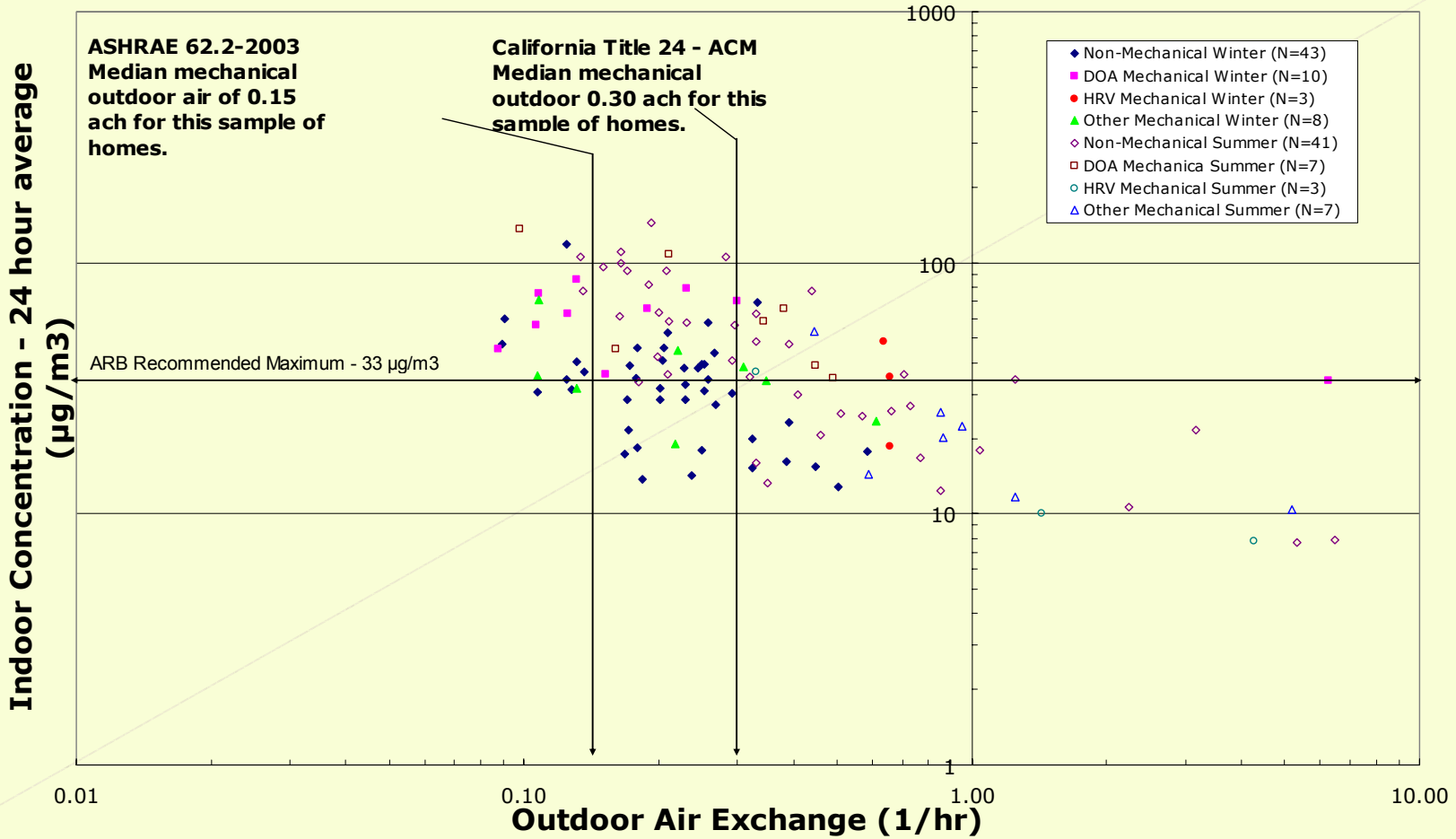

Conclusions

- We conclude that the new single-family detached homes in California are built relatively tight (i.e. 60% of the homes had an SLA < 3.0).

- 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

- Very few homeowners use their kitchen range exhaust fans (i.e. 80% never during the Test Day)

- 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

- The indoor air contaminants measured in this study that most frequently exceeded recommended indoor air quality guidelines were formaldehyde and acetaldehyde.

- With respect to Proposition 65 requirements for carcinogenic risk, a total of 63% exceeded the NSRL for benzene and 27% for naphthalene

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

Recommendations

- Multivariate analyses of the data collected in this study should be conducted to further develop the understanding of the relationships between indoor air contaminant concentrations, indoor sources, and ventilation.

- Construction of a population weighted exposure assessment from the data collected in this field study should be performed to better understand the health risks caused by exposure to air contaminants in homes.

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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