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Seminar 5: Smart Residential Ventilation Control for IAQ and Energy Efficiency

Development of Advanced Smart Ventilation Controls for Residential Applications

Iain Walker, Lawrence Berkeley National Laboratory

iswalker@lbl.gov

BERKELEY LAB

Lawrence Berkeley National Laboratory

Learning Objectives

1. Attendees will learn which ventilation control strategies are the most effective at energy saving while maintaining acceptable IAQ.
2. Understand how real-time infiltration could be estimated and how to use it to adjust ventilation rates
3. Understand how varying ventilation rates impacts indoor air quality, comfort and energy
4. Understand how pollutant exposure is modeled to determine equivalency among continuous and time-varying ventilation strategies.

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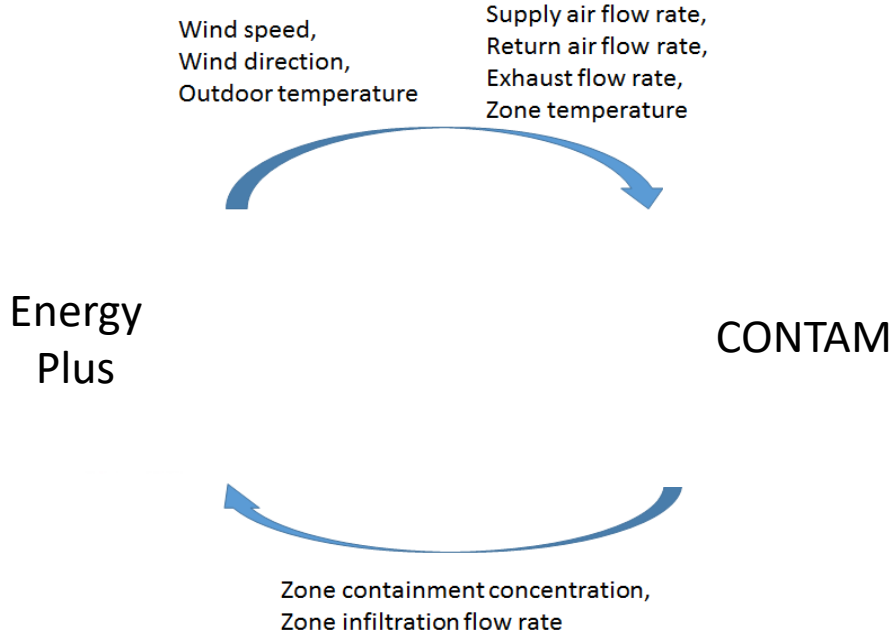
Simulation Background



New California code compliant homes:

- single family with envelope leakage of 0.6, 2 and 3 ACH50
- Apartment, 3 ACH50

Central forced air for non-zoned and distributed zonal heat pumps for zoned systems

All ventilation fans assumed a fixed watts per unit flow rate of 436.1 watts per m^3/s (5 cfm/W).

For supply ventilation systems the tempering quadrupled fan energy

For balanced systems there additional fan power requirements quintupled fan energy.

California Climate Zone	HDD	CDD
1	2400	5
3	1700	70
10	950	950
16	2800	250

Contaminant Emissions and Exposures

Emission rates from HENGH field study of 70 new California homes

Continuous emission:

- “Generic” contaminant
- Formaldehyde (depends on Temperature, Humidity and Ventilation Rate)

Periodic Emission:

- PM2.5 from cooking
- CO_2 and H_2O from occupants on schedules

Exposure limits for chronic exposure from the literature:

- Formaldehyde: OEHHA REL is 9 μg/m^3 for 8-hour and chronic exposures
- PM2.5: WHO Chronic level of 10 μg/m^3
- CO_2 : 1100 ppm
- Moisture: 60% RH

Smart Ventilation Strategies

Track occupants (assumes we know occupancy)

- Ventilate only occupied zones

Zonal Air flow options:

1. Air flow

   Strategy 1: Keep total air flow constant. Direct air to to zones that need venting.

   Strategy 2: Reduce total air flow. Vent each zone that calls for venting at rate proportional to fraction of total floor area.

2. Number of zones

   Option 1: Four + zones: kitchen, bathrooms, bedrooms and “other” living spaces

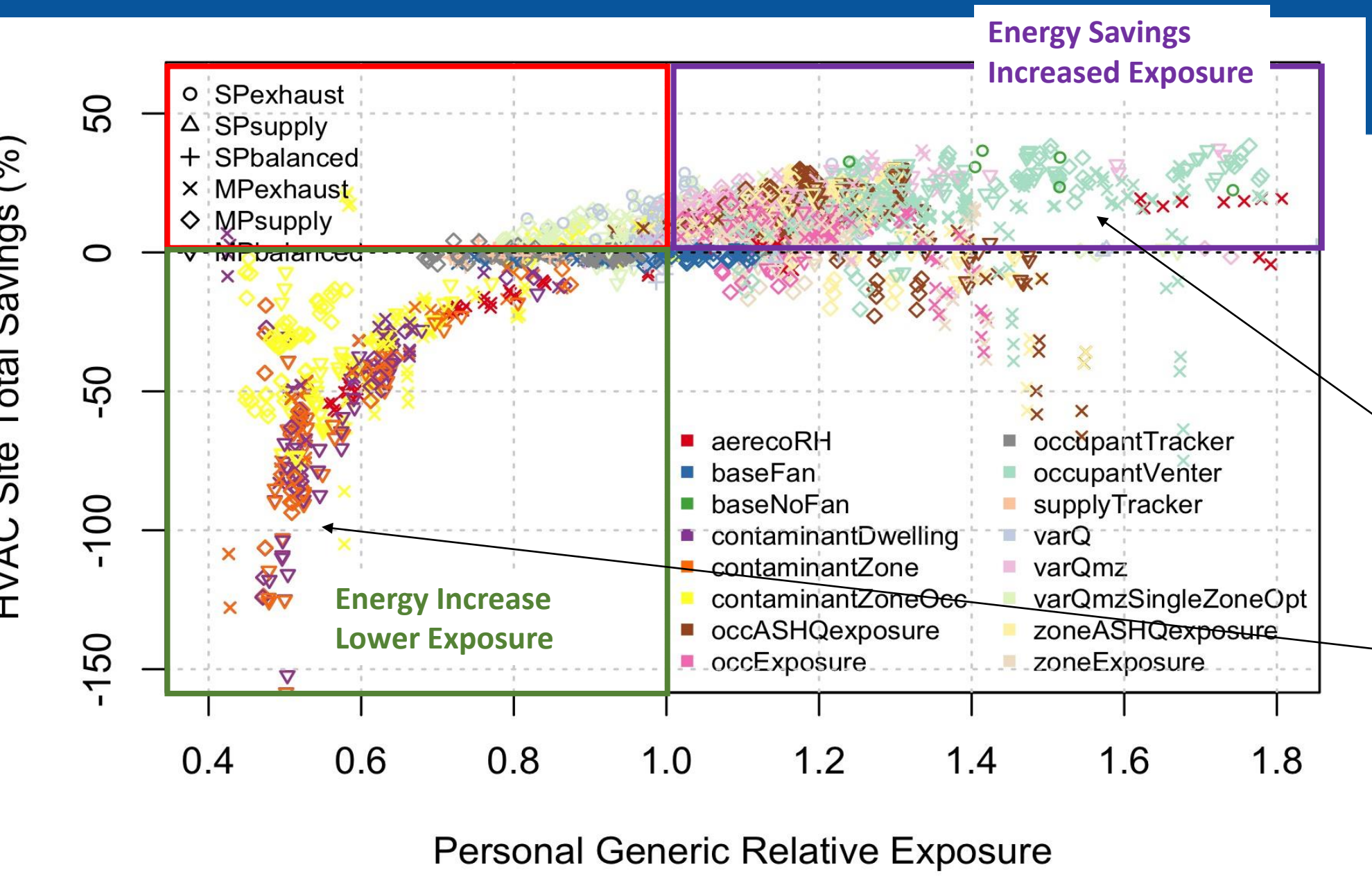
   Option 2: Two zones: 1. sleeping & 2. All other spaces

Combine these with load shifting based on outdoor temperature (shift to milder conditions)

Exposure-based Controls

1. Keep relative exposure below 1 when occupied, 5 when vacant
2. Match relative exposure to continuously operating system
3. Track occupant individual exposure
4. Ventilate at low rate unoccupied, higher when occupied. No exposure calculations
5. Contaminant-based:
   - Vent dwelling if any contaminant in any zone above threshold
   - Vent zone if that zone above threshold
   - Vent zone if occupied and above threshold
   - Control RH between 30% and 60%

Relative exposure:
Ratio of exposure for a given ventilation approach or system to the exposure from a continuously emitted pollutant and a continuously operated ventilation fan sized to ASHRAE 62.2

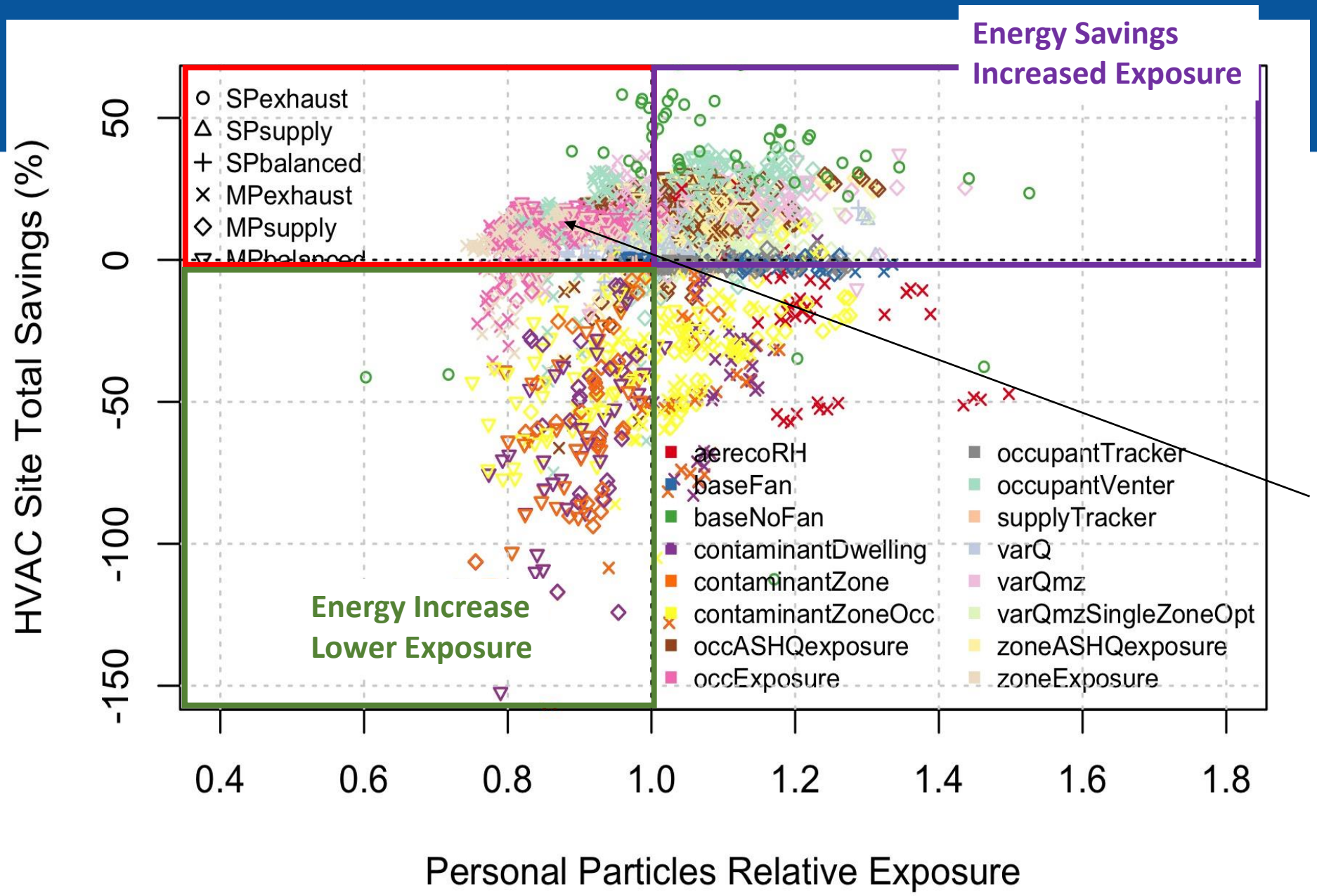


Many controls saved energy but increased exposure OR decreased exposure but used more energy

Occupancy-based systems without exposure control lead to high exposures

Contaminant controls operate a lot – driven by need to control formaldehyde

Zoning not a clear advantage



Best performance was for exhaust systems

Zoning using occupancy controls looks OK

Exposures and Ventilation Rates – no contaminant controls

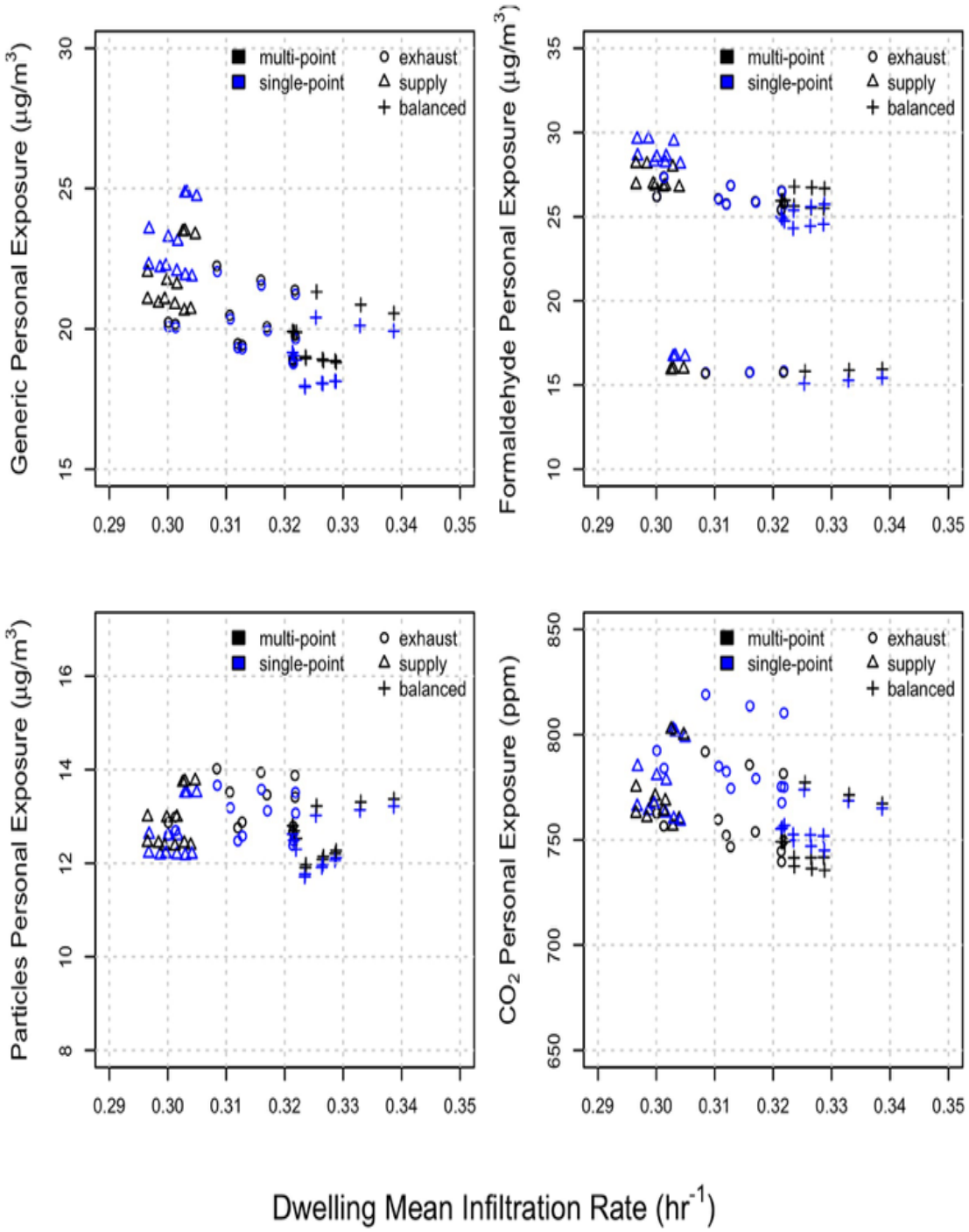
Zoning can:

increase exposure

- For particles
- For generic and formaldehyde exposure

decrease exposure

- For most CO_2 cases



Zoning Exposure Results for VarQ controller (best energy performance) with contaminant controls

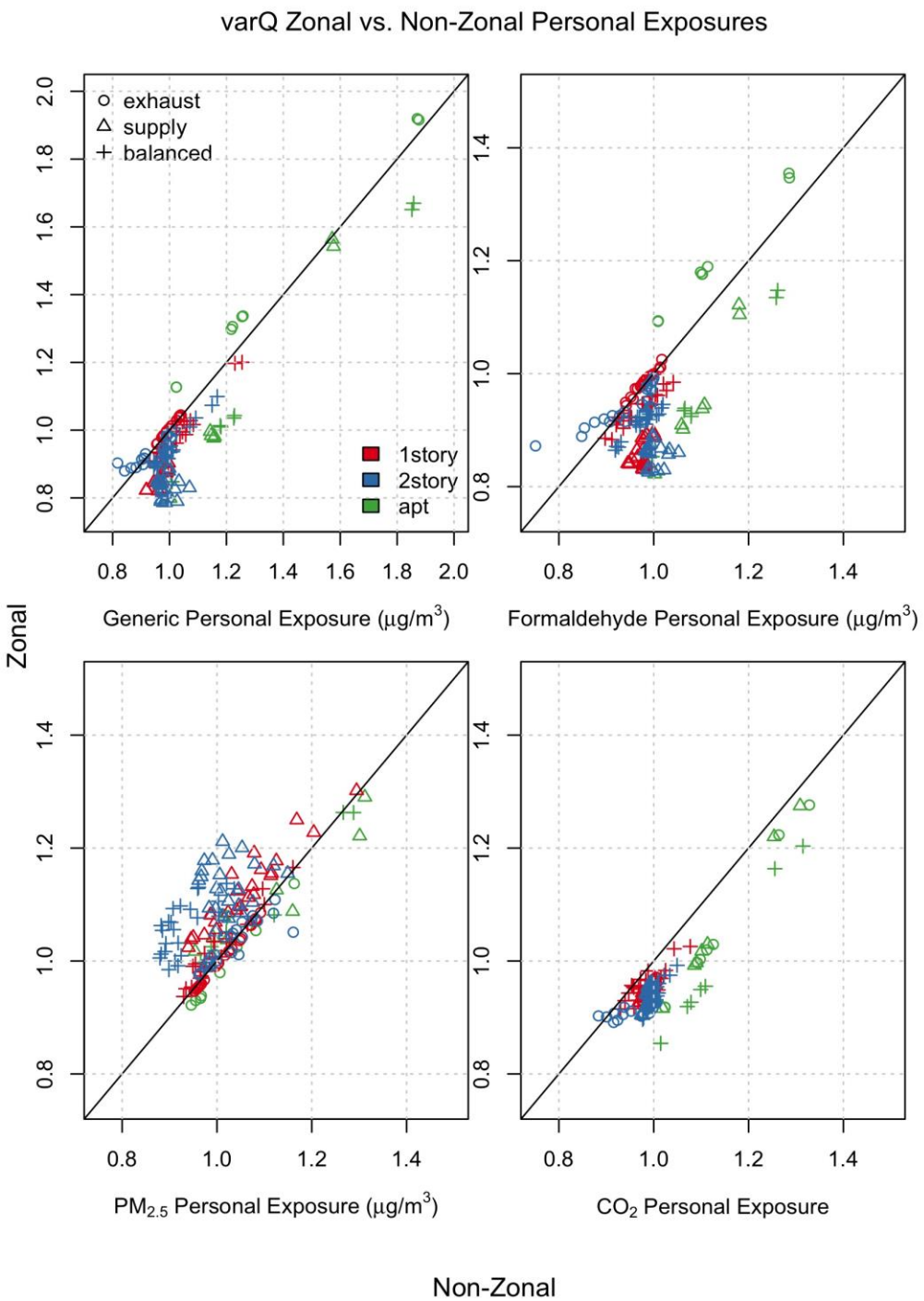
Zonal controls can either ***increase*** or ***decrease*** exposure:

Biggest ***decrease***: consistently better for CO_2

- because occupants are source

Biggest ***increase***: consistently poor for $PM_{2.5}$ supply & balanced systems

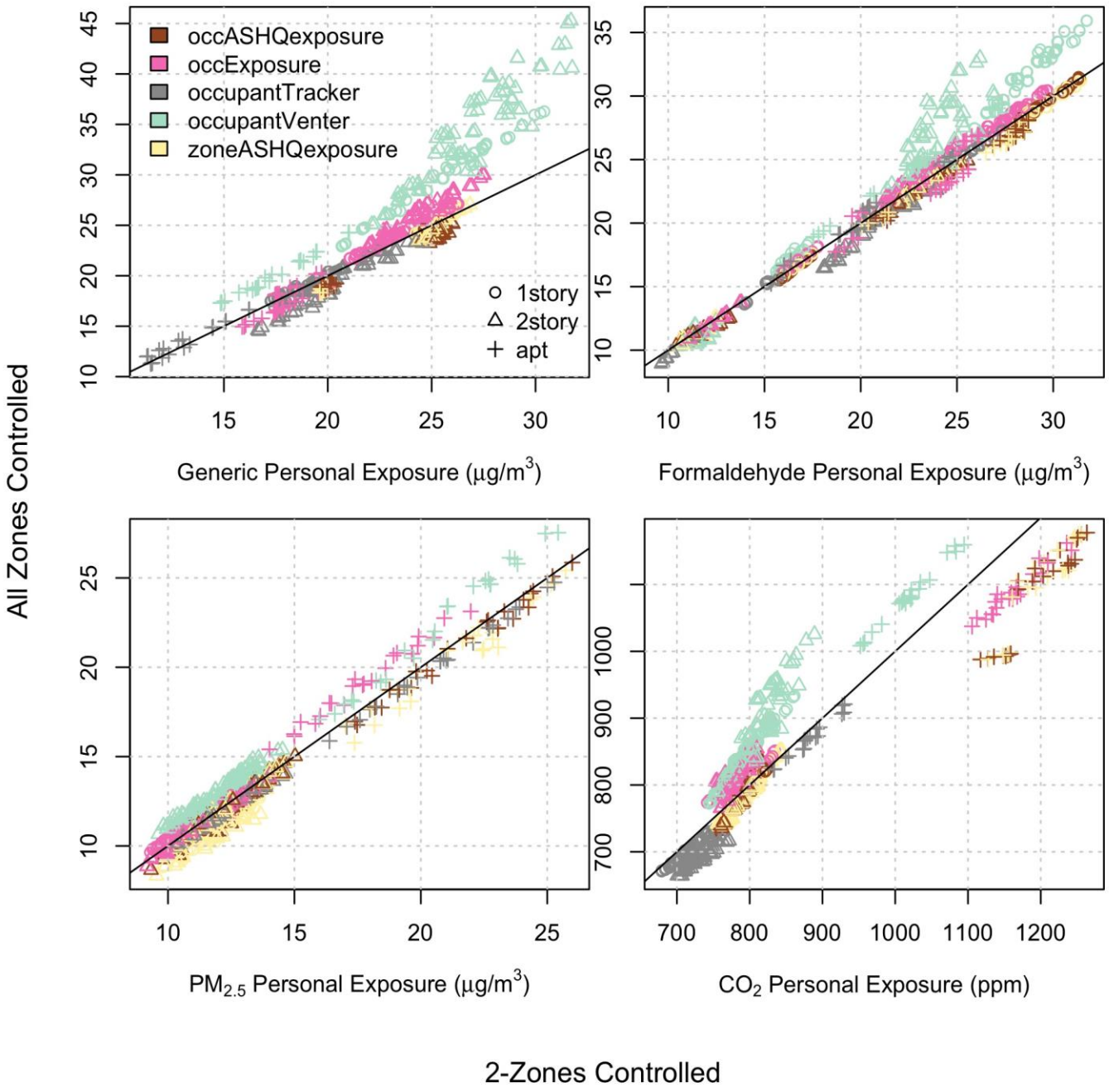
- Exhaust more effective at concentrated contaminant removal



Are more zones better for contaminants?

Controlling more zones is sometimes good, some times bad

As occupants move from zone to zone they are exposed to higher contaminant levels upon entry to a zone that was previously under-ventilated.

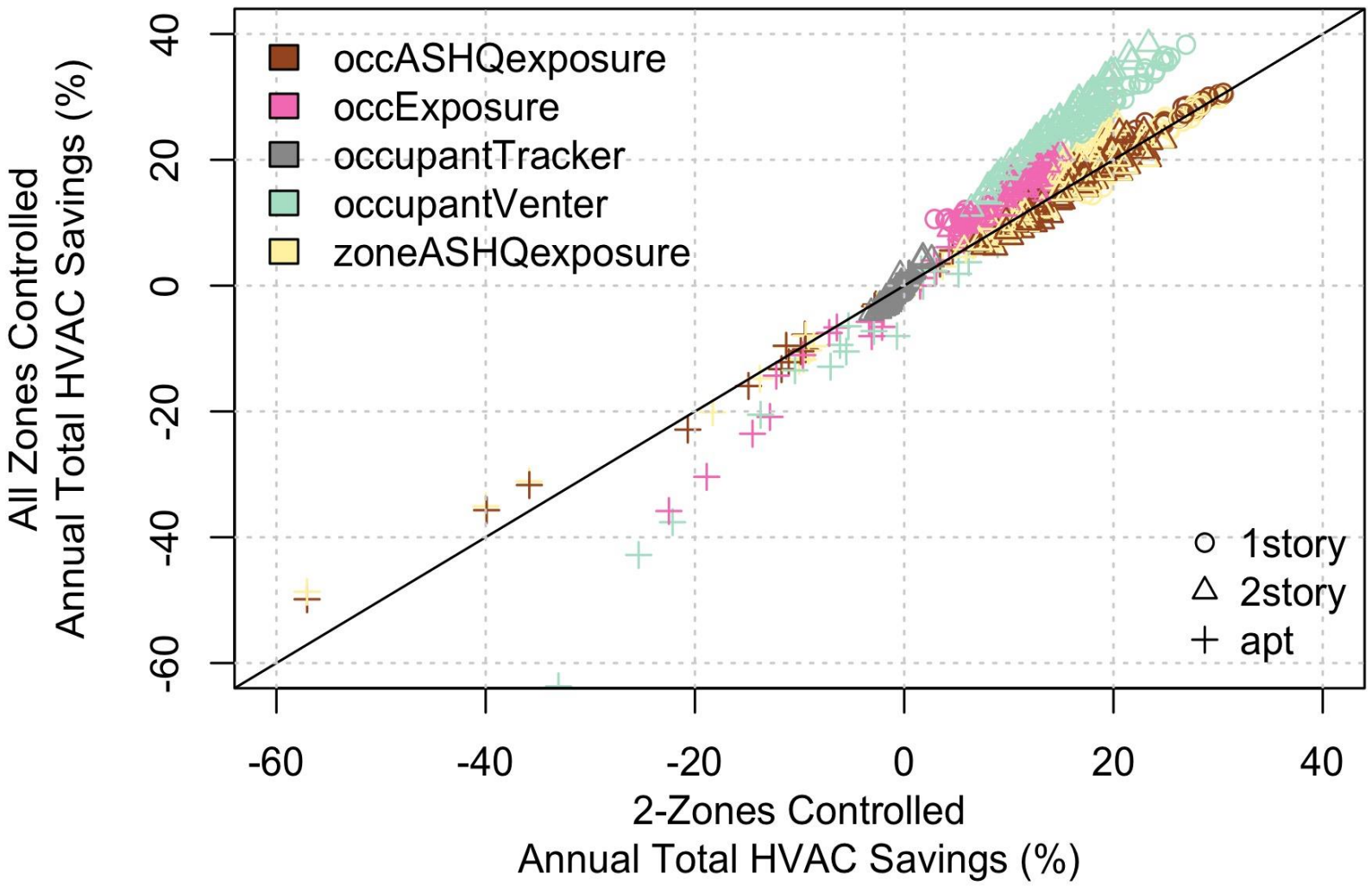


Are more zones better for energy savings?

Sometimes good:
Single Family homes

Sometimes not:
apartment

Most zone-number-sensitive strategy is “occupantVenter”:
All zones get a minimum flow rate when unoccupied. Additional airflow is distributed to occupied zones. There is no tracking of controller estimated exposure, dose or contaminants.



Other observations

Direct contaminant control

- Can't vent enough to control formaldehyde – even at double the ASHRAE 62.2 minimum required rate
- Future work will need to allow for much higher formaldehyde – is this OK?

Exhaust systems:

- Least zonal (but still good for bedroom CO_2 control)
- Most consistent contaminant control

Supply systems

- More effective zoning – lowest total ventilation
- Higher power fans mean bigger energy use… but also bigger savings when controlled
- Not so good for particles: more from outside + not as good at removing particles from cooking

Balanced systems

- Effective zoning – highest total ventilation but also highest fan power. Had the biggest energy savings from smart controls

Air leakage

- Results independent of air leakage for these code-compliant (IECC) homes
- Across all 1-story cases, the mean infiltration rates were 0.316, 0.318 and 0.324 hr^{-1} for the 0.6, 2 and 3 ACH_{50} cases, respectively.

Conclusions

Few control strategies saved energy without increasing exposure

Hard for zonal ventilation to control all contaminants

- Generally better for occupant-related contaminants, worse for continuously emitted contaminants

Exhaust systems most consistently saved energy

Effective zoning limited by:

- Open doors
- Occupant movement (continually entering less ventilated space)
- Zoning effect depends on contaminant
  - Particles increased, CO_2 decreased, HCHO/generic source up or down

Direct contaminant controls were ineffective due to the inability to control formaldehyde below chronic levels

Adding more than two zones not very effective

Bibliography

Walker, I.S., Less, B.D, Lorenzetti, D. and Sohn, M. 2022. Analysis of zoned ventilation systems. Proc. IAQ 2020. Athens, Greece. May 6th2022.

Additional details in:

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Questions

Iain Walker

iswalker@lbl.gov