Residential Applications of Smart Ventilation Controls

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Why are we ventilating?

Odour – Health - Moisture

1. Contaminants from the building:
- Formaldehyde is the classic example – but many other VOCs
2. Contaminants from human activities:
- Bioeffluents
- Health-related: e.g., particles from cooking or water vapour and cleaning chemicals from cleaning/bathing

These are not all reduced equally by different smart ventilation systems and strategies

Residential Smart Controls

AIVC VIP 38 "What is Smart Ventilation"
Definition includes controls based on:

- Weather
- Occupancy
- Contaminant sensing
- Energy supply signals

Today's discussion: assessing applications of smart ventilation controls through simulations:

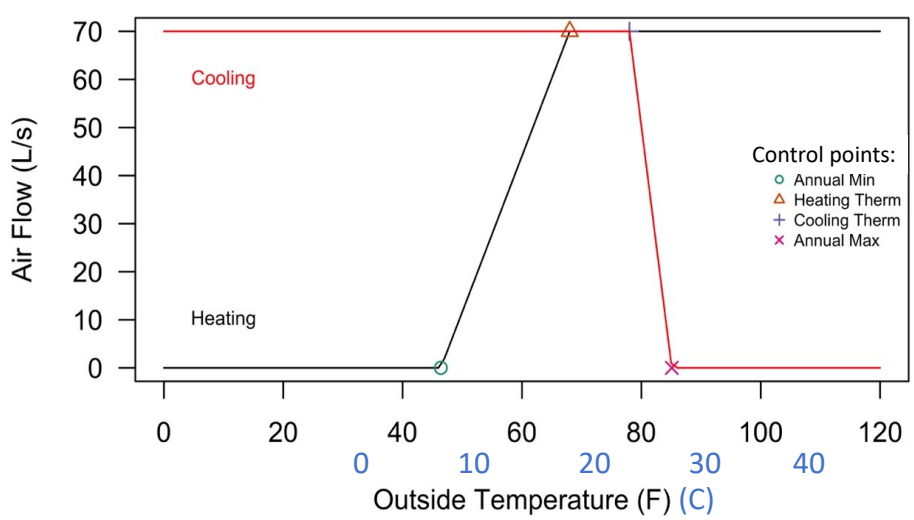
- combined CONTAM/EnergyPlus – full year, 5 minute timestep – range of climates, envelope leakage etc.

Control Strategies

- Weather (outdoor temperature) controls
  - Pre-calculated temperatures to give the same annual exposure
  - Real time exposure calculations + temperature cutoffs
- Occupancy Controls
  - Reduce ventilation when unoccupied
- Zonal controls
  - Tracking relative exposure and dose in each zone during occupied periods
  - Flow directed to occupied zones
- Contaminant controls
  - Whole dwelling vented if any contaminant is above its threshold
  - Zone vented if it is above threshold
  - Zone vented if it is above threshold AND occupied

Weather **Controls**

Change Mechanical System Flow Rate With Outdoor Temperature



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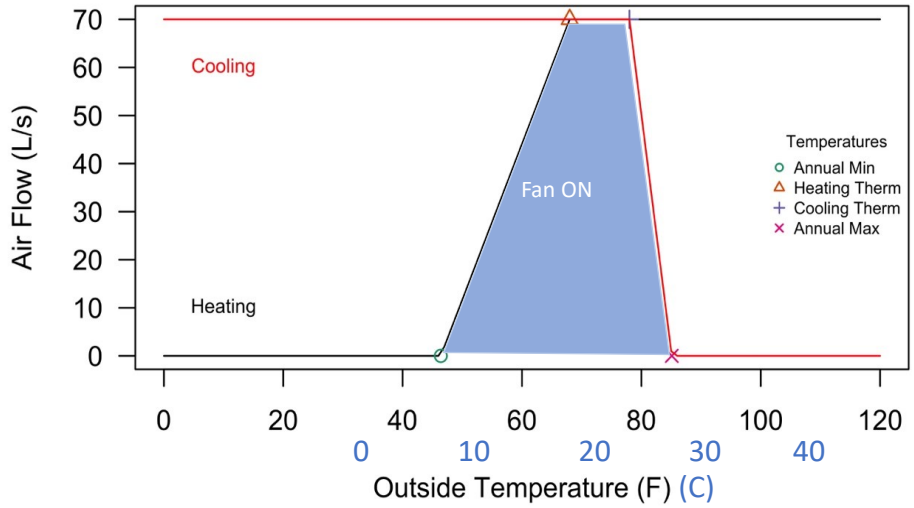

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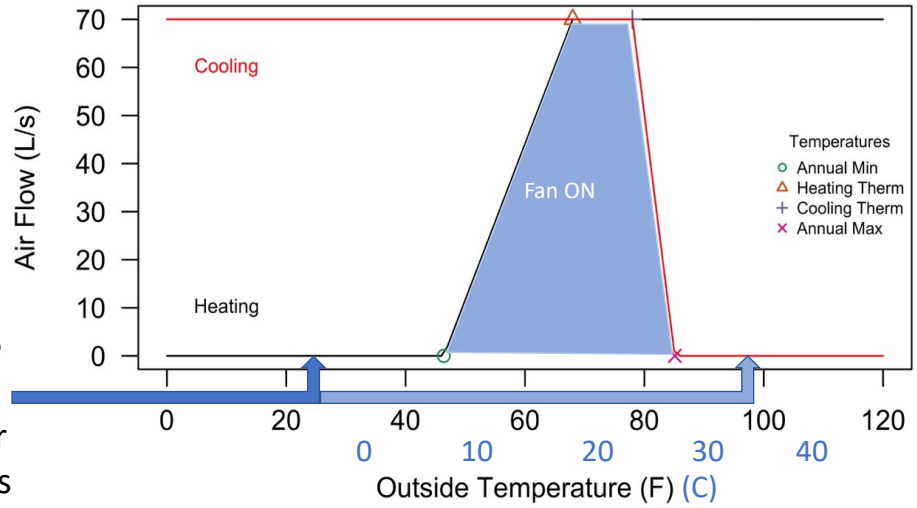
Change Mechanical System Flow Rate With Outdoor Temperature

Include some minimum other than "zero"? Controlling relative exposure to less than 5 accounts for any acute problems



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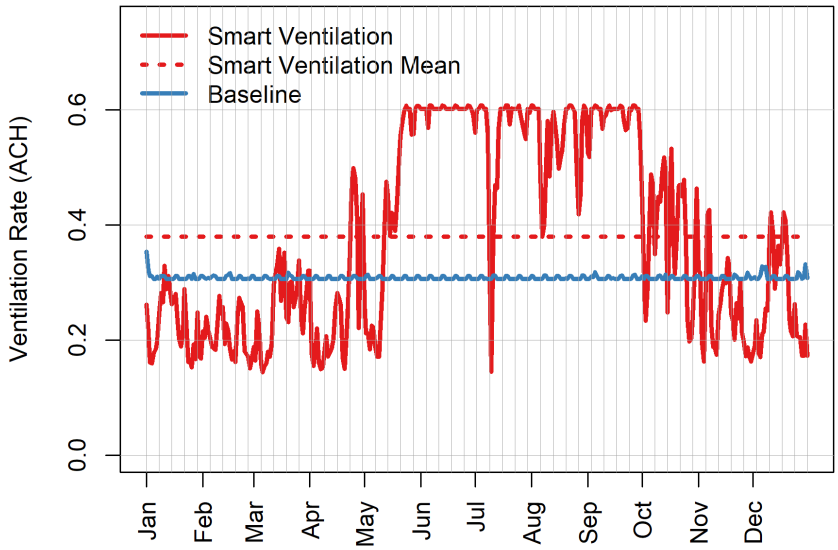
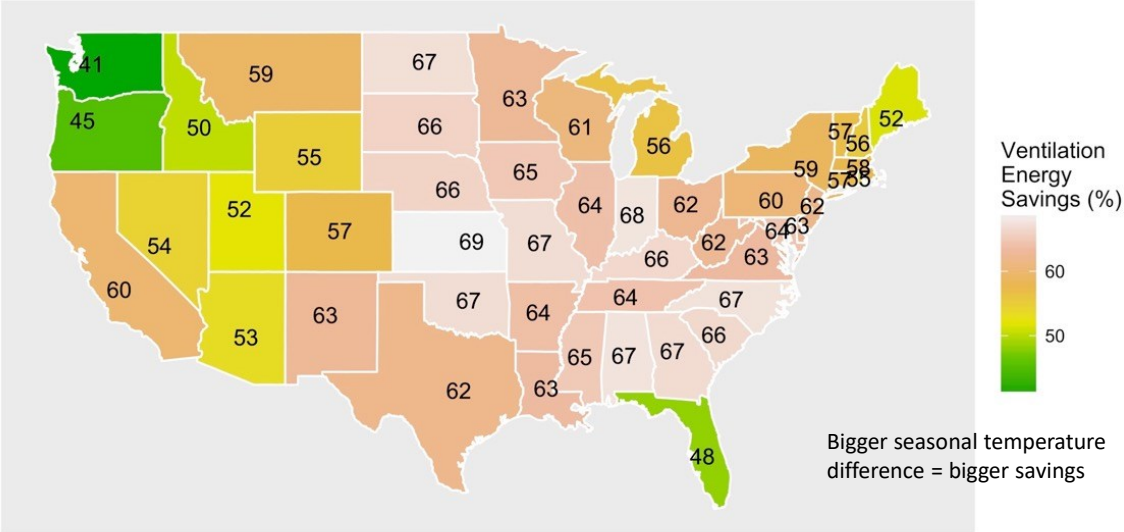
Daily Average Ventilation Rate With Outdoor Temperature Control



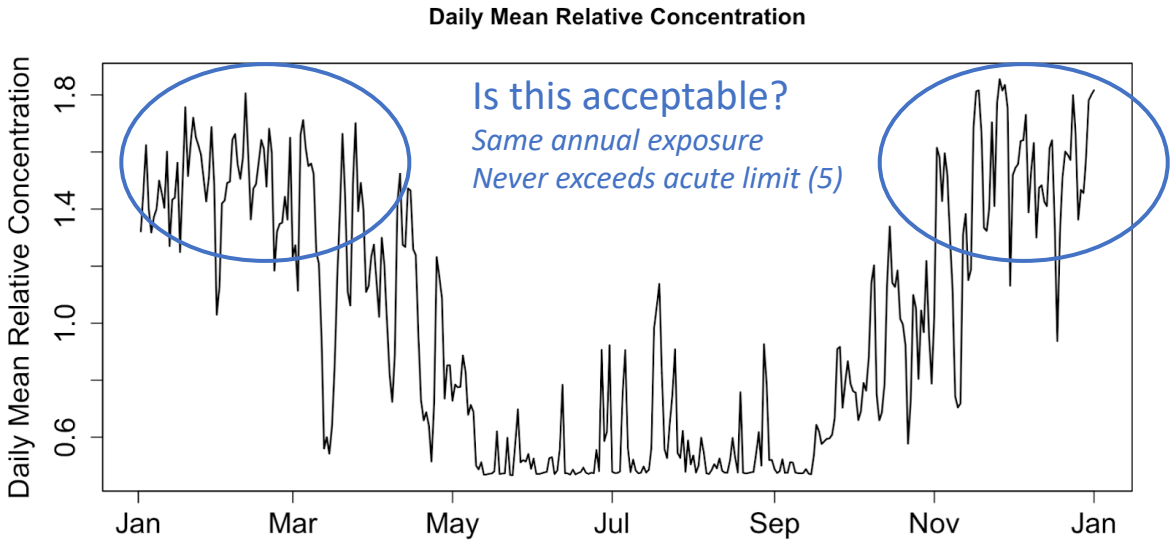
shifts ventilation from winter to summer

Ventilation Energy Savings



Bigger seasonal temperature difference = bigger savings

Daily Average Concentration With Outdoor Temperature Control



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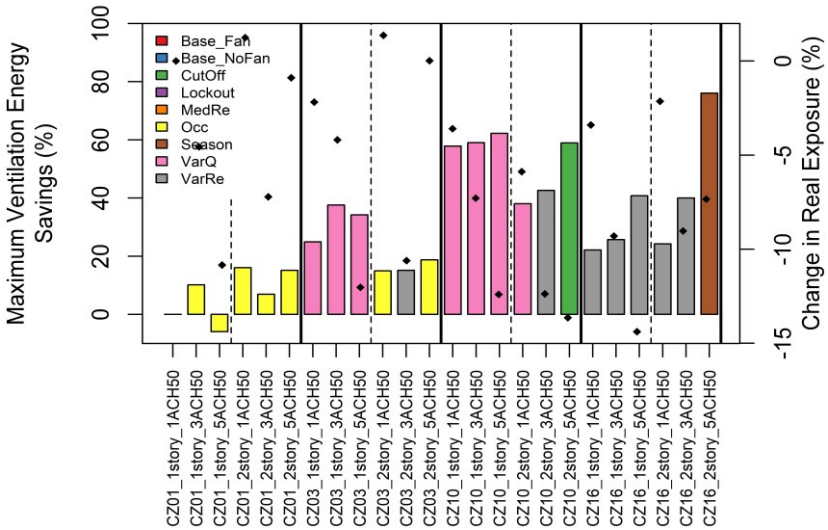
Optimum control depends on climate and house being ventilated



CZ 1: North Coast cool: Arcata
CZ03: Temperate: Oakland/SF
CZ10: Inland: Sacramento
CZ16: Mountains

1 & 2 Stories

1, 3 & 5 ACH50

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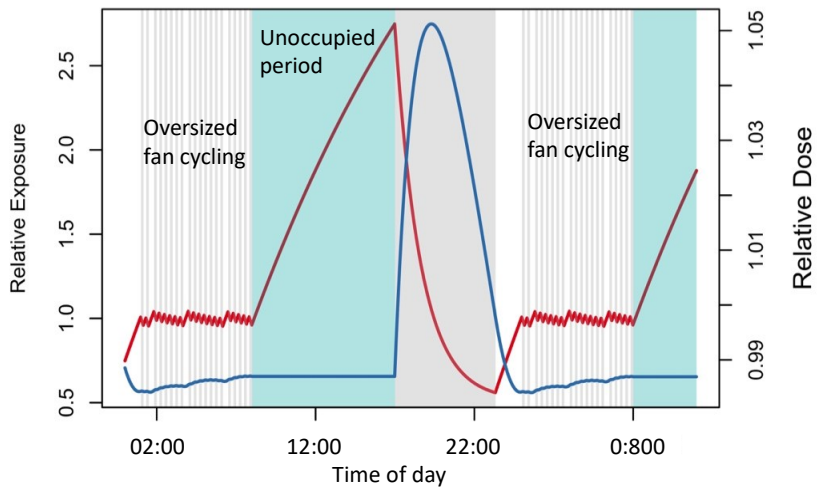
Occupancy Controls

Occupancy Control

- Assuming actual occupancy NOT using CO_2 or RH as a surrogate
- Include non-occupant generated contaminants:
  - E.g., Formaldehyde and other building-related VOCs or Radon

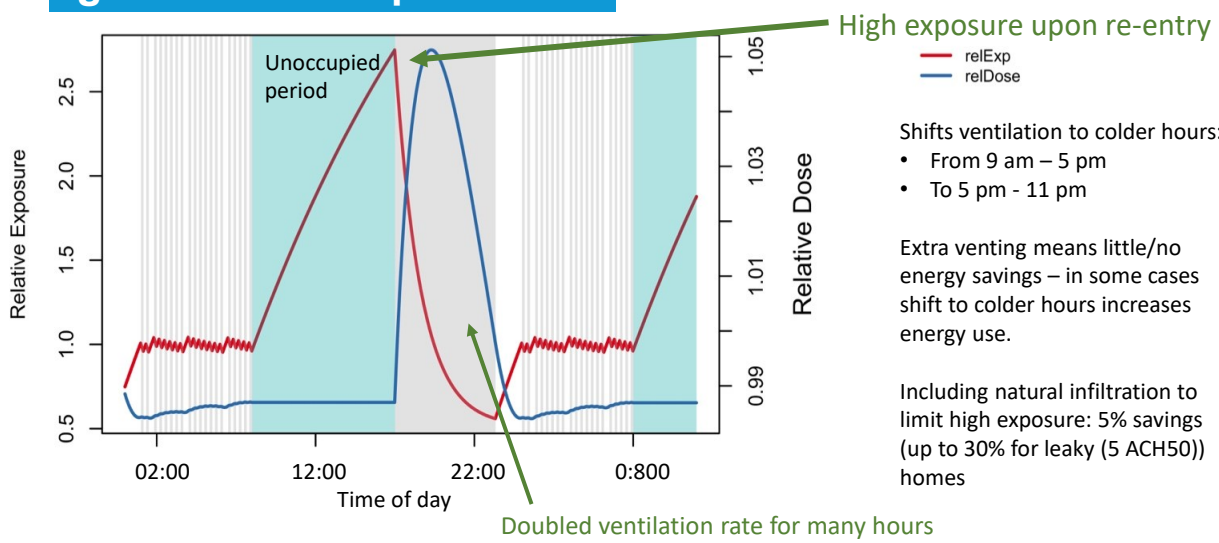
Fan off when unoccupied: generic VOC exposure



Relative Exposure tracks contaminants at all times: accounts for emissions when vacant

Relative dose based on occupant being exposed – unchanged during unoccupied hours

Fan off when unoccupied: generic VOC exposure



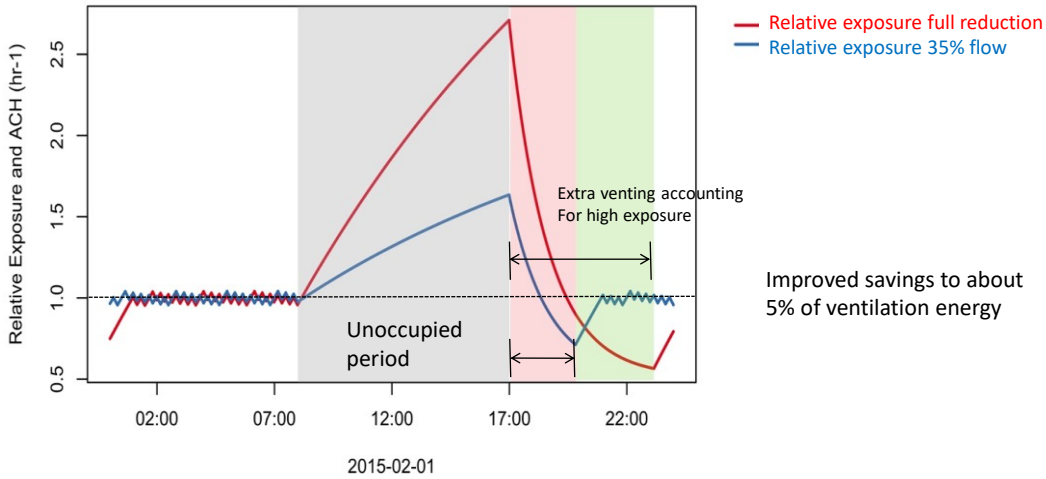
Shifts ventilation to colder hours:

- From 9 am – 5 pm
- To 5 pm - 11 pm

Extra venting means little/no energy savings – in some cases shift to colder hours increases energy use.

Including natural infiltration to limit high exposure: 5% savings (up to 30% for leaky (5 ACH50)) homes

Occupancy Control – Reduced but not zero when unoccupied?



Improved savings to about 5% of ventilation energy

Unoccupied period in grey, 35% ventilation recovery period in pink, full ventilation reduction recovery period in green

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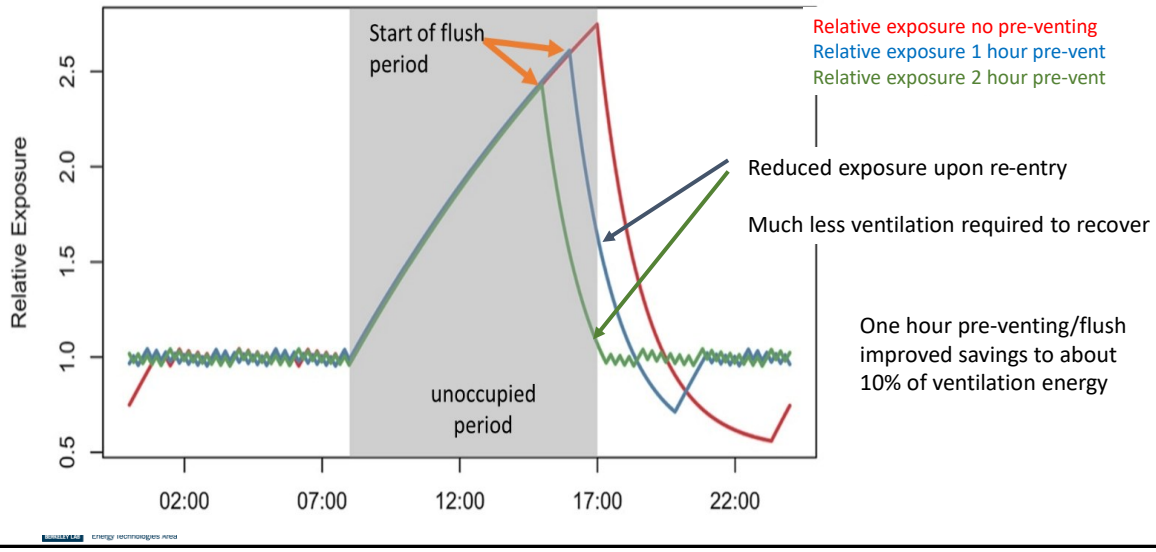
Occupancy Control – Pre-venting (or flushing)



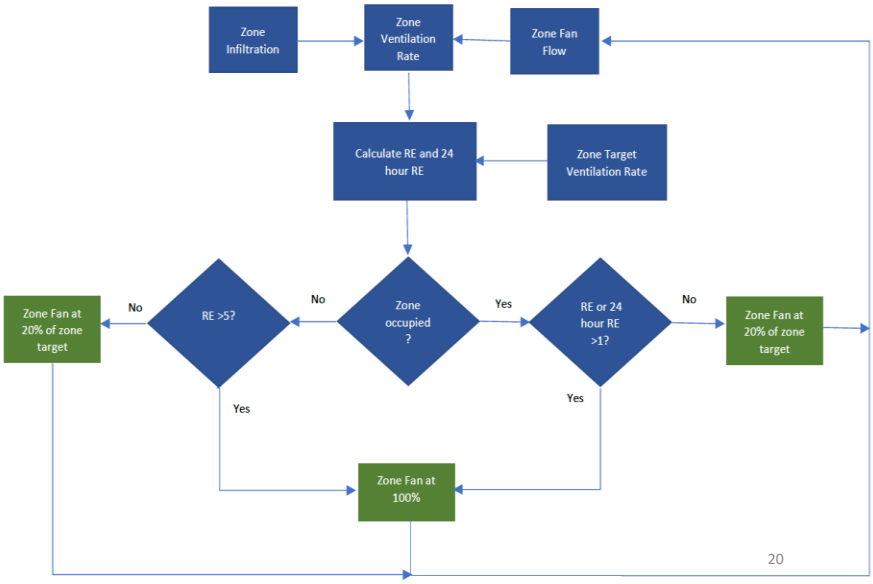
One hour pre-venting/flush improved savings to about 10% of ventilation energy

Zoning Controls

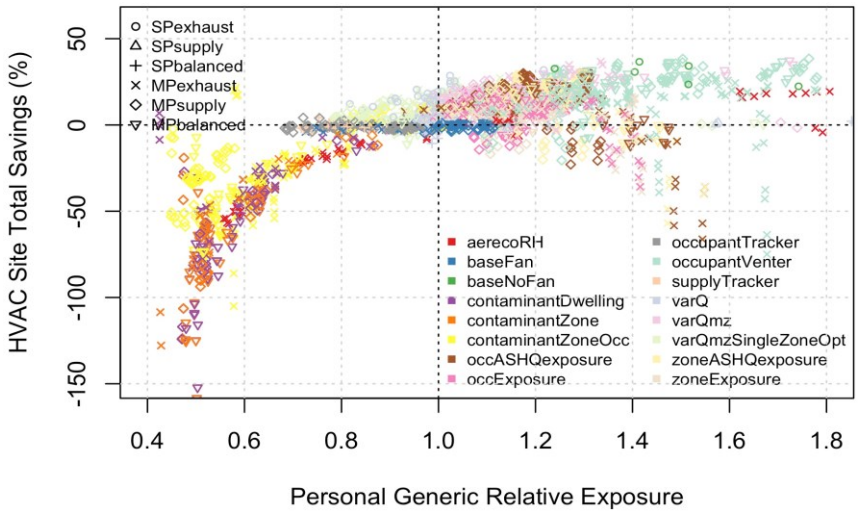
Example controller flowchart for a zonal exposure controller

This control process is for a single zone and is repeated for each zone in the dwelling.

"RE" is the relative exposure calculated for an individual zone.

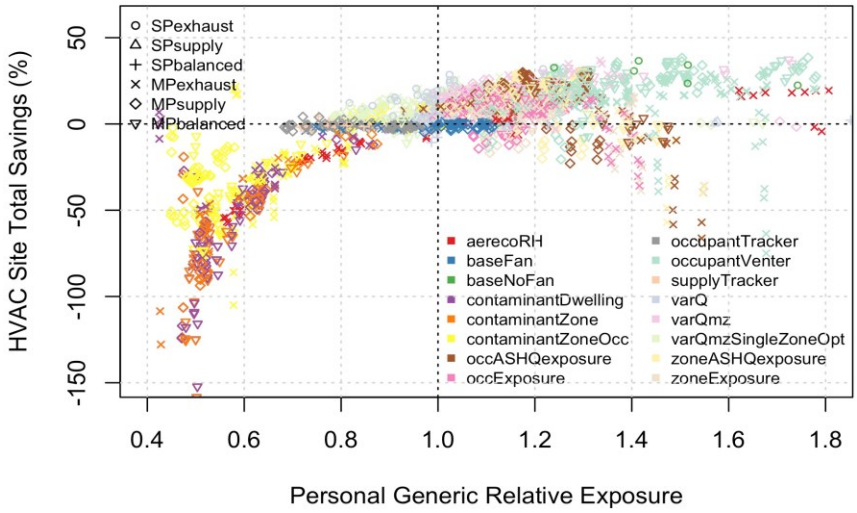


Zonal Control



Best controllers saved 10-25% of ventilation energy compared to about 7% for non-zoned versions

Zonal Control

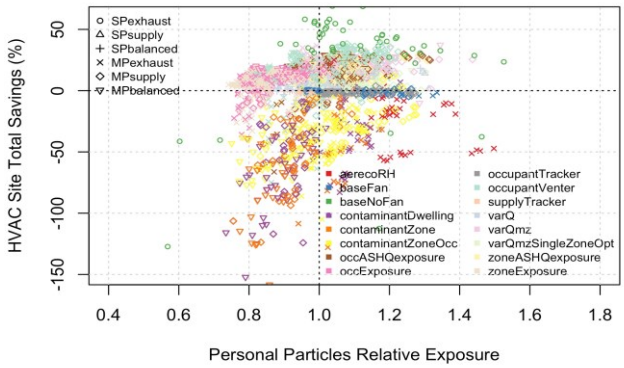


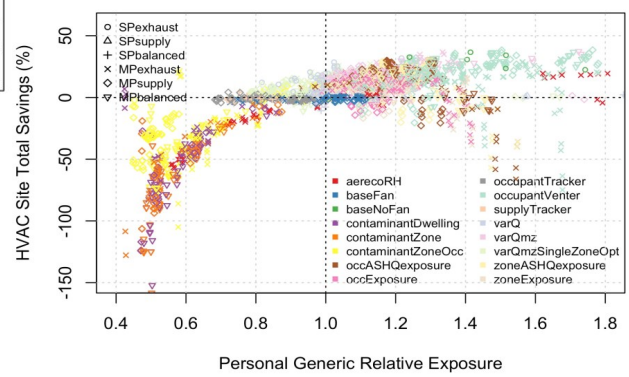
BUT.. increased contaminant concentrations for at least one contaminant:

- diversity of sources: continuous vs. periodic vs. outdoors
- diversity of removal mechanisms: outside air ventilation, deposition, filtration

People move from zone to zone – same problem as occupancy with contaminant build-up

Zonal Control - Different results for different contaminants



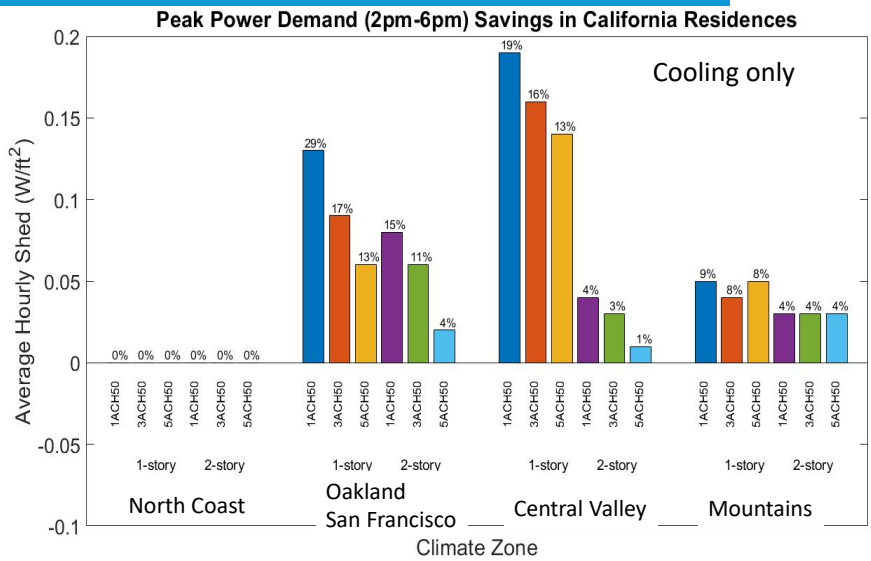


Zoning

- Zone control:
  - reduces IAQ when point-source contaminant emissions (e.g., cooking, breathing, bathing) were aligned with the location of the single-point fan
  - improves IAQ when contaminant sources (e.g., CO_2 in bedrooms with closed doors) are NOT aligned with the location of the single-point fan
  - improves IAQ when unzoned systems do not evenly serve the dwelling. E.g., two-story dwellings, where first and second levels are ventilated at substantially different rates by unzoned supply and exhaust

Peak Demand

Turning off ventilation on peak



Works best for:
- Hot climates
- Low natural infiltration:
  - Tight homes
  - Single-story homes

Note: % = cooling energy savings

Contaminant Sensing

Key issues for contaminant sensing

1. Can we ignore formaldehyde?
   - Even at double ASHRAE minimum rate (>0.5 ACH) to get concentrations down to 9 µg/m^3 (California OEHHA 24 hour target)
   - Need lower emitting materials
2. Are sensors good enough and affordable?
   - Particles – YES
   - CO_2 – NEARLY (best have autozero and actually sense CO_2 – but are expensive)
   - NO_2 – NO (but all-electric decarbonized homes don't need this)
   - T & RH – YES
   - TVOC – limited applicability (solvent = opening wine bottle or peeling an orange)
   - Formaldehyde – NO
3. Where should we sense?
   - In all rooms combined with occupancy sensor and pre-occupancy "learned" flushing?
     - Expensive, impractical?
   - Maybe restrict sensor-based controls to kitchens and bathrooms?
4. How to combine contaminants: if a strategy decreases particles but increases formaldehyde.. What do we do?

Questions?

Background papers from LBNL

Walker, I. Less, B. Lorenzetti, D. Sohn, M. (2021). Development of Advanced Smart Ventilation Controls for Residential Applications. Energies 2021, 14, 5257. https://doi.org/10.3390/en14175257

Young, M., Less, B.D., Dutton, S.M., Walker, I.S., Sherman, M.H. and Clark, J.D. (2020). Assessment of peak power demand reduction available via modulation of building ventilation systems. Energy and Buildings. 10.1016/j.enbuild.2020.109867

Less, B.D., Dutton, S., Walker, I, Sherman, M. and Clark, J. (2019) Energy savings with outdoor temperature-based smart ventilation control strategies in advanced California homes. Energy and Buildings. 194 (2019) 317 - 327. https://doi.org/10.1016/j.enbuild.2019.04.028. LBNL 2001207

Clark, J., Less, B., Dutton, S., Walker, I. and Sherman, M. (2019). Efficacy of occupancy-based smart ventilation control strategies in energy-efficient homes in the United States. Building and Environment, Vol. 156, https://doi.org/10.1016/j.buildenv.2019.03.002. LBNL 201199

Guyot, G., Sherman, M.H. and Walker, I.S. (2018). Smart ventilation energy and indoor air quality performance in residential buildings: a review. Energy and Buildings. Vol. 163, pp. 416-430. https://doi.org/10.1016/j.enbuild.2017.12.051

Guyot, G., Sherman, M.H. and Walker, I.S. (2018). Performance based approaches for smart ventilation in residential buildings. International Journal of Ventilation. Vol. 18, No. 2 https://doi.org/10.1080/14733315.2018.1435025

Turner, W.J.N., Walker, I.S. and Roux, J. (2015). Peak Load Reductions: Electric Load Shifting with Mechanical Pre-Cooling of Residential Buildings with Low Thermal Mass. Energy. DOI: 10.1016/j.energy.2015.02.011. LBNL-180912.

Less, B., Walker, I., Lorenzetti, D., Mills, E., Rapp, V., Dutton, S., Sohn, M., Li, X., Clark, J. and Sherman, M. 2020. Smart Ventilation for Advanced California Homes. LBNL-2001342. https://doi.org/10.2172/1635274

Less, B., Walker, I and Ticci, S. 2016. Development of Smart Ventilation Control Algorithms for Humidity Control in High-Performance Homes in Humid US Climates. LBNL-1007244. http://eta-publications.lbl.gov/sites/default/files/1007244.pdf

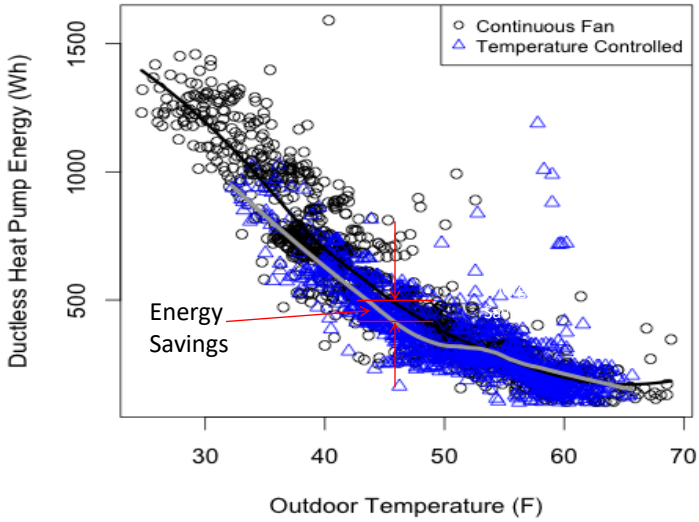
Field Measurement of Temperature Control

- Long term monitoring of two homes
  - One with Washington State University – an energy efficient retrofitted home
  - One with University of Illinois – typical US midwest home
- Flip-flop – one week controlled one week continuous
- Measure energy use and indoor T, RH, CO2

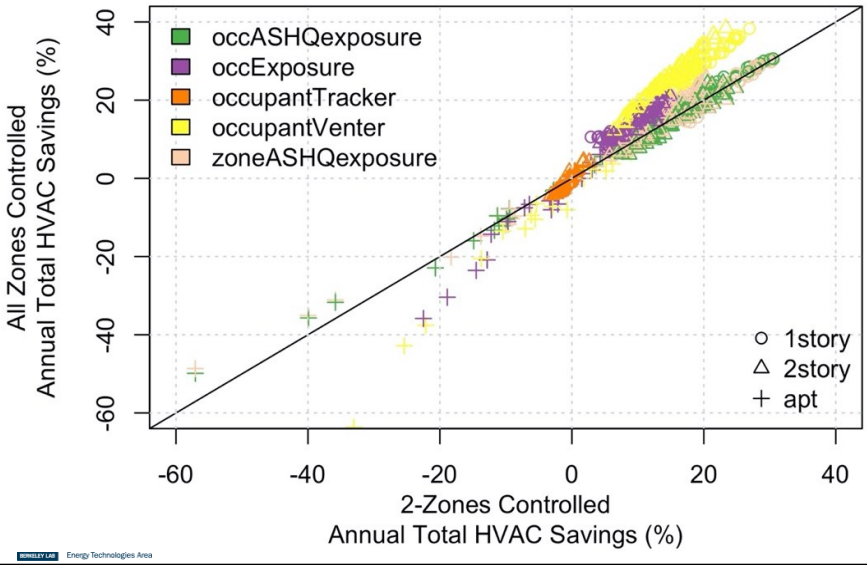
Lubliner, M. Francisco, P. Martin, E., Walker, I. Less, B., Viera, R., Kunkle, R. and Merrin, Z. (2016). Practical Applications and Case Study of Temperature Smart Ventilation Controls. Thermal Performance of the Exterior Envelopes of Buildings XIII, ASHRAE/DOE/BTECC

Photo thanks to Mike Lubliner

Field Measurement of Temperature Control



More zones does not necessarily mean more savings



Best controllers saved 10-25% of ventilation energy compared to about 7% for non-zoned versions

BUT

Most also increased contaminant concentrations by up to 20%

Example zonal controllers

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

occupantTracker – Flows directed to occupied zones. Total airflows are unchanged. It is possible for a single occupied zone to receive the full dwelling airflow rate.

occExposure – Zones are vented if any person in the zone has an integrated relative dose greater than 1, or if the zone relative exposure is greater than 1. Personal exposure in one zone can be compensated for by increased ventilation in another zone

zoneASHQexposure – Zones are vented if the zone has an integrated relative dose greater than 1, or if the zone relative exposure is greater than 1. Controls the zone Generic contaminant concentration to be the same as the steady-state zone concentration that would occur at the uncontrolled annual ventilation rate

occASHQexposure – This is the same control strategy as occExposure, but instead of using controller estimates of relative exposure and dose, it controls the zone Generic contaminant concentration to be the same as the steady-state zone concentration that would occur at the uncontrolled annual ventilation rate