Smart Ventilation

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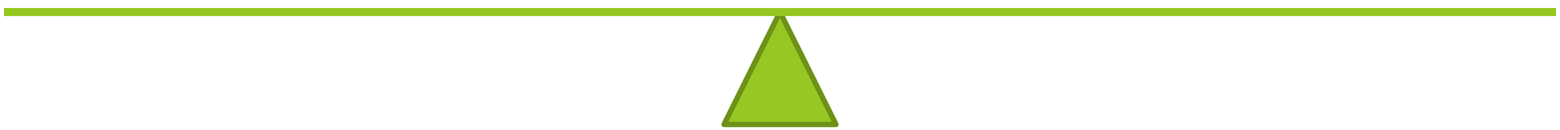
Home Ventilation

A classic balancing act

Ventilation is essential to remove and/or dilute indoor pollutants	Energy is required to condition ventilation air and operate fans



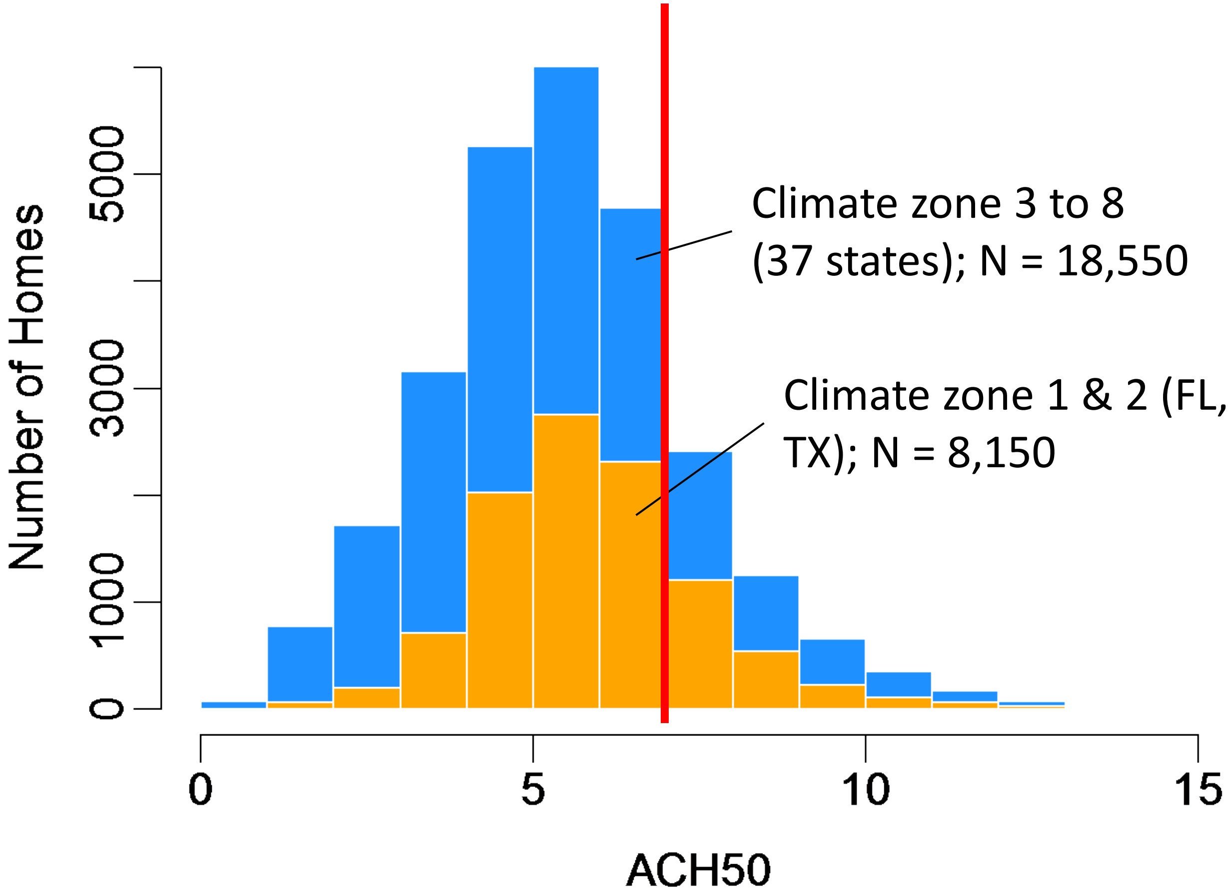
More air flow = better IAQ

More air flow = more energy

Smart Ventilation aims to minimize the energy penalty for ventilating

Homes are getting tighter

- Mean US home: 12 ACH50
- Homes since 2000: 80% < 7 ACH50



Mechanical ventilation becoming more important

- IECC <3 or <5 ACH50
- R2000 requires <1.5 ACH50
- PH requires <0.6 ACH50
- Using divide by 20 rule of thumb for natural air changes:
- IECC: 0.15 ACH to 0. 25 ACH
- R2000: 0.075 ACH
- PH: 0.03 ACH

Acceptable IAQ target: 0.3 to 0.35 ACH
We NEED mechanical ventilation

Indoor Sources: Biological agents

Indoor Sources: Chemicals

Indoor Sources: Combustion

Outdoor Sources

Outdoor Pollutants

- Outdoor pollutants (e.g. ozone, particles) can pose a serious health risk

- Certain times of day elevated levels of pollutants in outdoor air
- If outside air worse than indoor air negative energy & health benefit
- Shelter in place for rare outdoor air events – gas well blow out, chemical factory explosion, etc.

Smart ventilation needs to minimize ventilation if outdoor conditions are poor

Identifying Contaminants of Concern

- We live in a complex soup of many agents
- Which have the biggest health impact?
- Disability Adjusted Life Years: DALYs

Top 3:
PM2.5
Formaldehyde
NO_2

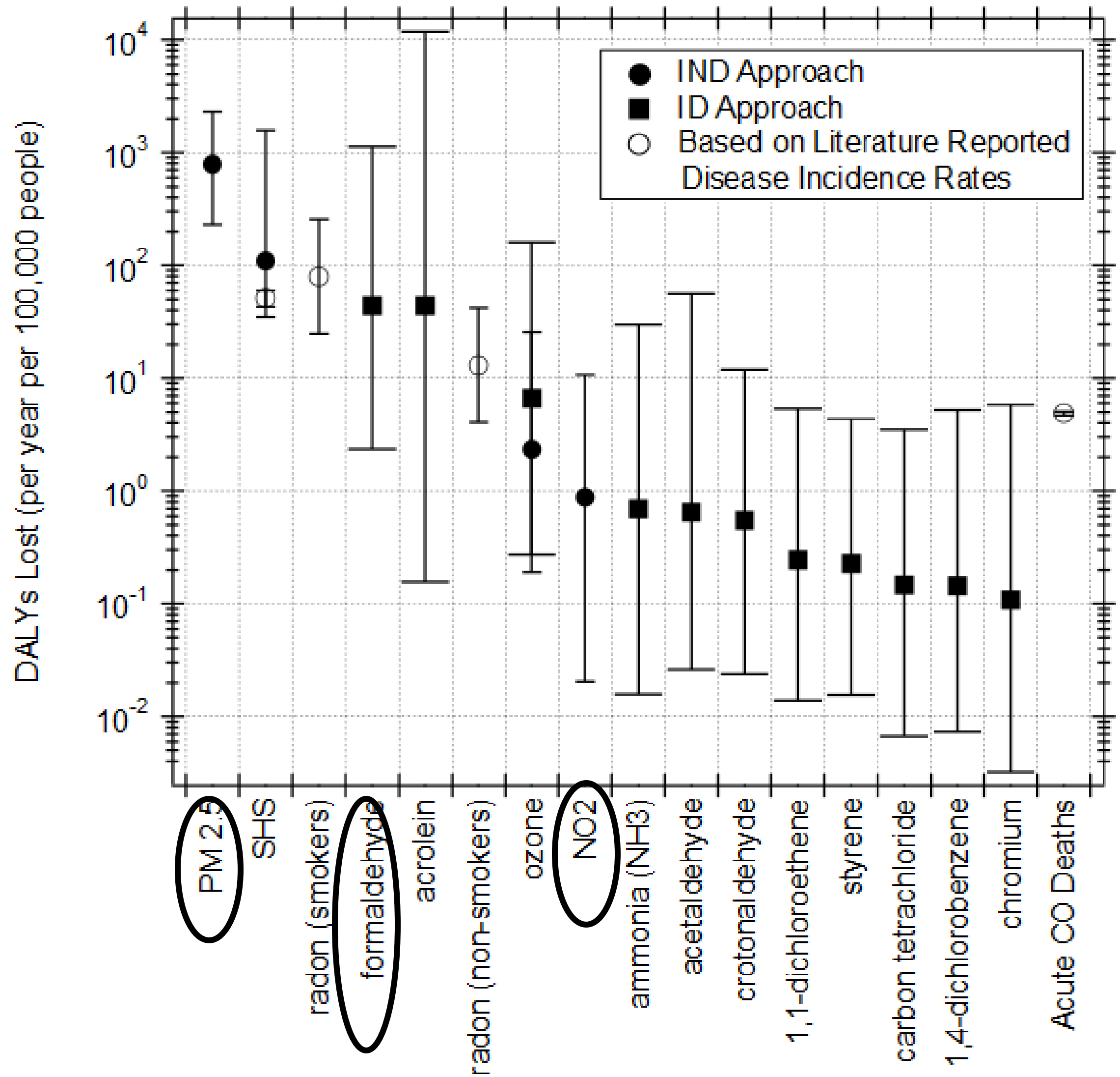


Image source: Logue et al. (2012)

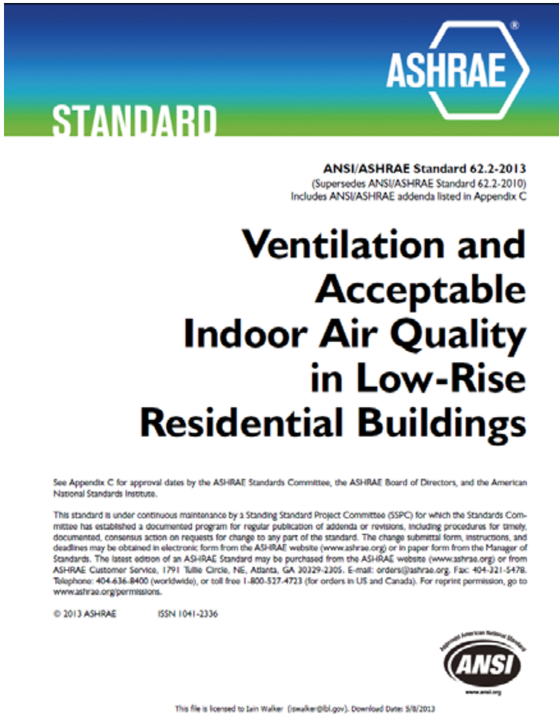
A reference for smart ventilation

- ASHRAE 62.2 specifies MINIMUM ventilation rates for homes
- Local exhaust in high pollutant areas: kitchens and bathrooms
  - Bathrooms: 50 CFM (25 L/s) on-demand, or 20 CFM (10 L/s) continuous.
  - Kitchen: 100 CFM (50 L/s) on-demand (a range hood) , or 5 ACH continuous, based on kitchen volume.
- Whole house ventilation
  - For everything else: people, furniture, pets
  - Dilutes pollutants

Continuous cfm = 0.03Afloor + 7.5(Nbr+1)

90 cfm for 2000 sq.ft. home

About 0.3 to 0.35 ACH → can be offset by infiltration based on a blower door test


STANDARD

ASHRAE

ANSI/ASHRAE Standard 62.2-2013
(Supersedes ANSI/ASHRAE Standard 62.2-2010)
Includes ANSI/ASHRAE addenda listed in Appendix C

Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings

See Appendix C for approval dates by the ASHRAE Standards Committee, the ASHRAE Board of Directors, and the American National Standards Institute.

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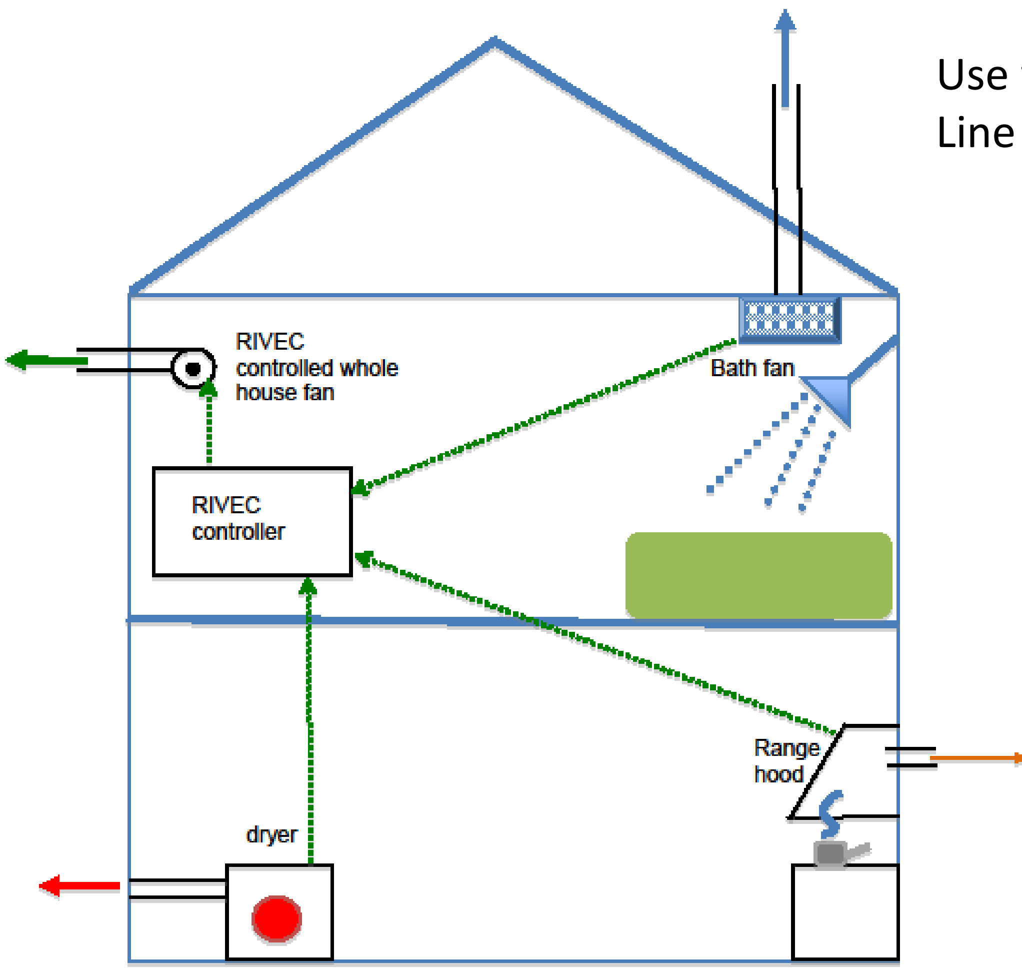
Smart Ventilation Principles

Time Shifting

- Ventilate when temperature differences are smallest
  - 2 am – 6 am in winter, 3 pm to 7 pm in summer
- This requires a bigger fan to ventilate more when it is running to offset the “off” times
- For a 4 hour window about 25% bigger
- Avoid peak times when energy grid loads are highest
- Reduce exposure to outdoor pollutants by not ventilating when outdoor concentrations are high

Other smart things to do

- Sense operation of other fans and account for their contribution



Use wireless or power
Line communication, e.g., X10

Other smart things to do

- Account for unoccupied times by ventilating an empty home less
- If you are not home you are not exposed to pollutants

- BUT….we need to protect you when you first reenter a home:
  - Limit peak exposure

Unoccupied Exposure Limits

- Prevent exposure to high pollutant concentrations upon re-entry to the home
- Limit by acute to chronic exposure limits

Concentration [μg/m^3]				
COMPOUND	Chronic	Acute		
		24 h	8 h	1 h
Formaldehyde*	1.67E+00	-	9.00E+00	5.50E+01
NO2*	4.00E+01	-	-	1.89E+02
PM2.5*	1.00E+01	2.5E+01	-	-
Lowest Acute-to-Chronic Ratio [-]	-	2.5	5.4	4.7

Controlling pollutant is PM2.5 – has the lowest chronic to acute concentration ratio of 2.5
We can allow indoor pollutants to get up to 2.5 times higher when home unoccupied

Other smart things to do

- Account for natural infiltration
  - Use measured envelope leakage
  - Use measured weather
  - Calculate natural infiltration with simple model (AIM-2)

$Qstack = Ck_{stack}(Tin\text{-}Tout)^{n}$ $\quad\quad$ $Qwind = Ck_{wind}(windspeed)^{2n}$

$Qinf =(Qstack^{1/n}+Qwind^{1/n}-1/3(QstackQwind)^{1/2n})^{n}$

OR

$Qinf = (Stack^{2} + Qwind^{2})^{0.5}$

  - C and n from multipoint blower door test
    - Or single point and assume n=0.65
  - k_{stack} and k_{wind} in lookup table based on house geometry and shelter from wind

Q: How do we do all this and maintain IAQ?
A: Ventilation Equivalency

1. Evaluate performance relative to a constant (or uniformly cycling) ventilation system
2. Calculate relative exposure and dose (24h running avg):
   - in real time as air flows vary – constant emission rate
   - for the airflows provided by the smart system (including other fans + infiltration) *relative to the continuous non-smart system*
   - for occupied times only (?)
3. Use a controller that maintains relative dose and exposure < 1

Equivalency Calculations

Turnover time

Ai = airflow rate of ALL fans

Δt = time step

$$\tau_i = \frac{1 - e^{-A_i \Delta t}}{A_i} + \tau_{i-1} e^{-A_i \Delta t}$$

Relative Exposure, R

Aeq = target air flow rate from 62.2

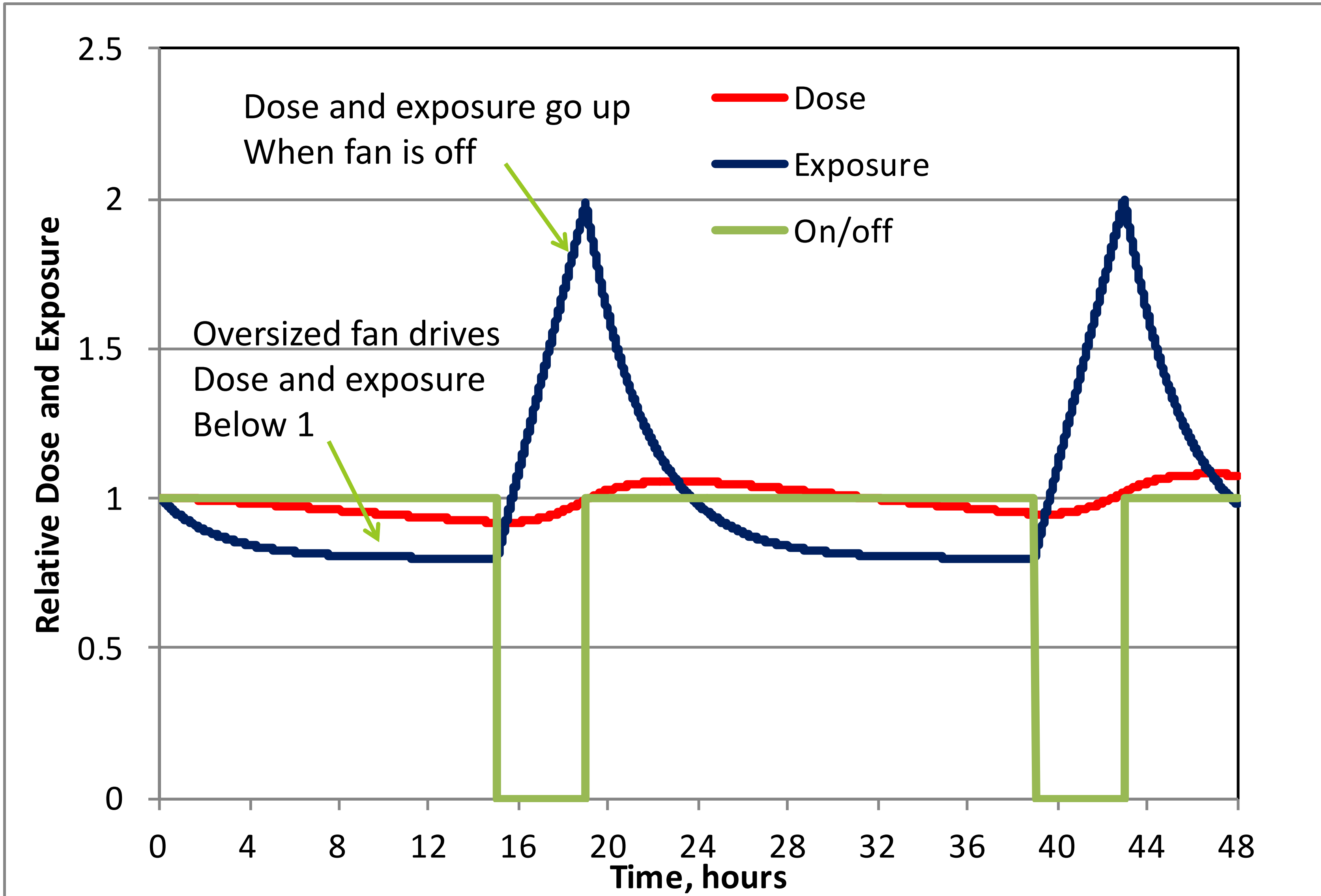
$$R(t) = A_{eq} \tau_e(t)$$

Relative Dose di = dose at the ith timestep

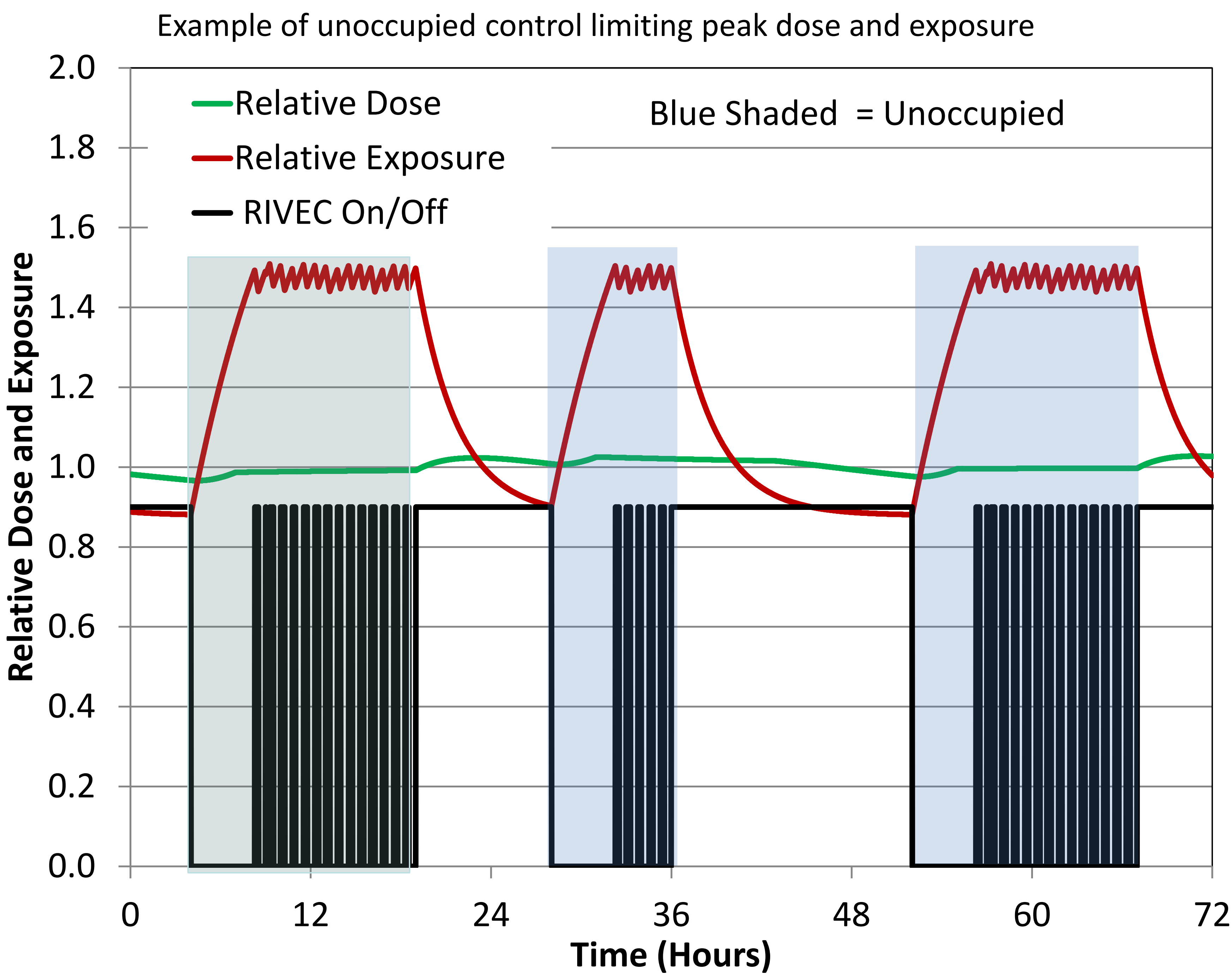
Recursive 24 hour running average

$$d_i = A_{eq} \tau_i (1 - e^{-\Delta t / 24hrs}) + d_{i-1} e^{-\Delta t / 24hrs}$$

Illustration of Relative Dose and Exposure



Dose and exposure need to average to be 1



Example of unoccupied control limiting peak dose and exposure
Relative Dose
Relative Exposure
RIVEC On/Off
Blue Shaded = Unoccupied
Relative Dose and Exposure
Time (Hours)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
12
24
36
48
60
72

Residential Integrated VEntilation Controller - RIVEC

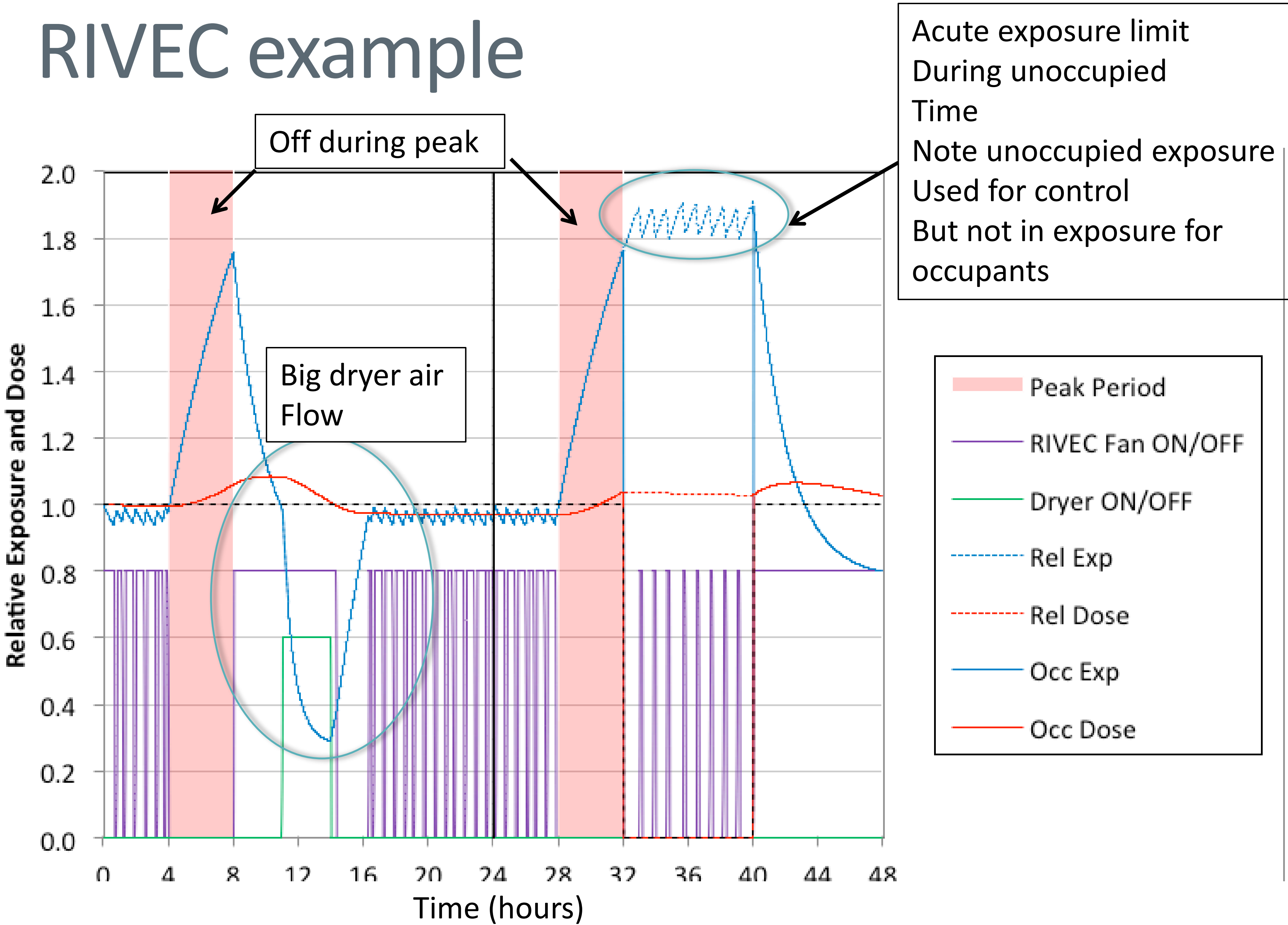
- Specific implementation of relative dose and exposure approach
- Uses calculated relative dose and exposure to control the whole house ventilation fan
- Deliberately turns off whole house ventilation at peak times
- Senses operation of other fans and includes their air flows in the relative dose and exposure calculations
- Tracks occupied and unoccupied dose and exposure
- Has a target ventilation rate input from ASHRAE 62.2
- Can include AIM2 infiltration model to calculate natural infiltration
- Needs a larger fan to ventilate more when energy impacts are less
  - Current algorithms require 25% oversizing – empirically determined due to complexity and variability of exogenous ventilation

Change fan status every 10 minutes: on if exposure > 0.95 or dose > 1

RIVEC smart controller

- Inputs for controller:
  - Target ventilation rate in air changes per hour (from ASHRAE 62.2)
    - Floor area of house
    - Volume of house
    - Number of bedrooms (a surrogate for the number of occupants)
  - Airflow capacities of each exogenous mechanical ventilation system (e.g. bathroom fans, kitchen range hoods and clothes dryers)
  - Infiltration contribution to ventilation from simple model (optional)
    - Envelope leakage + house geometry (number of stories, foundation type)
    - Weather data
  - Peak hours for turning off the whole-house fan
    - 4 am to 8 am heating, 2 pm to 6 pm cooling
  - Airflow capacity of the whole-house mechanical ventilation system – usually 25% more than for continuous operation
  - Occupancy

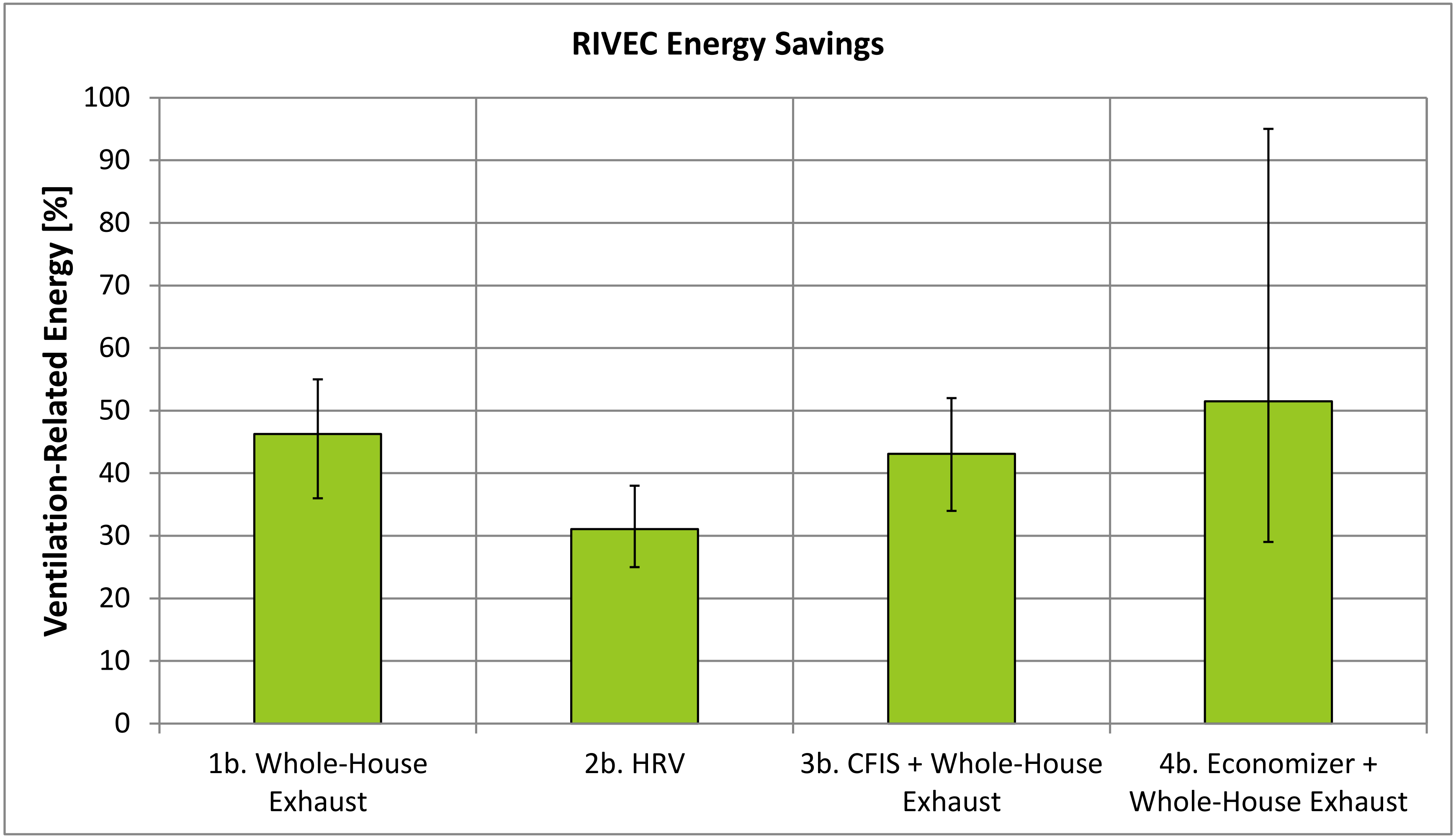
RIVEC example



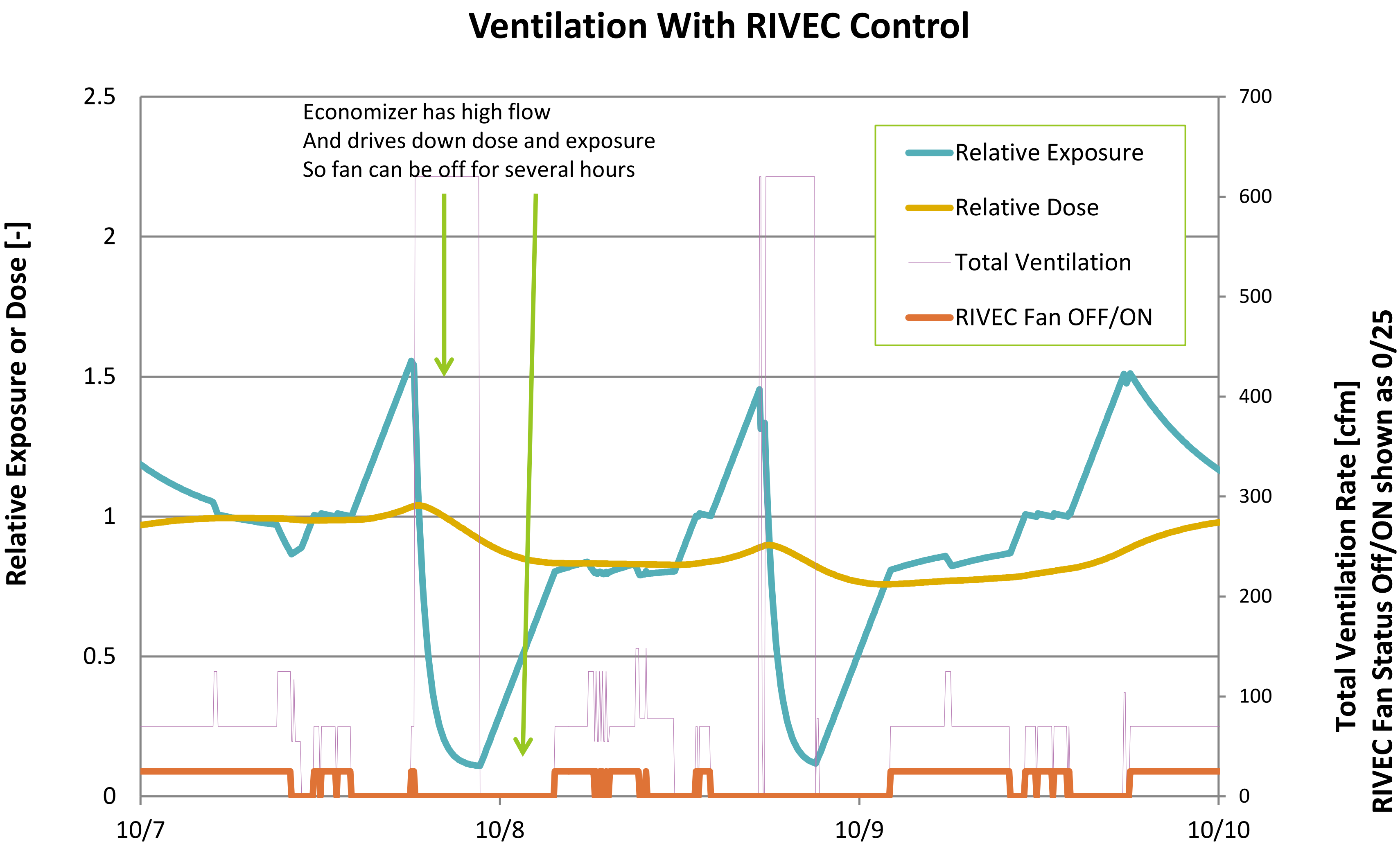
Performance capability from simulations

- Saves at least 40% of ventilation energy (fan power + conditioning)
- Robust independent of climate, house size & envelope leakage
  - 500 – 2000 kWh/yr for typical house depending on climate
- Reduce peak power by 2 kW
- No exposure to pollutants at acute levels

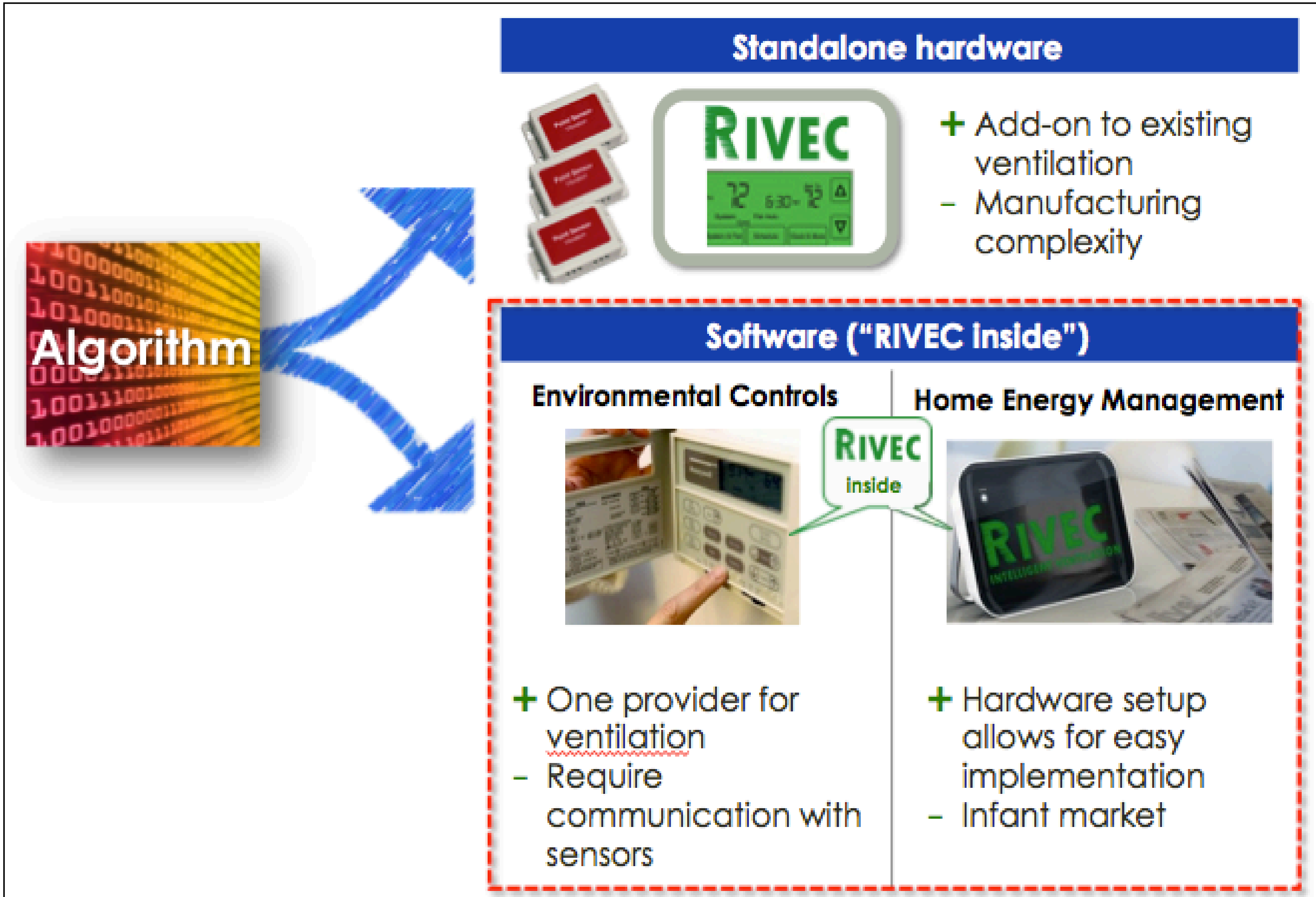
RIVEC Energy Savings – average over all US Climates



Pilot Study Field Results



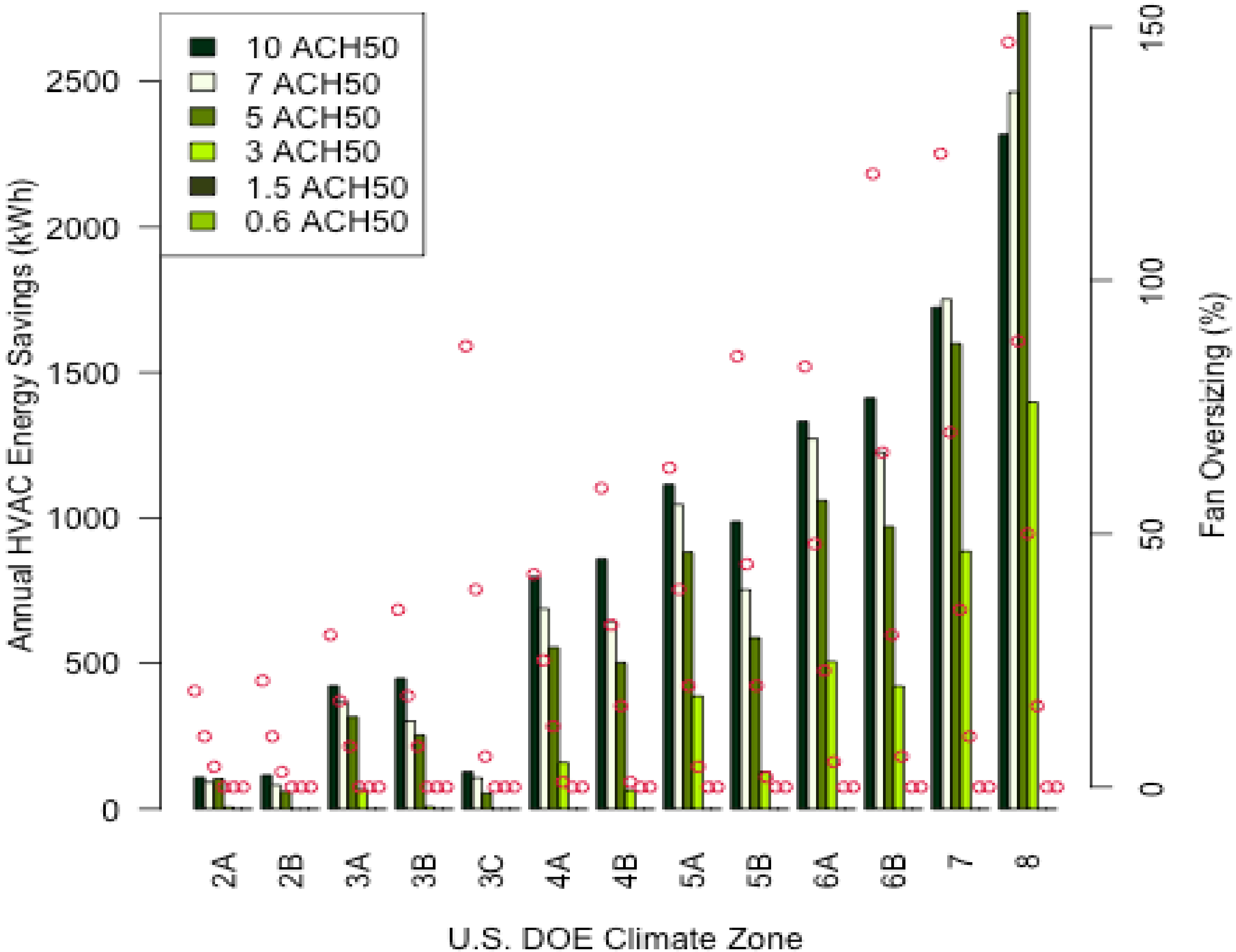
Implementation?



Temperature Control

- Tries to maximize benefits of existing air leakage
  - Could be good for weatherization programs
- Turns ventilation fan off when outdoor temperature is below a certain limit:
  - 5C (41F)
  - 25th percentile of outdoor temperature
  - “Infiltration” cut-off temperature: Uses AIM-2 infiltration model (stack only) - depends on size of fan, air tightness, climate.
- Operates upsized exhaust fan to get correct equivalent dose
- *Smarts* are in pre-calculation of correct fan size
  - Installed control is just temperature switch
  - Use an excel spreadsheet (or an app)

Temperature control example

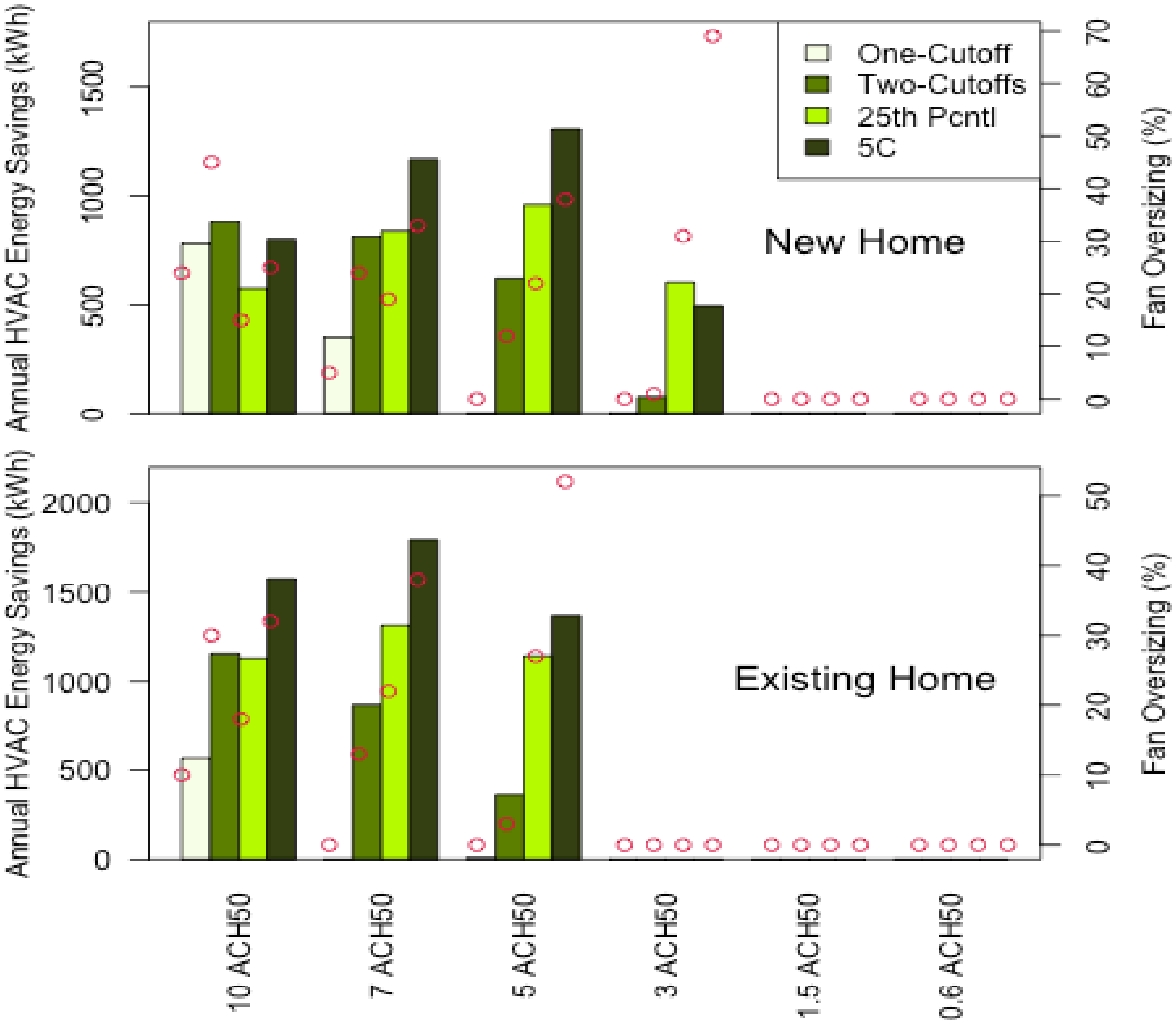


More fan oversizing
For leakier homes

More energy savings
In leakier homes
No effect below 2 ACH50

Best in colder climates

Other Control Options



Simple 5C (41F) cutoff
Works well

New vs. existing – different 62.2 requirements

Temperature Control: Estimated Results

- Saves up to 6% of HVAC energy
  - Depending on climate and leakage
  - Optimum control varies by climate and house leakage
- Works best in homes 5 ACH 50 and greater
  - Tight houses don’t have much infiltration to use
  - Beyond 10 ACH50 fans too small to have an effect

- May fill weatherization need
- Fan sizing and cutoff temperatures not independent: pick a fan oversizing and then calculate optimum cutoff temperature using computer tool

Guidance table for selecting temperature control

U.S. DOE Climate Zone	10 ACH_{50}	7 ACH_{50}	5 ACH_{50}	3 ACH_{50}	1.5 ACH_{50}	0.6 ACH_{50}
1	None	None	None	None	None	None
2A	Q25th	Q25th	Q25th	Q25th	5C	5C
3A	Q25th	Q25th	Q25th	Q25th	Q25th/5C	None
4A	Inf2/5C	5C	5C	5C	None	None
5A	Inf2/5C	5C	5C	5C	None	None
6A	Inf2/5C	5C	5C	5C	None	None
7	Inf2/5C	5C	5C	5C	None	None
8	Inf2/5C	5C	5C	5C	None	None

Example of Optimal Single Cut-Off Temperatures in CZ 5A, 50% Oversizing

ACH50	Age	Optimal Cut-Off Temp (C)	***Estimated*** HVAC Savings (kWh)	Change in Relative Exposure
10	New	11.7	1574	0.000632
10	Existing	12.7	568	0.000546
7	New	10.8	1542	0.00029
7	Existing	9.3	2156	0.004393
5	New	9.0	1615	0.002718
5	Existing	7.5	3003	0.002951
3	New	6.4	2262	0.002723
3	Existing	3.2	2419	0.007044
1.5	New	0.2	751	0.007744

Field measurements of temperature control

- Long term monitoring of two homes
  - One with Washington State University – a deeply retrofitted home
  - One with University of Illinois – typical midwest home
- Flip-flop – one week controlled one week continuous
- Measure energy use and indoor T, RH, CO_2
- Come back with results next year....

Photo thanks to Mike Lubliner

Smart Ventilation Advantages for High Performance Homes

- Get credit for systems that vent directly outside:
  - Kitchen Ventilation
  - Bathroom Ventilation
  - Clothes Dryers
- Get credit for passive stacks (if monitored)
- Allow use of simpler whole house ventilation systems, e.g., exhaust fans rather than HRV/ERVs
  - This can simplify HPH design and construction and allow use of less expensive systems
- Smart ventilation allows credit for:
  - Ventilation precooling (Economizers). Good in hot dry climates (like CA) – helps with HPH overheating issues

Where to now?

- In discussion with several equipment and control companies to use this approach
  - Integration with heating/cooling and other controls infrastructure

- Evaluate potential for humidity control in hot humid climates with FSEC and others from DOE Building America
- Evaluating outdoor temperature control with Building America partners
- How to get control strategies accepted/adopted in codes & standards and how to include them in modeling: code compliance/HERS etc.
  - Add equivalence calculation procedure to ASHRAE 62.2