SVACH

TAC Meeting #1

April 3rd 2017

Project Background

- On the path to ZNE homes air tightness is increasing
  - Less natural infiltration
- Need to ensure that IAQ is maintained
  - More mechanical ventilation
- This project will develop:

1. Smart ventilation technologies to allow for mechanical ventilation while reducing energy and peak demand
2. IAQ metrics to allow for optimizing ventilation
   - E.g., Comparing difference pollutants or allowing zonal approaches

- Phase I – generic contaminants (e.g., ASHRAE 62.2)
- Phase II – specific contaminants of concern

Technical Project Tasks

1. State of the Art Review
   - Draft Completed + 2 draft Journal Articles
2. IAQ Metrics
   - Getting beyond air flow requirements
   - In collaboration with DOE efforts
3. Single Zone Technology Evaluation
   - Find ways to better ventilate high performance California homes
   - Save energy and reduce peak demand
   - Maintain or improve IAQ (outdoor pollutants, source control…)
4. Multi-Zone Technology Evaluation
   - Are there better ways to ventilate if homes are zoned for ventilation like they are for heating/cooling?

State of the Art Review

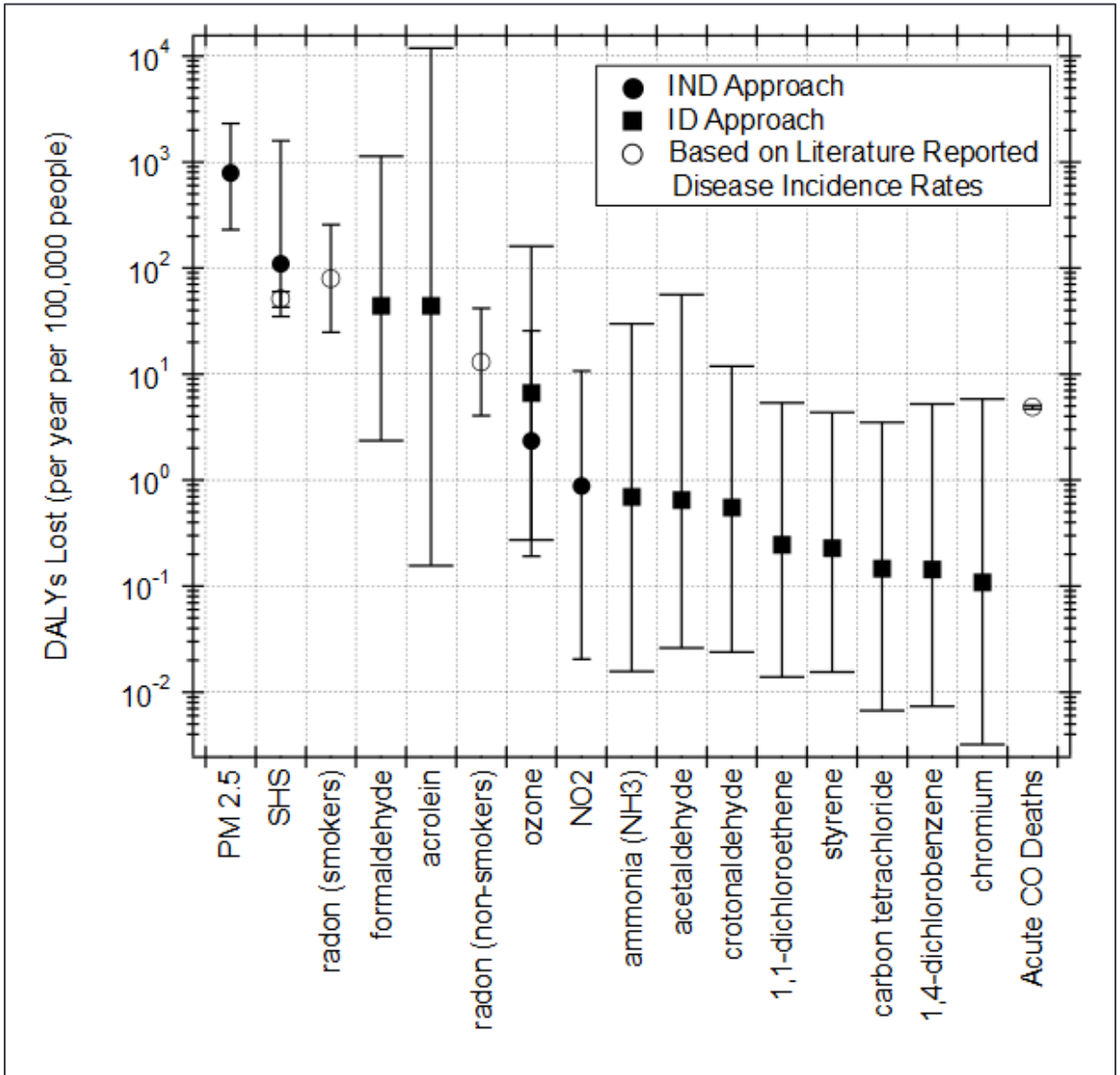
- Review the published literature for information on new and existing California homes including air leakage and ventilation systems; emission rates and COCs; equivalent dose and related exposure information
- Survey manufacturers regarding interest in or development of smart ventilation technologies
- Review availability of smart-ventilation-related market products, with particular emphasis on contaminant sensor and control technologies

State of the Art Review - Overview

- Almost 200 papers and articles reviewed
- Many international
  - Mostly Demand Controlled Ventilation (DCV)
  - DCV based on RH & CO_2 as surrogates for occupant-related pollutants and building occupancy
- Non-DCV systems currently very rare
- Limited success using outdoor temperature and TVOC-based controls
- Using other pollutants currently too expensive and not accurate enough

SOA for Contaminants of Concern

- Health metric: DALY (Disability Adjusted Life Year)
- What pollutants matter most?
- PM, NO_2, formaldehyde
- What to do about smokers and radon?



SOA for Contaminants of Concern II

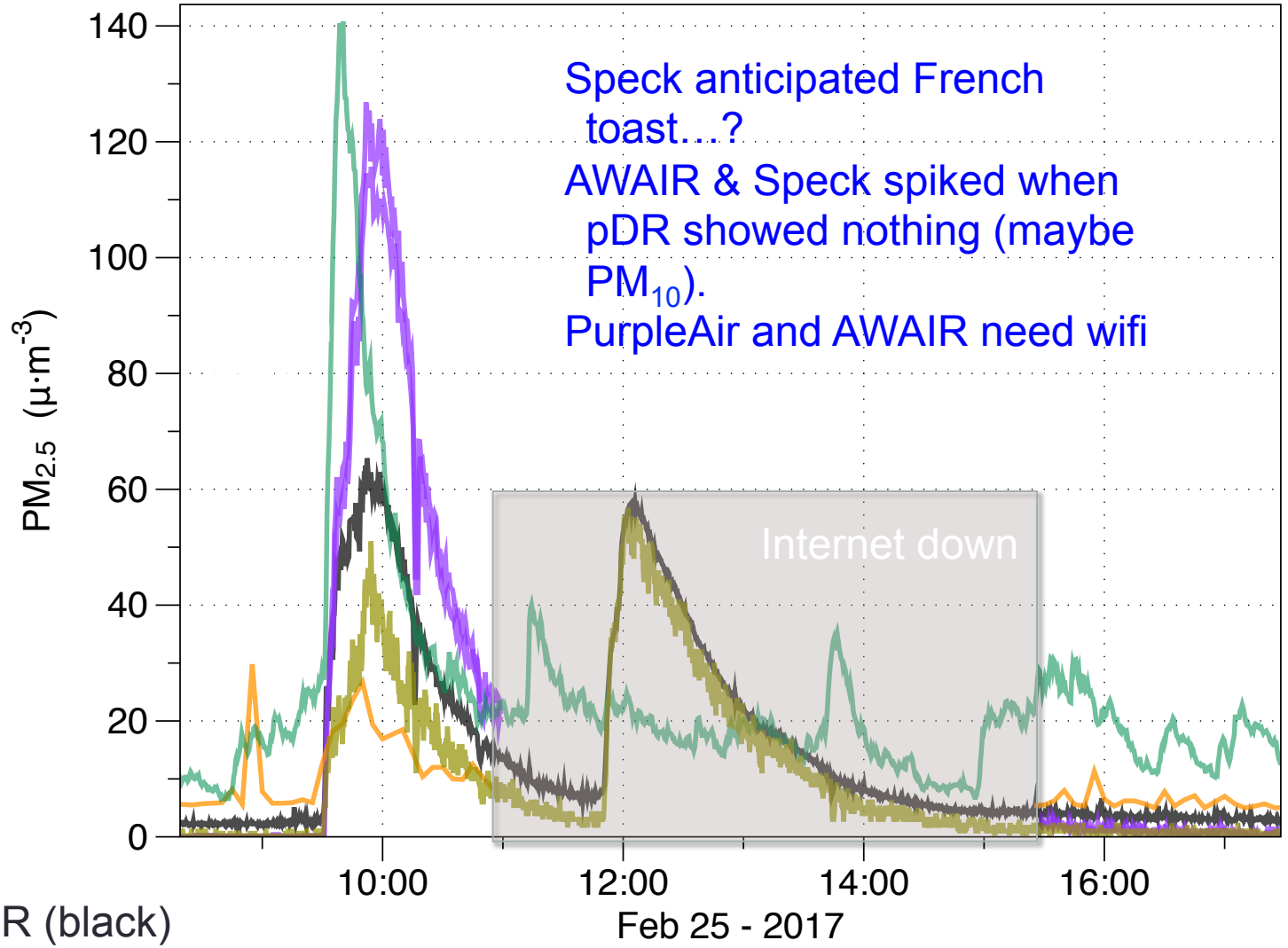
Proposed by European studies – considerable agreement!

High-priority pollutants for chronic exposure, ranked by population impact	High-priority pollutants for acute exposure
1. Particulate matter 2. Mold and moisture 3. Formaldehyde 4. Acrolein	Acrolein Chloroform Carbon monoxide Formaldehyde NO_2 $PM_{2.5}$

State of the Art Review - Sensor Technologies

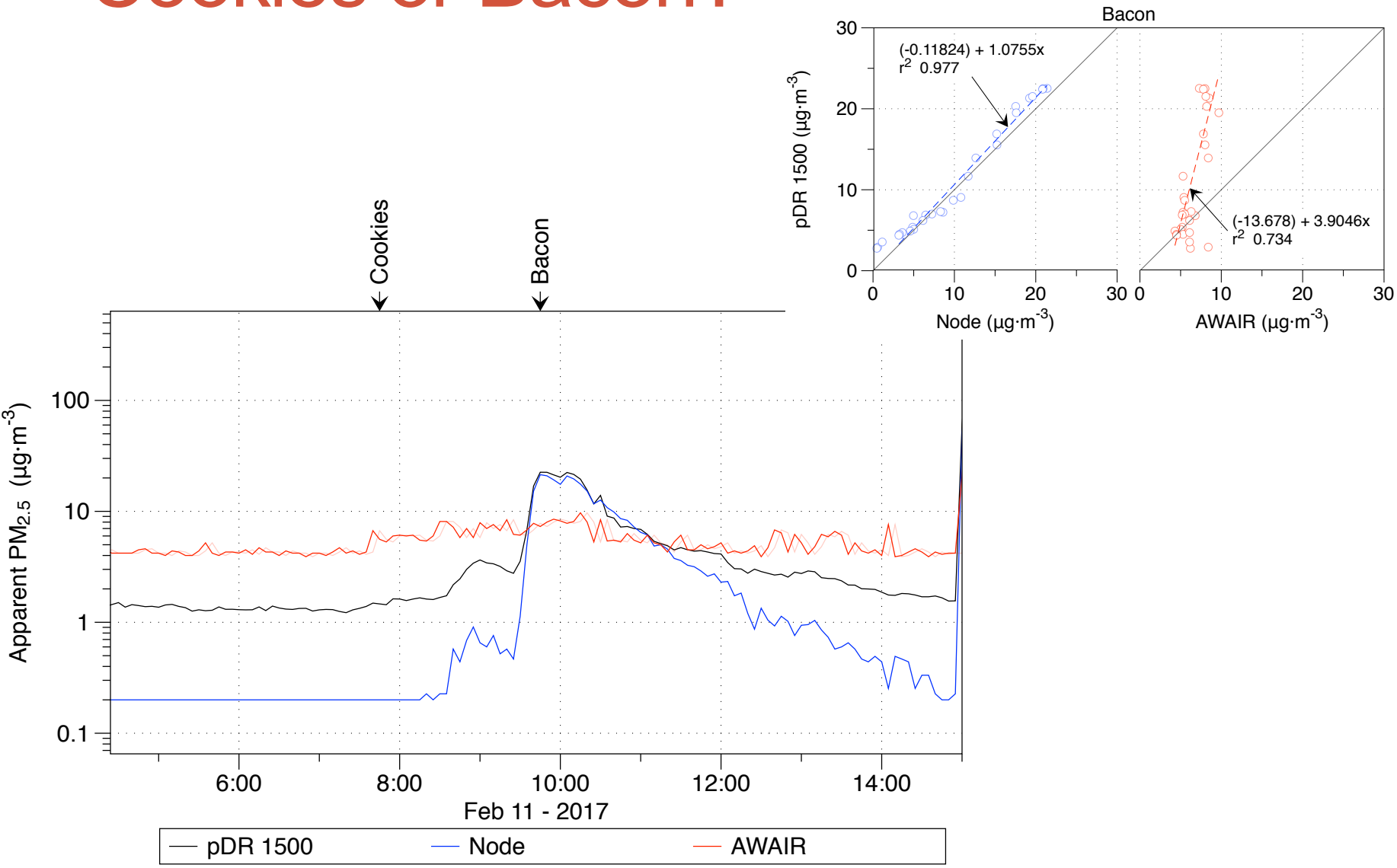
- CO_2 and RH are affordable and available
- TVOC: not very useful: which VOCs? At what concentration?
- Particles: Getting cheaper – but considerable concern about accuracy of low-cost sensors
- Individual VOCs: Getting cheaper – but considerable concern about accuracy of low-cost sensors

State of the Art Review - Low-Cost PM Sensors

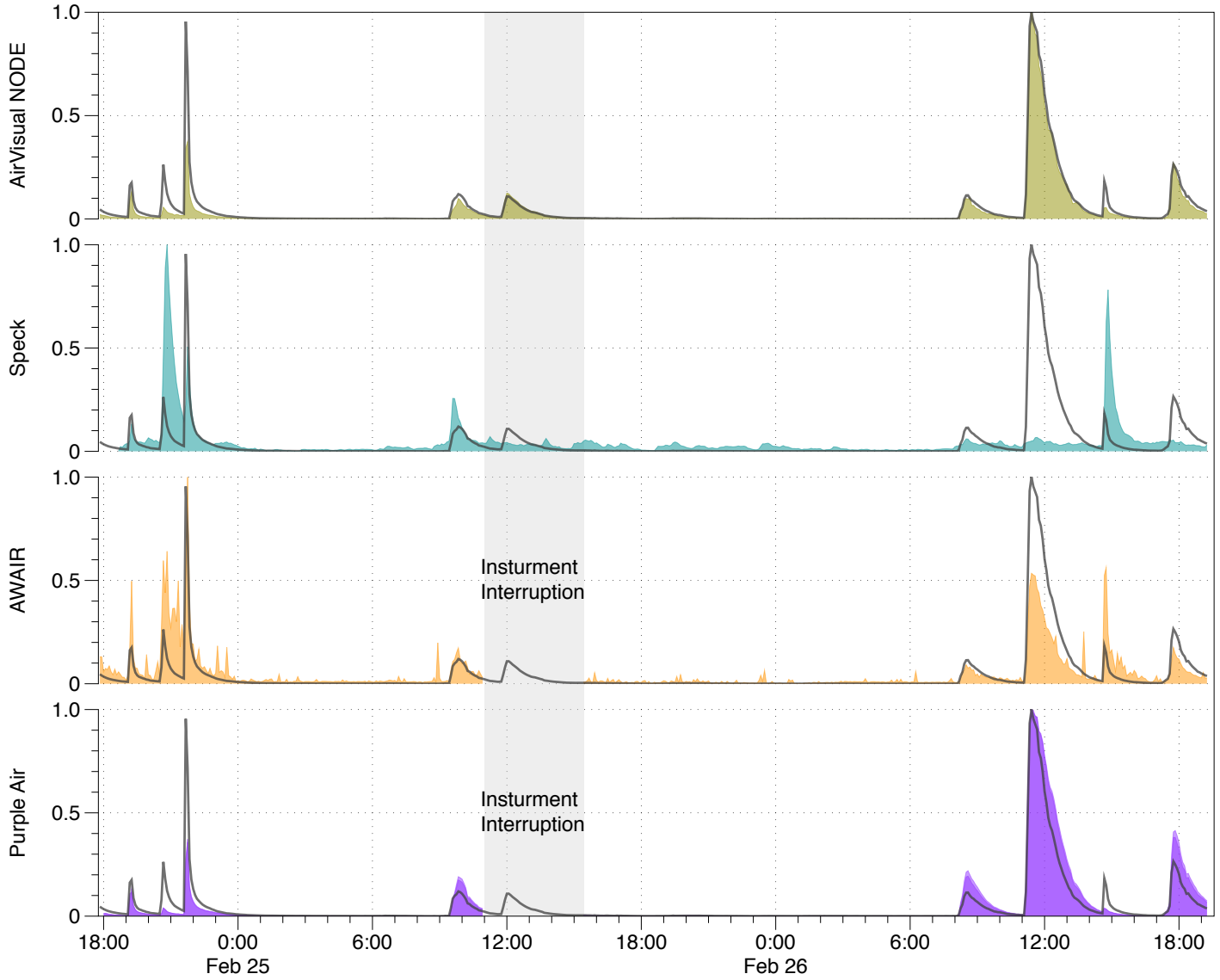


pDR (black) is research grade monitor

Cookies or Bacon?



Instruments do not see all events



State of the Art Review - Energy Saving Strategies

- **Current:** Turn off systems when unoccupied – very popular in Europe
  - Use CO_2 and RH as a surrogate for occupancy
  - Mostly ignores any non-occupant generated pollutants – very different from ASHRAE 62.2 Equivalency approach (assumes constant emission)
  - Sometimes have a low baseline ventilation rather than completely off
- **Emerging:** smarter controls based on
  - Timers to avoid known higher temperature differences
  - Measured outdoor T and/or RH
    - Onsite much harder to get right than remote access, sensor location critical
    - Remote access not 100% guaranteed – so need a good default

State of the Art Review - Multizone

- **Current controls & approaches almost exclusively single zone**
- Studies show tighter more energy efficient homes have room to room differences
  - Less natural infiltration & forced air system operation so less mixing
  - Is mixing a solution: I stink or you stink?
  - Highly dependent on door opening and ventilation system
  - Material emissions little variation
  - CO_2, RH and other occupant-related sources more variation
  - Two likely scenarios that might be useful:
    1. Bedrooms with closed doors tend to have higher CO_2 and RH (and related bioeffluents)
    2. Closing doors and isolating kitchens, bathrooms and laundry rooms might be a good idea (NO mixing)

State of the Art Review – Existing Regulation

- Four countries: Belgium, France, Netherlands and Spain
- CO_2 and RH based controls
- CO_2 and RH based IAQ evaluation – **not** health
- Use standardized calculation procedures to certify products meet IAQ requirements to get a ventilation energy use reduction (usually just a lower total flow in energy calculations)
  - Standardized occupancy for CO_2 and H_2O generation
  - Standardized home types
  - Generally heating season only
  - Generally using multizone CONTAM simulations
- Certification for fixed time: 3 to 5 years

Type of detection in dry spaces	Type of regulation of air inlets in dry spaces	Local detection in humid spaces with regulation of air outlet *Local regulation*	Local detection in humid spaces with regulation of air outlet *No local regulation*	Other or no detection in humid spaces
CO_2-local : at least a sensor in each dry space	Local	0.35	0.38	0.42
	2 zones (night/day) or more	0.41	0.45	0.49
	Central	0.51	0.56	0.61
CO_2- partially local : at least a sensor in each bedroom	Central	0.60	0.65	0.70
CO_2- partially local : at least a sensor in the main bedroom + at least a sensor in the living room	2 zones (night/day) or more	0.43	0.48	0.53
	Central	0.75	0.81	0.87
CO_2-central : at least a sensor in the exhaust duct(s)	Central	0.81	0.87	0.93
Occupancy-local : at least a sensor in each dry space	Local	0.54	0.60	0.64
	2 zones (night/day) or more	0.63	0.67	0.72
	Central	0.76	0.82	0.88
Occupancy-partially local : at least a sensor in each bedroom	Central	0.87	0.93	1.00
Occupancy-partially local : at least a sensor in the main bedroom + at least a sensor in the living room	2 zones (night/day) or more	0.66	0.72	0.78
	Central	0.87	0.93	1.00
Other or no detection in dry spaces	No, local, per zone, or central	0.90	0.95	1.00

Energy savings coefficient from Belgian Regulation

State of the Art Review – Existing Regulation - France

24 home types

Typical 40% saving

Fixed minimum flow of 10-35 m^3/hr (6-21 cfm)

CO_2 IAQ limit: time above 2000 ppm per room for heating period only

$$E_{2000} = \sum_{t=0}^{T} C_{CO_2>2000}(t) * t < 400\,000\ ppm.h$$

RH IAQ limit: time above 75% RH

$$T_{RH>75\%} = \sum_{t=0}^{T} t < 600\ h\ in\ kitchen, 1000\ h\ in\ bathrooms, 100\ h\ in\ other\ rooms$$

State of the Art Review – Existing Regulation - Spain

Fixed minimum flow when unoccupied of 1.5 L/s (3 cfm) per room for whole year

CO_2 IAQ limit: time above 1600 ppm in ***every room***

$$E_{1600} = \sum_{t=0}^{T} C_{CO_2>1600}(t) * t < 500\,000\ ppm.h$$

CO_2 annual average < 900 ppm

State of the Art Review – Existing Regulation - Belgium

Variable savings – see earlier table

Generates time above CO_2 IAQ limit:

- time above 950 ppm in every room for whole year

$$E'_{950} = \sum_{t=0}^{T} \left(C_{CO_2 > 950}(t) - 950 \right) * t$$

Compares this to reference systems to get energy savings factor

RH condensation limit: average time per month critical thermal bridges > 80% RH

State of the Art Review – Existing Regulation - Netherlands

Variable savings

Generates time above CO_2 IAQ limit: time above 1200 ppm

$$LKI_{1200} = \sum_{t=0}^{T} \left(\frac{C_{CO_2>1200}(t) - 1200}{1000} \right) * t < 30\ kppm.h$$

Compares this to reference systems to get energy savings factor

Recognizes outdoor CO_2 – index also used for time when 800 ppm above outdoors

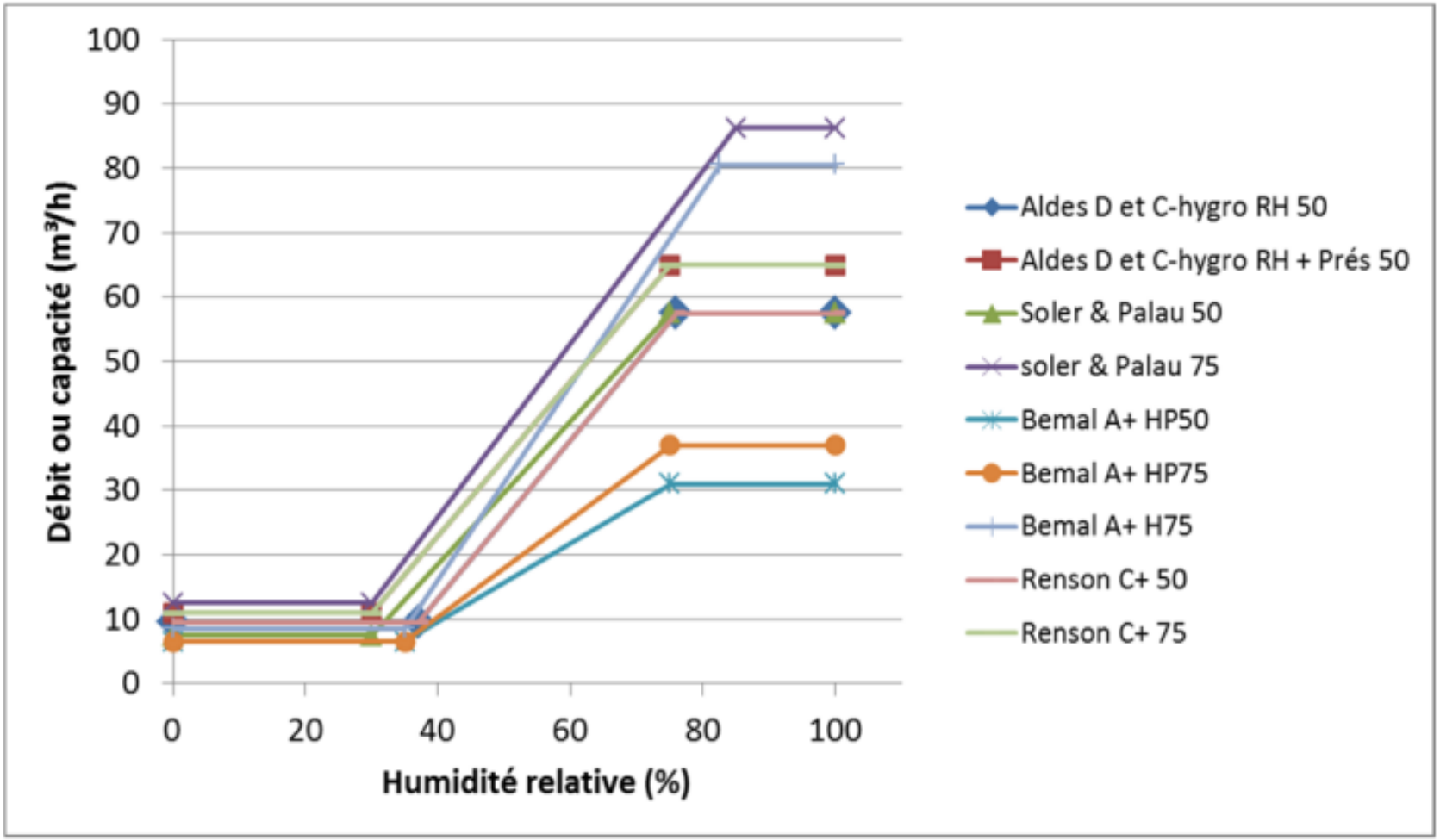
Has minimum air flow specification

State of the Art Review – European Certified Systems

Country	Number of total DCV systems	Source
France	23	http://evaluation.cstb.fr/recherche/produits-evalues
Belgium	34	http://energie.wallonie.be/fr/concepts-novateurs-liste-des-equivalences-peb.html?IDC=8825&IDD=52265
The Netherlands	37	http://www.vla.nu/gelijkwaardigheidsverklaringen/ soon on: www.dcrg.nl
Spain	3	http://www.ietcc.csic.es/index.php/es/?option=com_chronoforms&chronoform=RespuestaDIT

State of the Art Review – DCV Example Technology

Humidity controlled air inlets



Sate of the art review – Emerging Regulation In the US:

1. ASHRAE 62.2 – Ventilation Equivalence
   - Equivalent ventilation allows time varying air flow to show equivalence to constant air flow specification
2. IAQ "Equivalence" – not just air flow
   - Identify Unit Damage Estimate based on DALYs
   - Multiply concentration by UDE to get DALYS and sum over contaminants

Compound	UDE $\left[\frac{\mu DALYS}{year*person} * \frac{m^3}{\mu g}\right]$	Chronic Standard $\left[\frac{\mu g}{m^3}\right]$	Chronic Standard damage $\left[\frac{\mu DALYS}{year*person}\right]$
Priority Pollutants			
1,3 Butadiene	0.02	0.06	0.001
1,4-dichlorobenzene	0.03	0.91	0.024
Acetaldehyde	0.3	3.7	0.96
Acrolein	190	0.02	3.7
Benzene	0.08	0.34	0.025
Formaldehyde	6.8	1.7	11.4
Naphthalene	0.47	0.29	0.14
Nitrogen Dioxide	0.70	40	27
$PM_{2.5}$	500	15	7,500
Other contaminants			
Ammonia	0.23	200	46
Ozone	1.4	147	200
Crotonaldehyde	1.02	N/A	N/A

Set limits of: 8200 µDaly per person per year

Or 90 µDaly per person per year without PM

Is PM too dominant????

Advanced smart ventilation strategies – beyond just CO_2 and RH

N°	Goal	Sensor/input	Fan operation
1	Shift ventilation to times of lower temperature difference	Outdoor temperature sensor / timer	$ACH=ACH_{MIN}$ (high ΔT) ; ACH_{MAX} (low ΔT)
2	Avoid peak utility loads; especially when cooling needs are high	Timer + Utility signal	$ACH=ACH_{MIN}$
3	Reduce ventilation in empty rooms/homes	Occupancy sensors	$ACH=ACH_{MIN}$
4	Avoid outdoor pollution peaks	Outdoor pollutant (PM,O_3,HCHO) sensor Or Signals/web connection (spareheair.com)	$ACH=ACH_{MIN}$ + air cleaning system
5	Adapt ventilation rates to indoor pollutant load, calculating instantaneous exposure and long term dose	Indoor pollutant sensors	$ACH = f(C_i)$
6	Avoid acute exposure	Indoor pollutant sensors in kitchen (and baths)	$ACH=ACH_{MAX}$ $ACH=ACH_{MIN}$;never 0
7	Take credit for operation of other air systems (bath fans, clothes dryers, economizers, kitchen range hoods)	Electric sensors (on/off + speed detection)	ACH= ACH_{ASHRAE} -ACH_{others}
8	Collection of data to anticipate future adjustments	Cloud/connected platform	
9	Take credit for natural infiltration	Weather and house leakage	ACH= ACH_{ASHRAE} -ΦACH_{infi}

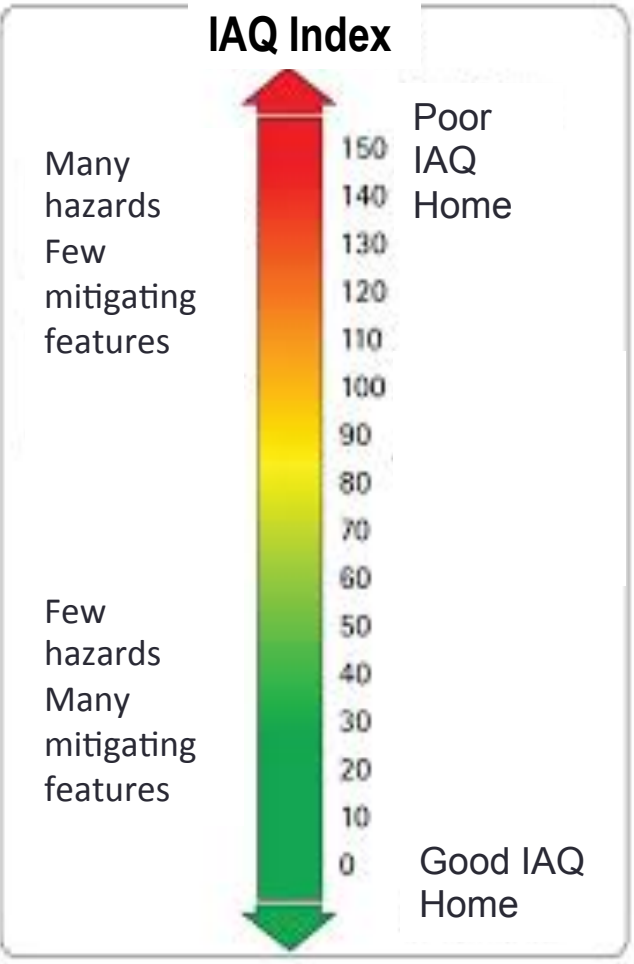
Sate of the art review – next steps:

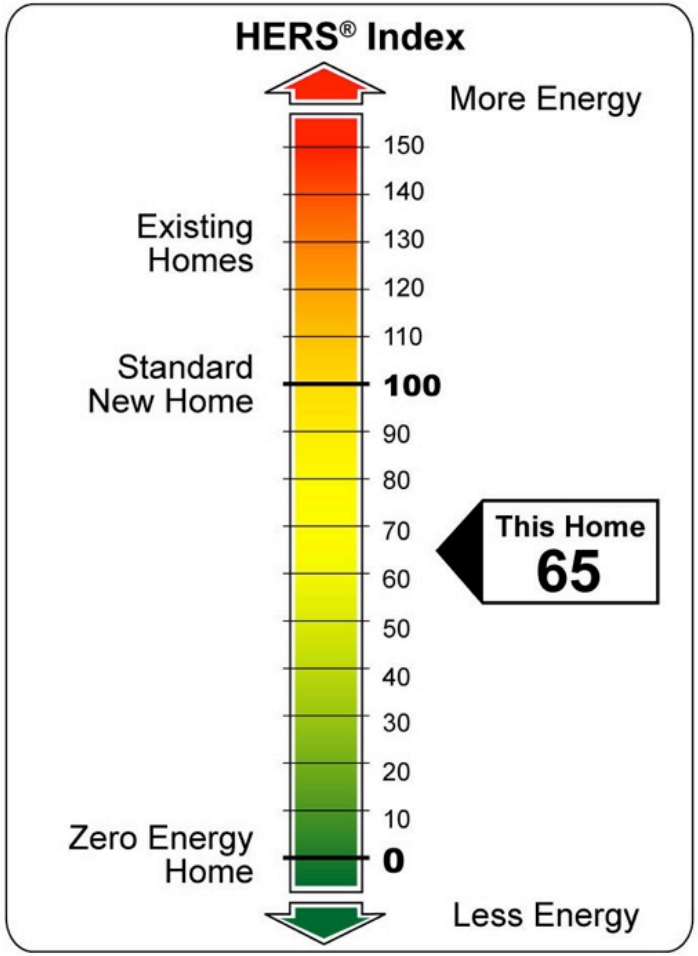
- Complete review report and journal articles
- Add information on source control – filtration
- Add more information on low-cost sensors

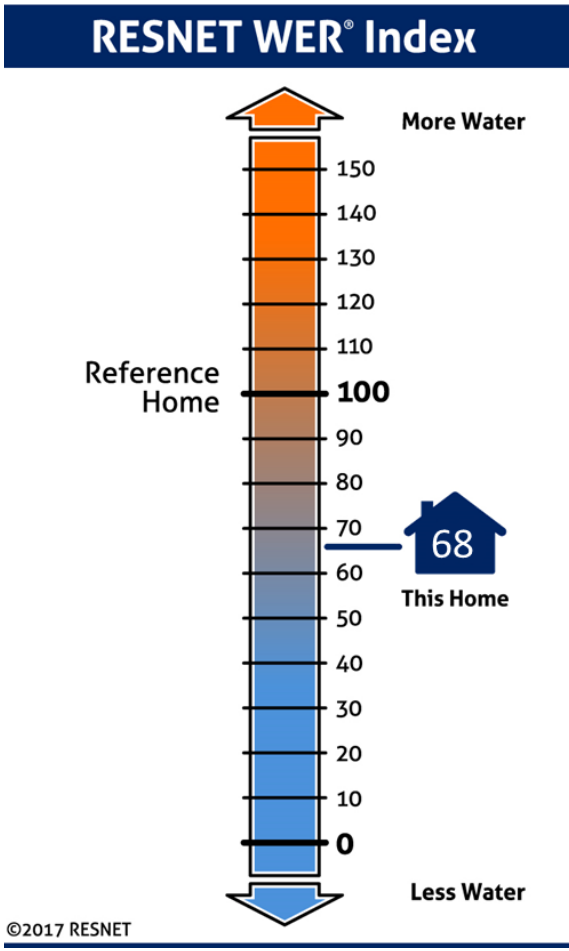
Task 2 IAQ Metrics – Quantitative Rating

- **Phase I** metrics suitable for technology evaluation
  - **ASHRAE 62.2-based**: exposure to a generic contaminant
  - Include health, moisture and odor
    - For health build on previous DALY work for comparing pollutants
  - Multi-zone approaches – includes effect of tight homes and low recirculation volume space conditioning systems
  - Room-by-room requirements and systems – ZNE home loads thermal *and* IAQ
- Expand metrics to be suitable for **Phase II** technology evaluation
  - Investigate individual contaminants of concern (COC)
  - Address occupancy impacts – ventilate less if unoccupied
  - Create IAQ screening tools in cooperation with U.S. DOE
  - DOE IAQ Scoring tool – *today's focus* – single zone only

IAQ Index – Like a HERS for IAQ







IAQ Index - Methodology

Identify potential hazards that add points to the index score

Identify Home features that mitigate hazards and subtract points, e.g.,

- A good filtration system would subtract points
- A lack of kitchen ventilation would add points

Magnitude of points based on:

- the hazard level
- how much the feature mitigates the hazard, and
- the effectiveness of the mitigation strategy

Combine three separate sub-scores: health, odor, moisture

- Health based on DALYS - Odor and moisture less clear

There is no definitive approach – expert opinion required

IAQ Index - Methodology

Health

- Use DALYs based on contaminants of concern and their likely concentrations
- Based on existing literature, plus current and soon to be started field studies

Moisture

- Various indexes: mean RH, hours above RH limit, number of times above RH limit for more than 24 hours… etc.
- Adapt ASHRAE 160 Mold Index (currently LBNL using this in Attic study for CEC)

Odor

- Most sources are from occupants
- Could use CO_2 or RH as surrogate for bioeffluents?

Odor and moisture scoring

California Department of Public Health Survey of 20 other studies:

- Observation-based – mold-related health issues happen when problems are visible

Index will identify visible mold hazards
Index will credit mitigation strategies/systems/house attributes

Odor and moisture scoring

- Identify home features that improve (or make worse) odor and moisture issues:
  - Kitchen, bathroom and toilet exhaust are good – lack of these features is bad
  - Air and moisture sealed crawlspace floor is good – bare earth is bad
  - Meeting minimum per person ventilation rates is good – going higher is better, lower is worse

Index will debit or credit for mitigating features

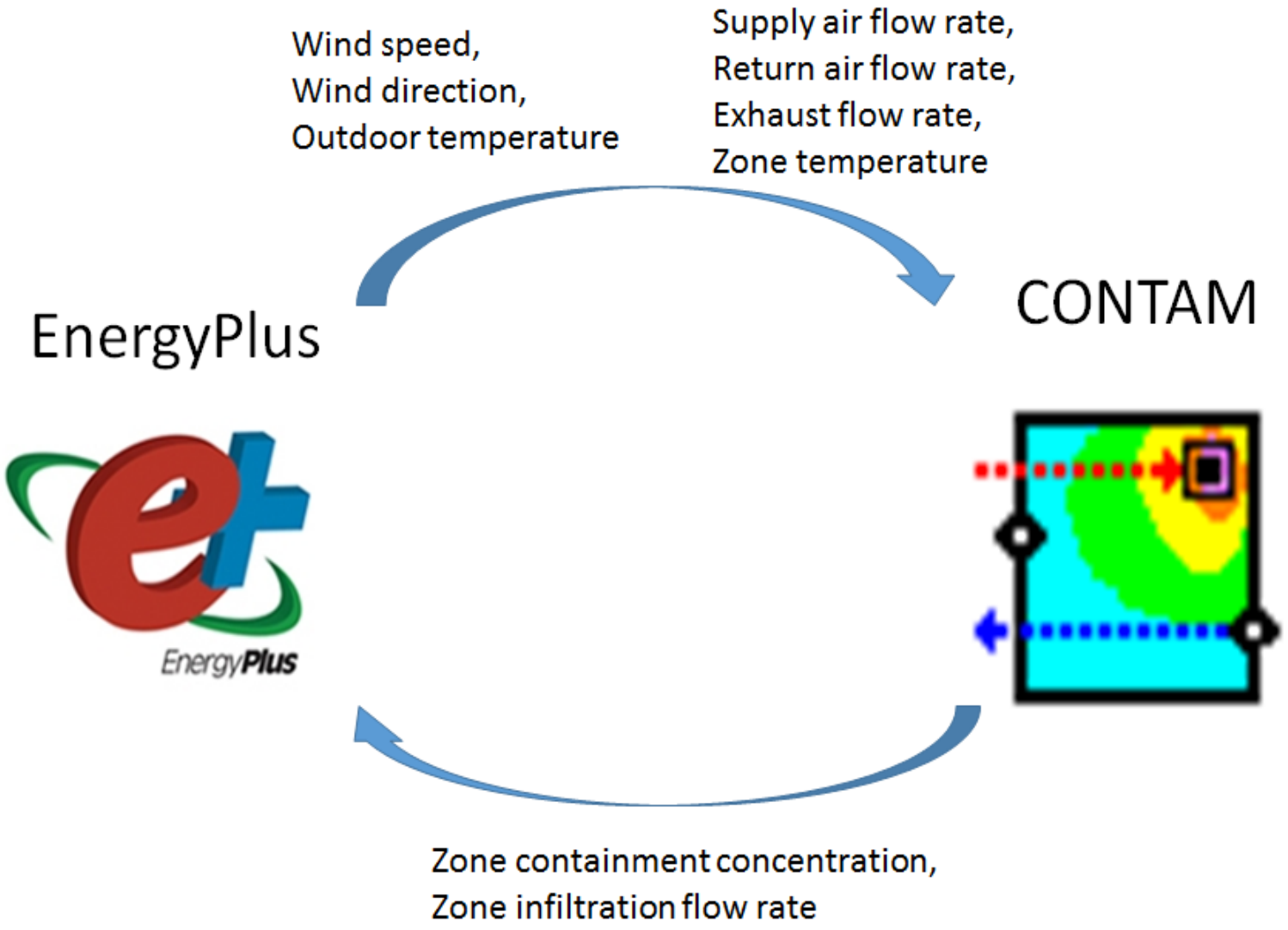
IAQ Index current status

- Getting expert input
- Engaging constituents:
  - Presentations at RESNET, EEBA and HPC (ACI)
  - Recruiting for volunteers to try it out
- Developing Beta version
  - Combines hazard level with home mitigation features and mitigation feature effectiveness
  - Effectiveness: e.g., measured air flows get a better score than non-measured systems

Phase I Technology Evaluation: Single and Multi-Zone (Tasks 3 &4)

- Simulations of different Smart Ventilation approaches
  - Results for IAQ (equivalent dose and exposure) as well as energy use and peak demand
- Use measured data from HENGH study for inputs and model validation
- **Initial plan**: use existing REGCAP software for single zone & CONTAM/EnergyPlus for multizone
- **New plan**: use CONTAM/EnergyPlus for all
- Pros: ability to compare single and multizone approaches
- Cons: need to adapt CONTAM/EnergyPlus for residential
- Draft plan sent to TAC – comments welcome

CONTAM & EnergyPlus Co-Simulation



Technology Evaluation: Single and Multi-Zone

- Estimate contaminant sources from measured concentrations and estimated ventilation rates
  - Use measured pollutants: PM, NO_2, formaldehyde, RH from HENGH study
  - Estimate natural infiltration rates from single-zone ventilation model (and possibly CO_2 decay in field test homes?): Enhanced Model from ASHRAE Handbook
  - Combine mechanical ventilation and natural infiltration using ASHRAE 62.2 Appendix C superposition
- Model Validation
  - Use contaminant sources in CONTAM/EnergyPlus and compare to measured data

Technology Evaluation: Home Characteristics

- Three homes:
  1. CEC single family prototype one-story
  2. CEC single family prototype two-story
  3. TBD in Collaboration with Aereco: apartment/multi-family option
- Three tightness levels:
  1. “Good” new home: 3 ACH50
  2. “High-performance” home: 2 ACH50
  3. Passive House: 0.6 ACH50
- Mechanical ventilation:
  - ASHRAE 62.2-2016 for fan sizing including infiltration credit
  - Exhaust fan in 2 and 3 ACH50 homes, HRV in 0.6 ACH50 home
  - Fan oversizing for smart ventilation controls: 50 to 100% depending on ventilation strategy
- Heating and Cooling:
  - High efficiency heat pump (SEER 18? EER = ?)
  - Gas furnace ?

Technology Evaluation: IAQ and Energy Evaluation

- Energy:
  - Annual kWh
  - Annual Therms
  - Peak demand reduction
- IAQ:
  - Annual Relative exposure <= 1
  - Relative exposure based on real-time calculation procedures from ASHRAE 62.2 appendix C
  - Compares exposure to contaminants for time varying ventilation to constant ventilation assuming constant emission rates
  - For occupancy – possibly change emission rate during unoccupied times – still uses same calculation procedure.
  - Peak relative exposure < 5 (for acute pollutant issues)

Technology Evaluation: Smart Control Options

- Occupancy:
  - Assume we have perfect occupancy detector
  - Fixed occupancy patterns based on bathing, cooking, away (work/ school etc.). For multi-zone we need the time in each room.
  - In Phase II look at differences between pollutants generated by occupants and those from the building
  - Reduce ventilation when unoccupied as long as equivalent exposure maintained during occupied time
- Operation of other fans:
  - Have bath, kitchen and clothes dryer fans on schedules. Include these flows in real-time dose and exposure calculations
  - Use an economizer in cooling mode and include its airflows in dose and exposure calculations

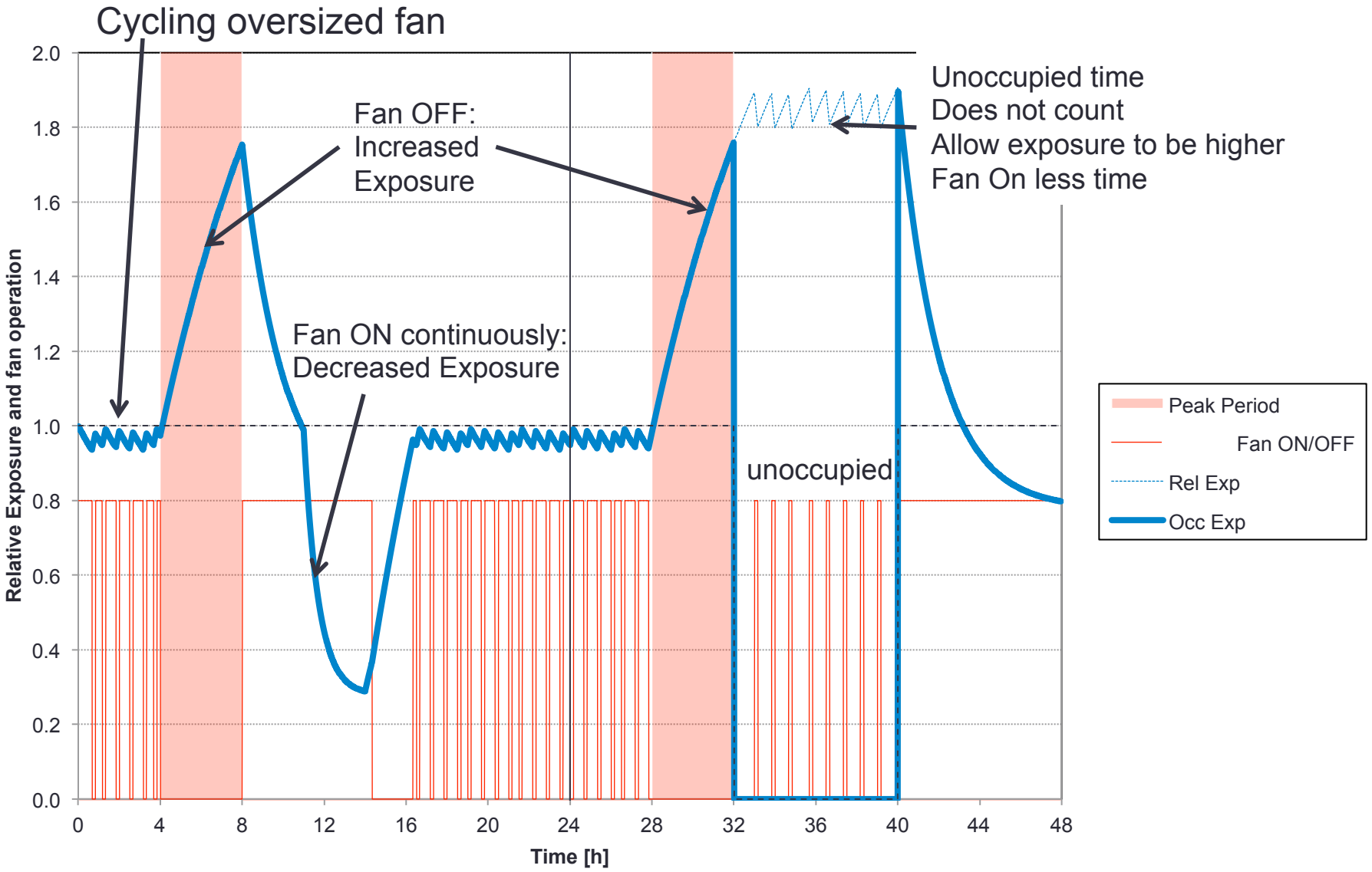
Technology Evaluation: Smart Control Options

- Contaminant Control:
  - Account for particle filtration using ASHRAE 62.2 procedures
  - Whole house ventilation requirement reduced by 20%
  - Either central forced air or air cleaner system with MERV 13 filter
  - From ASHRAE 62.2 – this needs to move 2.1 times the 62.2. total required air flow (on average for an hour)
- Time Shifting to reduce temperature differences
  - Fixed schedule: Turn ventilation off from 5-8 am for heating and 2-5 pm for cooling
  - Possibly temperature sensing: assume we can get a reliable outdoor temperature measurement. Need to use previously developed strategies for fan sizing and temperature cutoffs

Technology Evaluation: Home Characteristics

- Time shifting to avoid outdoor pollutants:
  - Use CalEPA or LBNL datasets for outdoor particle concentrations
  - Reduce or eliminate ventilation when outdoor particle concentrations above a threshold
- Zone Ventilation
  - Simulate a home with no central forced air system (assume mini-split heating/cooling)
  - Enable zonal control via HRV dampers or variable air inlets and an exhaust fan
  - Change where air is delivered in the home
  - Primary case will be night time closed bedroom door scenario: can we reduce overall ventilation if we selectively ventilate the bedrooms.

Illustrative REGCAP Example



Phase II

- Control based on specific contaminants
- Will need to use a metric like the IAQ Index
- Use same CONTAM/EnergyPlus simulation software
- Use same metrics for energy use
- For health:
  - What is the absolute minimum set of contaminants to control?
    - Particles, formaldehyde, moisture, CO_2,
    - Radon?, other VOCs (and which ones)?,
- Can we develop an odor sensor or is the CO_2/RH/ Occupancy surrogate good enough?

US DOE Technical Support

- Support for: algorithm development, simulation tool development, laboratory evaluation of technologies, and literature reviews
- Travel and related support for participation in ASHRAE 62.2 development and related national (and international) meetings.
- Travel support to attend other national meetings of interest, including relevant builders' and retrofitters' conferences and similar events

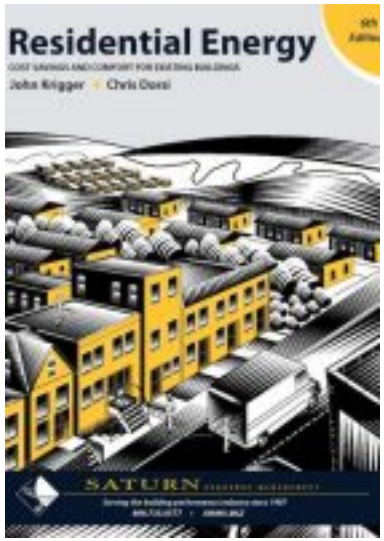
Building AMERICA
U.S. Department of Energy

Aereco Technical Support

- Aereco is a manufacturer of advanced demand-controlled ventilation products
- Aereco has agreed to make available appropriate test sites (and equipment) using their current technology. Aereco will also provide technical expertise on the performance of its specific equipment and, as needed, materials.

Project Management – Saturn Resource Management

- For Technology Transfer Task – create a public website to share project results
- Saturn Resource Management is one of the leading publishers, curriculum developers, and training organizations in the building performance business



Questions & Comments