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Building AMERICA
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U.S. DEPARTMENT OF ENERGY

Clearing the Air: National Baseline IAQ Study

RESNET

February 26, 2018

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OUTLINE

IAQ Score

Previous Studies

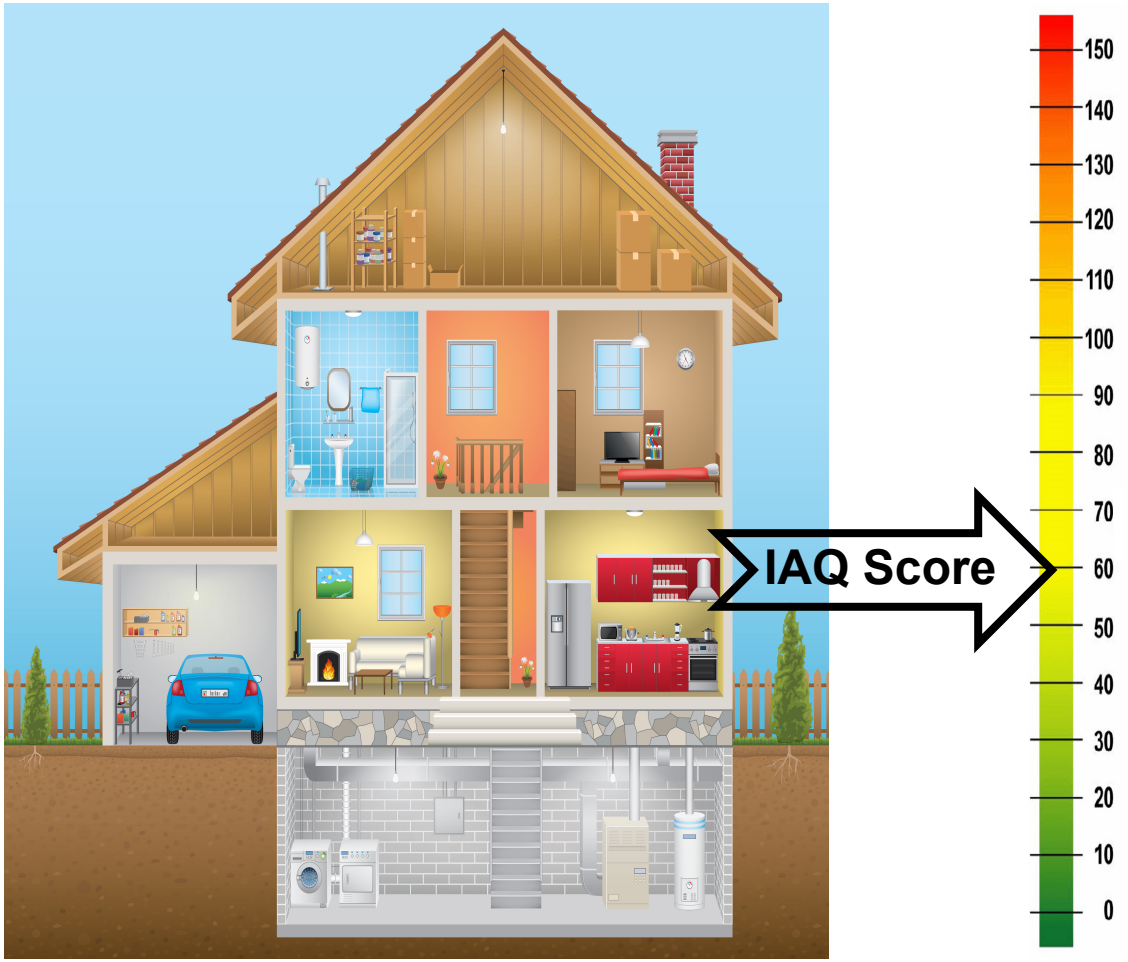
Recent LBNL Study in CA

New DOE Building America Study

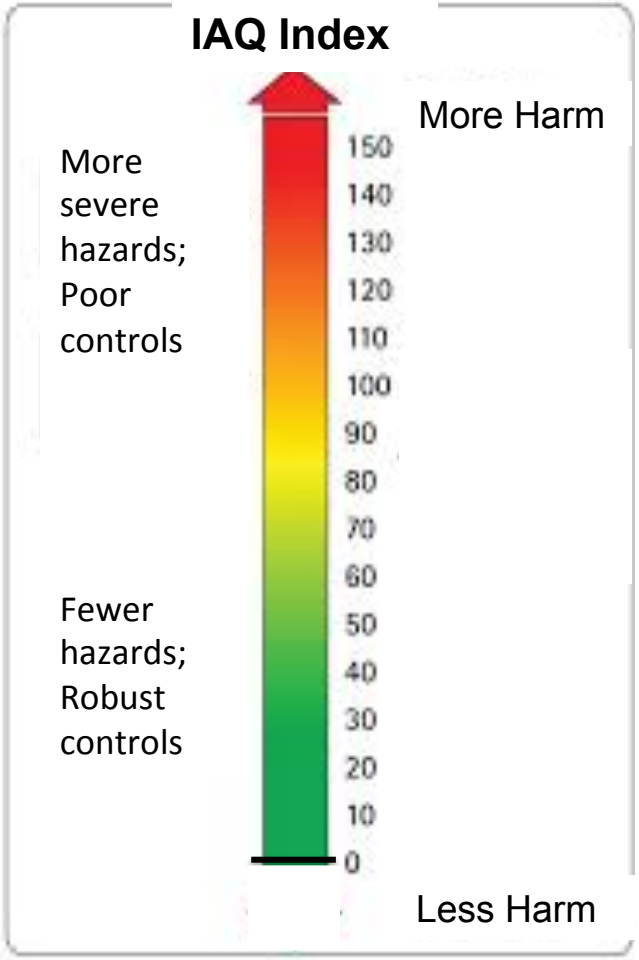
IAQ Score Development

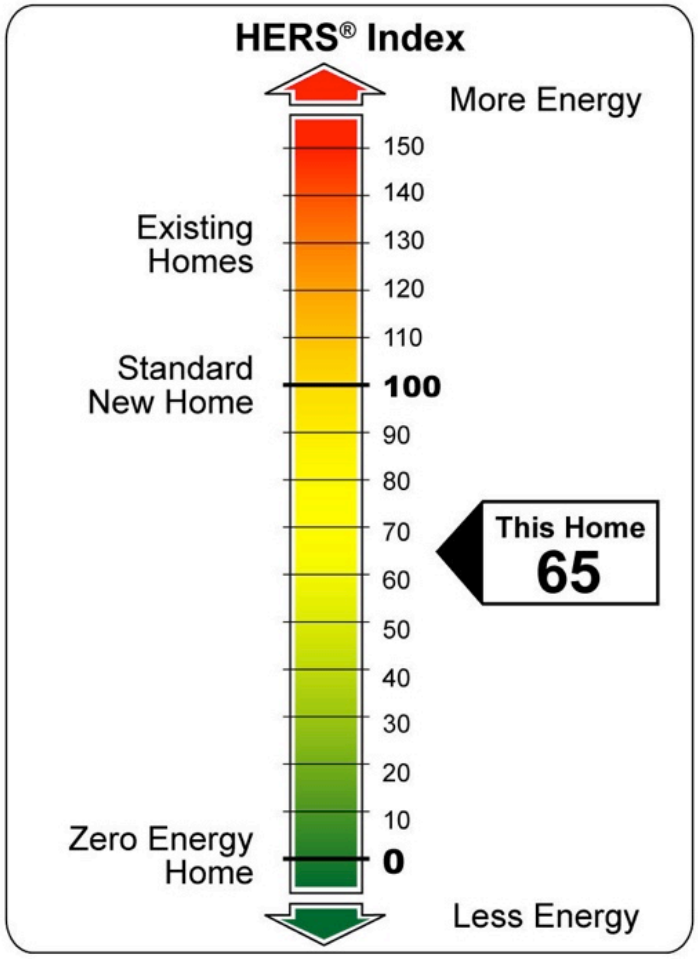
Like HERS Index but for IAQ

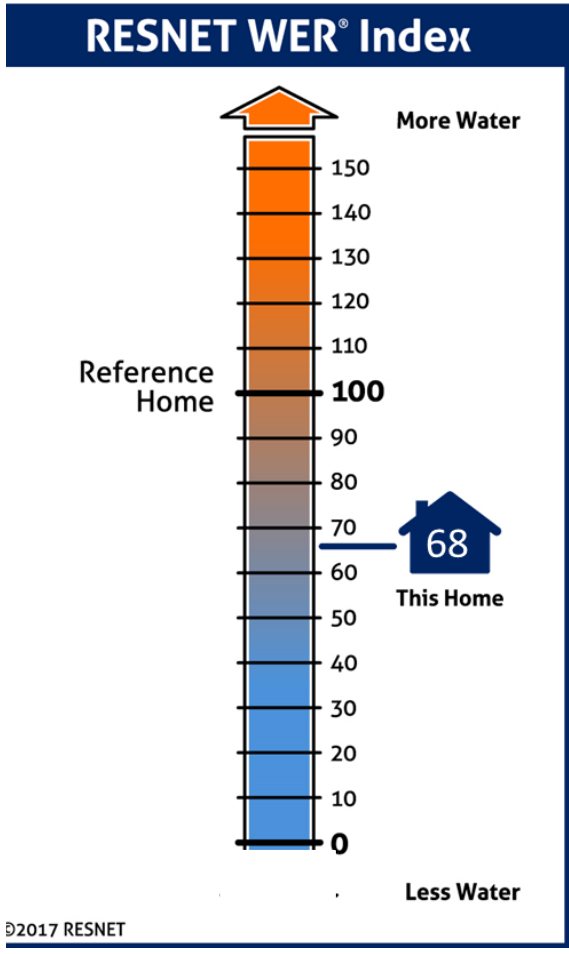
For raters NOT researchers



A Score for IAQ







IAQ Scoring Framework

- **Quantify hazards** that may negatively impact IAQ
- **Identify & score controls** that mitigate risk
- Based on typical activities, not present occupants
- Implemented by raters, not researchers
- Clear methodology; scores from expert input
- New and existing homes
- Home is scored as found
- Score built from relative risks of hazards and benefits of controls

Important Features

- No prescriptive requirements
- Measurements not required; but scores improve when device performance is verified
- Many parameters have defaults; rater enters locally correct values
  - Enables score when data not available
  - Examples: Outdoor AQ, Radon, Fan flows....
- Raters have to assess some hazards or controls

IAQ Hazards

- **Health**
  - Exposure to potentially harmful air pollutants
- **Moisture**
  - Risk factor for mold growth
  - Comfort implicitly included
- **Odor and Irritancy**
  - Short-term problem; no physiological damage

IAQ Health Risks

- Contaminants identified by location and source
  - Kitchen: Cooking emits $PM_{2.5}$, NO2, VOCs, etc.
  - Outdoors: NO_2, PM2.5, ozone, etc.
  - Building materials: formaldehyde, VOCs, SVOC
  - Foundation: Moisture from ground
- Contaminants
  - CO, NO_2 & NO;
  - PM: PM2.5, PM10, UFP
  - VOCs: Formaldehyde, general VOC, SVOC, and other chemical hazards;
  - Ozone; Radon;
  - Mold; Allergens; Other biological hazards
- Risks assessed for general population
  - Hazard score considers toxicity and typical amount of exposure
  - Risk for general population including susceptible groups

Special Hazards That Increase Score

- Unvented combustion appliance(s)
- Traditional fireplace
- Bad outdoor air quality, nearby sources
- Indoor hot tub or sauna
- Chemical contamination, e.g. from tobacco
- Visual or odor evidence of dampness & mold

NOT Included in Score – Occupant Specific*

- Current smoking
- Pollutants from unusual hobbies, extreme activities
- Chemicals presently in home
- Number of current residents
- Current pets
- Clutter, dirt, grime, dirty laundry, etc.

Next Steps

- From IAQ experts:
  - Input on lists of included hazards and controls
  - Prelim scoring of hazards & controls
- Complete on-line browser-based interface for the tool
- Draft version of scoring tool shared for limited field application -> identify problems

- **Get better field data on home hazards**

And now the new home IAQ field study….

BACKGROUND

Ventilation and IAQ in California New Homes

- Impetus: air tightness reduces infiltration, dilution of indoor emitted contaminants
- **2004-5: Mailed survey of ~1500 new homes[1]**
  - Few opened windows in winter; many did not ventilate in other seasons
  - Kitchen and bath ventilation not used regularly
- **2007-8: Field study measured pollutants & ventilation in 108 new homes[2]**
  - 9 of 16 homes with ducted mechanical ventilation had grossly insufficient flow
  - Many homes did not use windows for ventilation; 67% below code requirement
  - Majority of homes exceeded formaldehyde health guidelines
- **2016-7: Field study (HENGH) of new homes with mechanical ventilation[3]**
  - Web-based survey of ventilation and IAQ satisfaction in homes built since 2002 (2800 responses)
  - 1-week monitoring of pollutants and ventilation use; design and installed performance (Target of 70 homes built to 2008 or newer standards)

[1]Price and Sherman, 2006; [2] Offermann, 2009; [3] hengh.lbl.gov

Other New Home Studies of Ventilation and IAQ

- Canadian[1] IVAIRE study installed HRV or ERV in under-ventilated homes;
  - reduced mean formaldehyde, mold spores, a-pinene, etc., and
  - reduction of some measures of respiratory symptoms of asthmatic children
- Austrian study[2] found improved IAQ (e.g., lower CO_2, VOC, formaldehyde, radon) in new homes with mechanical ventilation (MV), compared to similar homes without MV
- Measured ventilation airflow different from design targets in FL[3] and CA[4] homes.
  - Florida: only 2 of 21 systems operating; only 12 met design standards
  - California: In 13 of 15 homes, airflows **exceeded** 62.2 reqs by 40% on average

[1] Lajoie et al. 2015; [2] Wallner et al. 2015; [3] Sonne et al. 2015; [4] Stratton et al. 2012

Austrian Study

IAQ and health in new Austrian homes with/out MV

62 Homes energy efficient homes with mechanical ventilation
61 Homes without mechanical ventilation
In both groups the ratio of Single Family to Multifamily ~ 70/30

Two field measurement appointments in each Home:
- 3 months (+/- 3 weeks) after move-in
- 1 year (+/- 3 weeks) after move-in

Measurement/survey:
- VOC‘s
- Aldehydes
- Mould spores
- Dust mites allergens
- Radon: annual average
- CO_2 (one week), Temperature, R.H.
- Interview of all occupants (>16yrs age) on medical and comfort/hygene
- In mechanically ventilated homes: air exchange rate / supply air flow and noise

Canadian IVAIRE study*

Measurements in homes of 83 asthmatic children over 2 years

- 43 received HRV or ERV; 40 controls
- Ventilation increased from 0.17 to 0.34 ACH using H/ERV
- Control group ventilation increased 0.18 to 0.21 ACH
- Contaminants + T/RH – measured in child's bedroom and/or living room
  - CO_2 – time resolved
  - Formaldehyde, speciated VOCs, NO_2 - integrated
  - Mold spores and allergens - integrated
- Survey for symptoms, medication use, hospital visits

*Aubin et al. 2013, Lajoie et al. 2015

IVAIRE Results

Table 1: Median concentrations of selected IAQ relevant parameters measured during the heating season before and after the intervention for the control and intervention groups.

Parameter	Cohort	Pre-Intervention	Post–Intervention
CO_2 (24-hr, ppm)	Control	1020	1027
	Intervention	899	770*
Formaldehyde ($\mu g\ m^{-3}$)	Control	35.9	36.0
	Intervention	34.3	24.1*
Airborne Mould Spores (DG18, CFU m^{-3})	Control	69	55
	Intervention	57	35*
Decane ($\mu g\ m^{-3}$)	Control	5.2	6.3
	Intervention	5.7	3.3*
Ethyl Acetate ($\mu g\ m^{-3}$)	Control	7.8	7.6
	Intervention	10.9	5.5*
α-pinene ($\mu g\ m^{-3}$)	Control	10.6	8.3
	Intervention	13.3	5.9*

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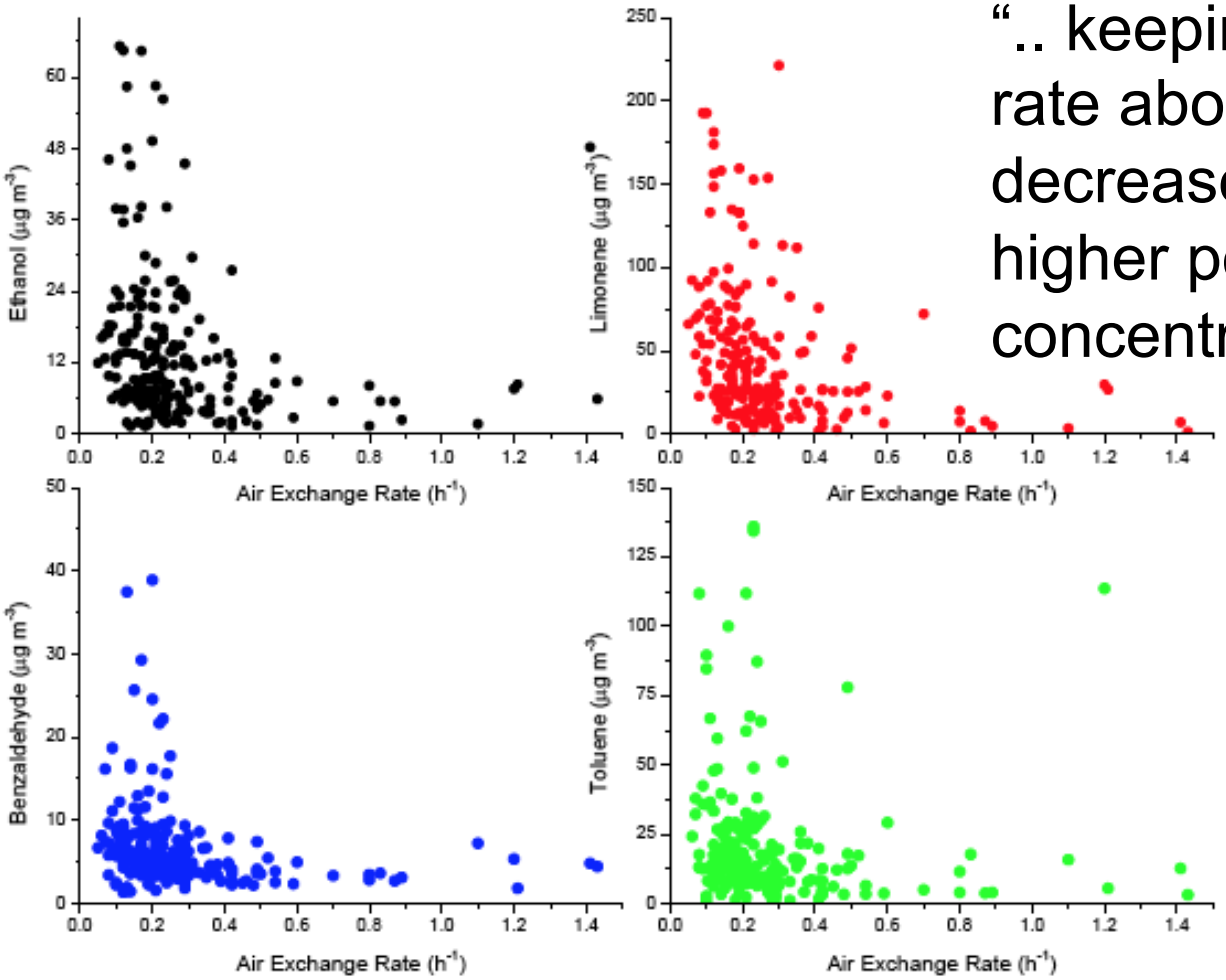
IVAIRE Results



"... keeping air change rate above 0.3-0.4 ACH decreases exposure to higher pollutant concentrations"

Figure 2: Concentration (µg m⁻³) as a function of air exchange rate (h⁻¹) for a selected number of VOCs (ethanol (●), limonene(●), benzaldehyde (●) and toluene (●)) during the heating season prior to the intervention for all homes in the study.

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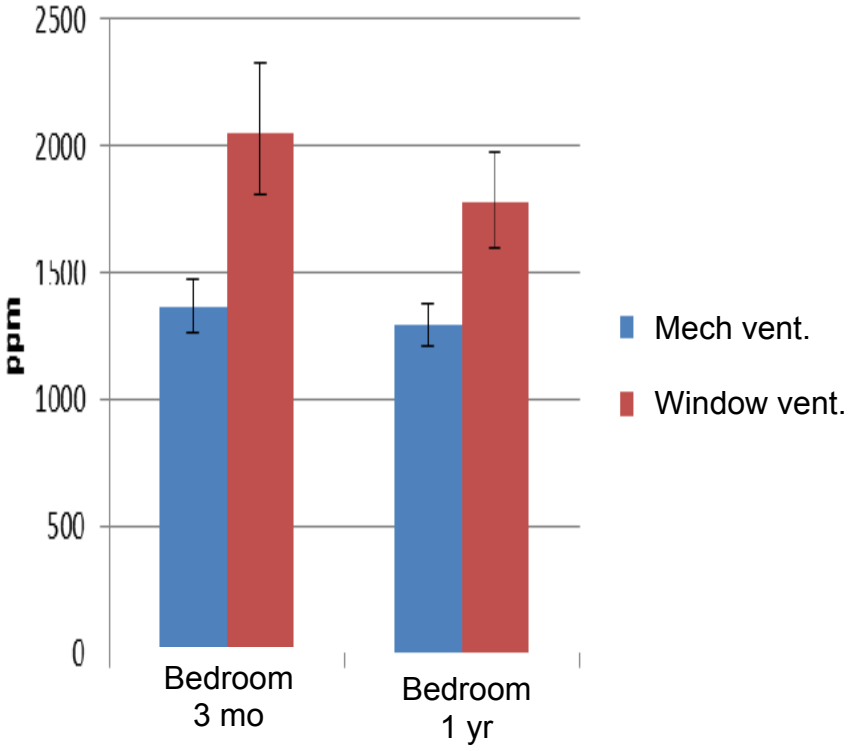
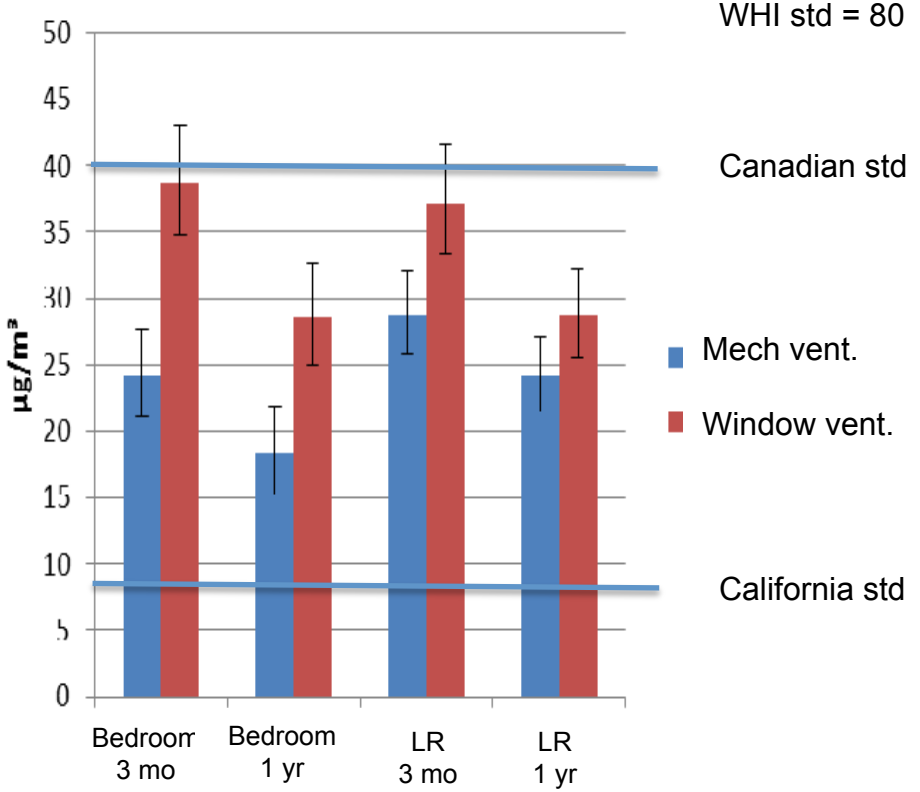
Austrian Study Results

CO2: Maximum of gliding hourly average

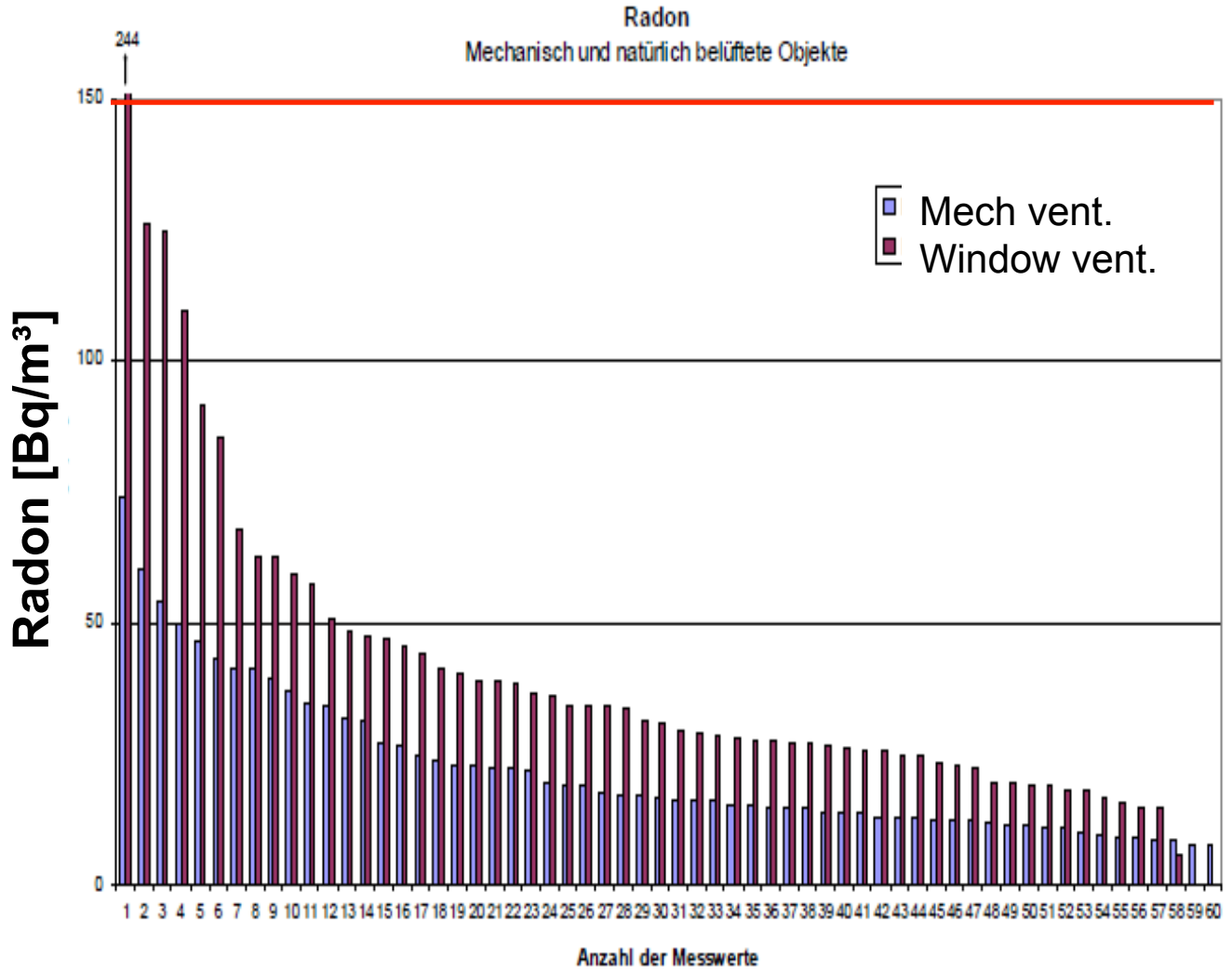


Formaldehyde



Tappler, P., Hutter, H.-P., Hengsberger, H., & Ringer, W. (2014). *Lüftung 3.0 - Bewohnergesundheit und Raumluftqualität in neu errichteten, energieeffizienten Wohnhäusern*. Vienna: Institut für Baubiologie und Bauökologie. Retrieved from http://innenraumanalytik.at/pdfs/lueftung_2014.pdf

Austrian Study Results



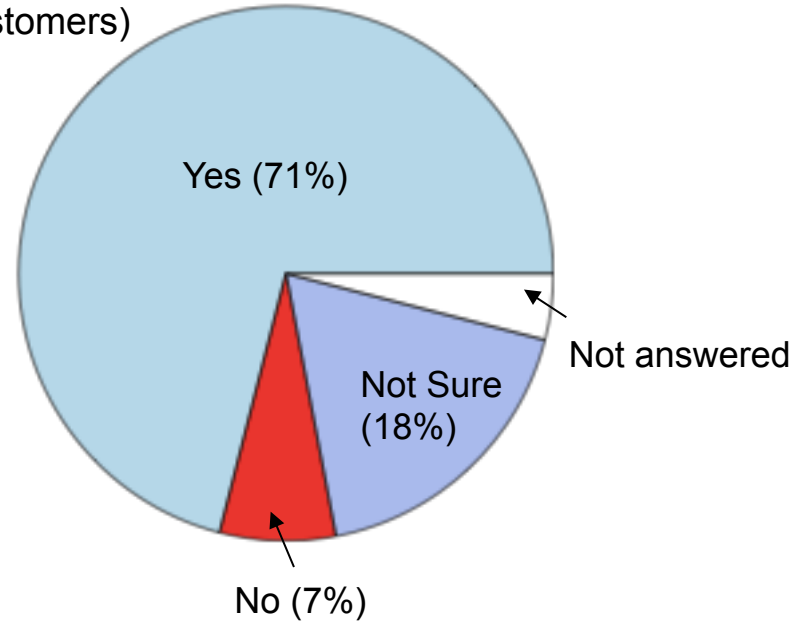
EPA limit
4 pCi/L
=
148 Bq/m^3

Tappler, P., Hutter, H.-P., Hengsberger, H., & Ringer, W. (2014). *Lüftung 3.0 - Bewohnergesundheit und Raumluftqualität in neu errichteten, energieeffizienten Wohnhäusern*. Vienna: Institut für Baubiologie und Bauökologie. Retrieved from http://innenraumanalytik.at/pdfs/lueftung_2014.pdf

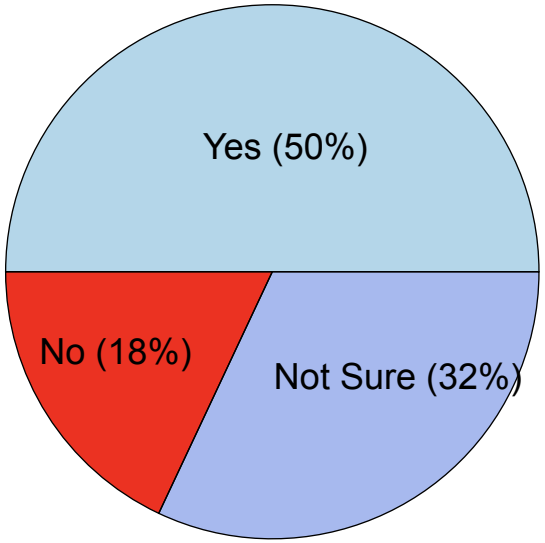
HENGH Study Results

Do you feel you understand your mechanical ventilation system properly? ?

Results from HENGH survey (2771 responses, mostly by Southern California Gas Company Customers)



Results from HENGH homes (43 homes)



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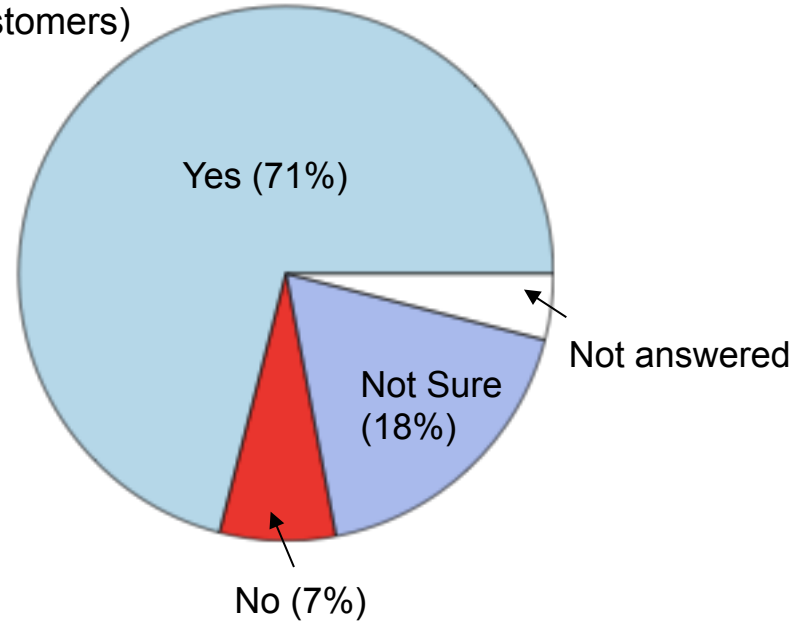

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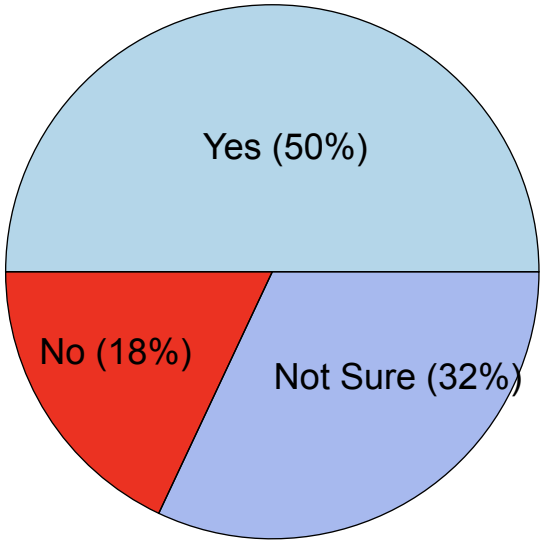

Only one home had operating mechanical ventilation system on our 1st visit

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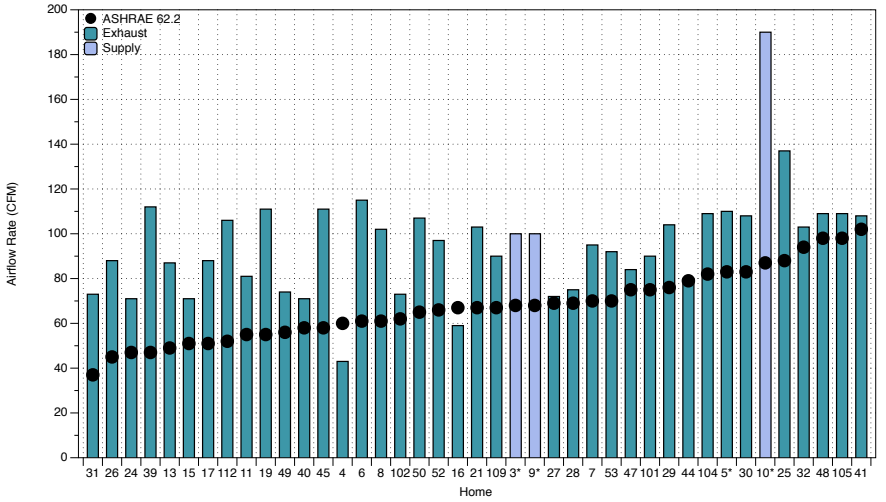
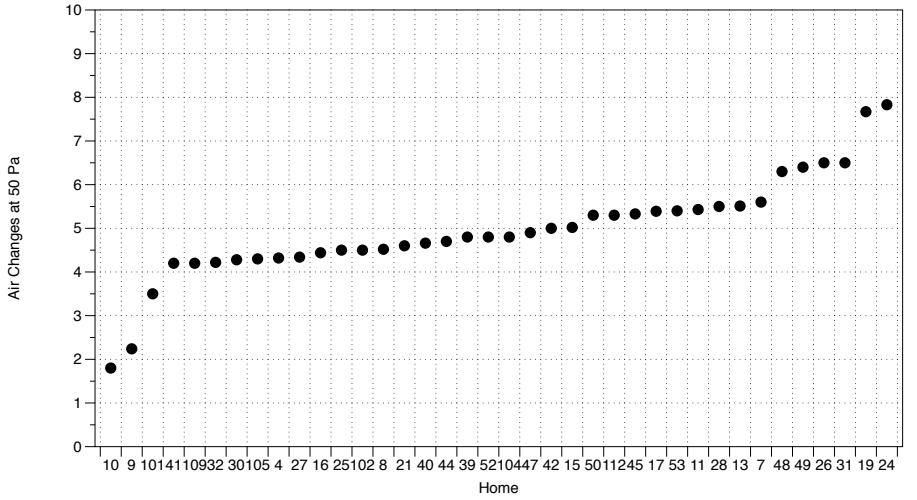
HENGH Home Characteristics

- All but 2 homes meet dwelling unit ventilation requirements
- Average 50% more flow than minimum
  - Opportunity for control retrofit?
- Kitchen and bath exhausts meet requirements
- Envelope leakage mostly 4 to 5.5 ACH50 (IECC limit would be 3 ACH50)





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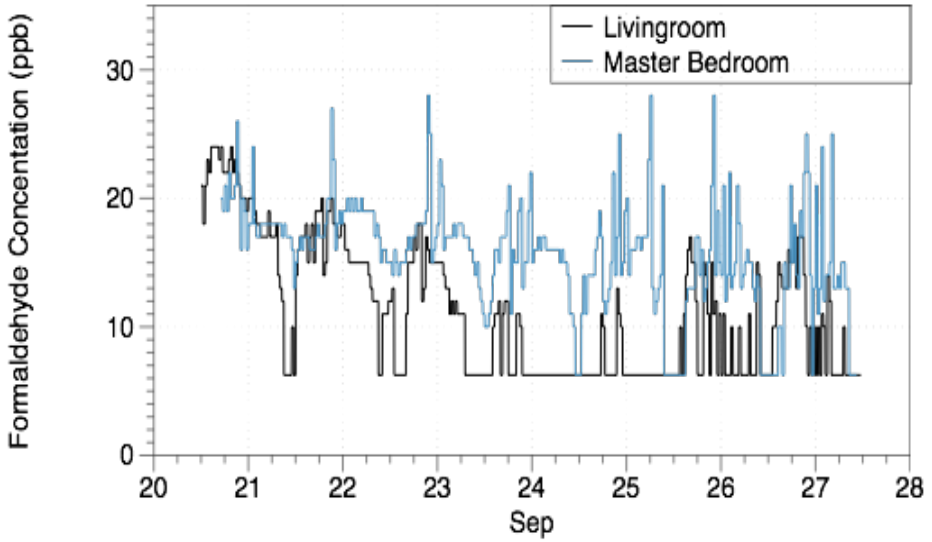
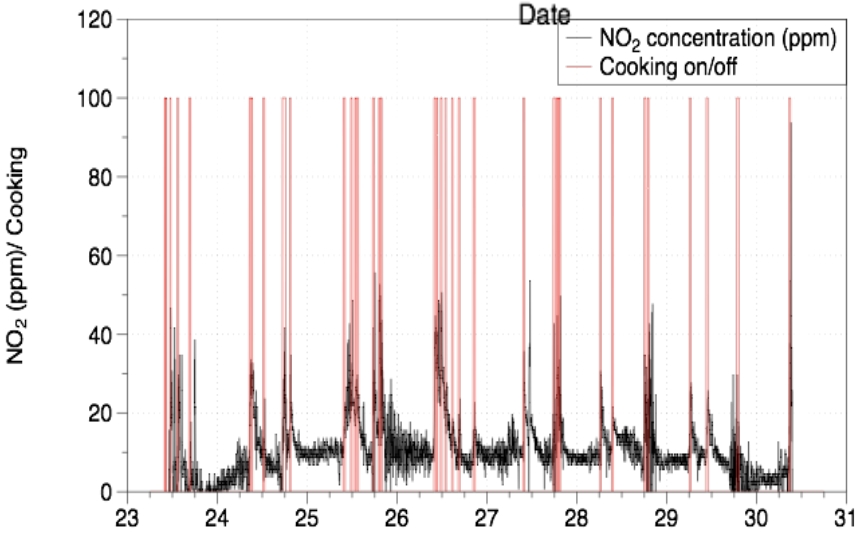
HENGH Pollutants (with ventilation operating)

- NO_2, Formaldehyde & PM2.5 all below reasonable limits
- Formaldehyde has strong temperature dependence
- NO_2 and PM2.5 strongly event driven (cooking)

When mechanical ventilation operates IAQ is fine in new CA homes





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FIELD STUDY DESIGN & PROCEDURES

(ADAPTED FROM CALIFORNIA HENGH STUDY)

Why do this study?

- Need metrics for assessing IAQ in homes (e.g., IAQ Score)
- Lack of information on pollutants in homes in general
- Very few studies have home performance characteristics AND pollutant measurements
  - Essential if we want to make decisions about what to do about IAQ
- Provide background information for standards (e.g., ASHRAE 62.2) and IAQ programs (EPA IAPlus, HUD Healthy Homes, ALA, etc.)
- Better understanding of occupant perceptions
- Input to possible ventilation controls: Occupied vs. unoccupied pollutant levels?

New Home IAQ Study Goals

- Collect data on indoor air pollutants, ventilation equipment and building characteristics in a diverse sample of occupied new homes (2013 or later).
- Analyze data to assess the impacts of current building practices, codes and standards on IAQ…
- To inform future standards and technology development needed to ensure acceptable IAQ in new homes.

Specific Data Collection Objectives

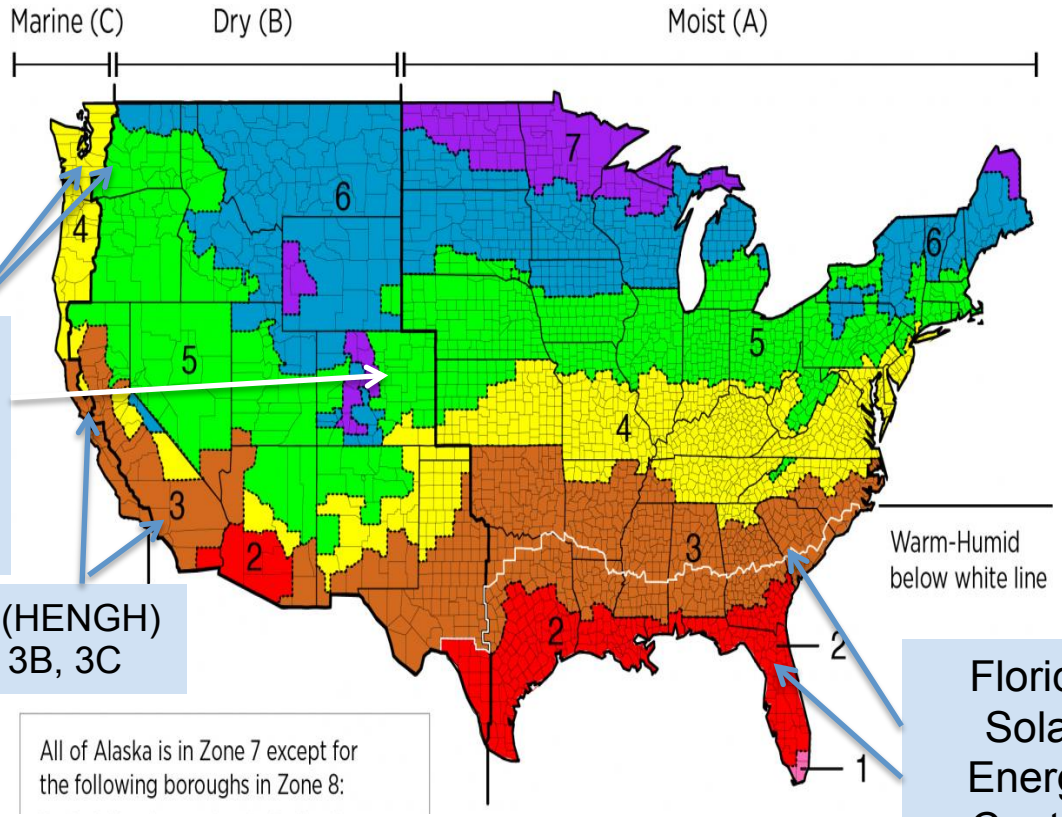
- Characterize mechanical ventilation equipment; explore variations in system designs and performance by climate & region.
- Measure humidity and air pollutants, monitor ventilation equipment use, and log activities that can impact pollutant emission and removal.
- Measure for a week to avoid “visiting researcher” effects and to get real-time pollutant variability
- Investigate associations of indoor humidity and air pollutants with the presence of control measures
  - Examples: mechanical ventilation, air tightness, commissioning, low-emitting materials

Project Team

- DOE Building America
  - Goals & objectives; funds; team selection; management
- Lawrence Berkeley National Lab
  - Design core field study procedures
  - Create and manage central database
  - Analyze data to inform standards and technology development
- Florida Solar Energy Center & Pacific Northwest National Lab
  - Develop and implement recruitment
  - Develop specific data collection procedures
  - Collect field data
  - QA and upload data to central database
  - Assist in communicating results to stakeholders

Field Study Scope

- Target 32 homes per climate zone (CZ):
  ~50% with mechanical ventilation (MV)



Pacific NW National Lab
CZ: 4C, 5B

LBNL (HENGH)
CZ: 3B, 3C

Florida Solar Energy Center
CZ: 2A, 3A

- Characterize home, mechanical equipment
- Monitor ventilation, IAQ, activities for 1 week; repeat for 2nd week in 8 homes / CZ
- Repeat monitoring to occur in homes with & without MV operating

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Related Study: LBNL Online IAQ Survey

- Developing from survey conducted in California
- Goal: National scope & large sample for context
- Topics:
  - IAQ satisfaction and perceptions
  - Building characteristics
  - Ventilation equipment
  - Pollutant sources including activities
  - IAQ management practices

Home Characterization

Obtain from participant or listing
- Year built, floor area, number of bedrooms and bathrooms, etc.

Observe
- Foundation, garage, attic & other construction details
- Mechanical systems models & performance specs
- Filters, grease screens, etc. (also photos)

Potentially challenging:
- Subsurface details (e.g., Radon)
- Low-emitting materials & finishes
- What was required in the house by code or program

Characterize state of ventilation system upon arrival

Measurements
- Envelope & duct airtightness
- Mechanical equipment flows
  - Exhaust fans
  - Ventilation supply fans
  - Air handler total flow in each mode

*Low-cost monitor used in this location

Monitoring

Pollutants & environmental

- Temp and RH
- $PM_{2.5}$
- CO_2
- Formaldehyde, acetaldehyde
- NO_2, NO_X
- SVOC in subset of homes
- Radon 1st floor + foundation
  - 6 month & 1-week all homes
  - Time-resolved in IAP homes

Equipment monitoring

- Dwelling unit ventilation
- Most used bath & toilet fans
- Kitchen exhaust
- Clothes dryer
- Water heater if inside
- Forced air system
- Standalone (de)humidification
- Standalone air cleaner
- Cooktop, oven, toaster oven
- Fireplace

*Low-cost monitor used in this location

Parameter	Time Res.	Example Instrument	Resolution	Accuracy
$PM_{2.5}$	1 min.	MetOne BT 645 (in) ES-642 (outdoor)	1 ug/m^3 LoQ ~3 ug/m^3	5%
$PM_{2.5}$ gravimetric	Time-integrated	MSP PEM + pump (flow control & log)	LoQ <1 ug/m^3 (>2 lpm for 1wk)	5% (pump)
Additional fine particles	1-5 min.	AirVisual	TBD	TBD
CO_2	1 minute	Extech SD800 or Air Visual	1 ppm	5%
NO_2, NO_X	Time-integrated	Ogawa passive sampler	2 ppb	25%
Formaldehyde & acetaldehyde	Time-integrated	SKC UMEx 100 passive sampler	1 ppb (Formaldehyde)	25%
T, RH	1 min.	Onset HOBO Pro v2	0.1 ^oC, 1% RH	T: 1%; RH: 2.5%

BA Study Key Points

- Add hot/mixed humid and cold/marine climates
  - Possibly add very cold/NE climates in the future
- Create baseline data for setting standards and technology development
- Examine effect of turning ventilation systems on and off

TEAM SLIDES

Baseline Indoor Air Quality Field Study in Occupied New US Homes: Hot Humid and Mixed Humid Climates

Prime Recipient

University of Central Florida, Florida Solar Energy Center
PI: Eric Martin
Co-PI's: Chuck Withers, Dave Chasar, Jeff Sonne

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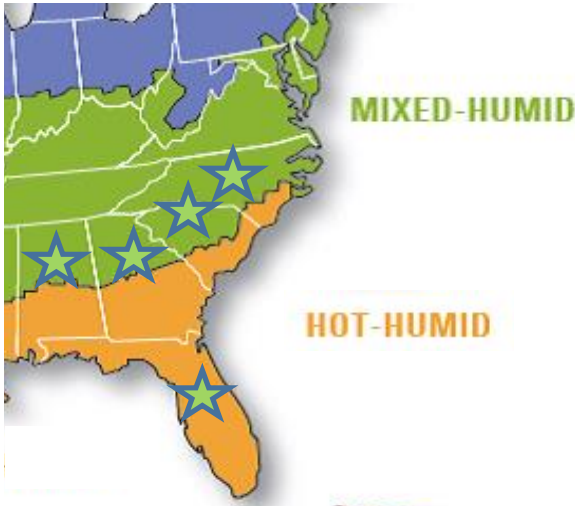
Creating Energy Independence

- Summary: 32 homes in each of two climate regions (64 homes total) with varying house and ventilation characteristics, about half meeting ASHRAE 62.2 mechanical ventilation requirements.
- Impact: Targeting the warm-humid region of the Southeastern US enables a dataset where the influence of outdoor moisture can be a focus for investigation.
- Project Goals:
  - Measure time-integrated and temporal profiles of humidity and contaminants of concern; monitor the use of ventilation equipment; and track activities impacting pollutant emissions.
  - Characterize the prevalence, type, and installed performance of mechanical ventilation equipment in new homes; explore regional variations in system designs and performance.
  - Investigate associations of indoor humidity and contaminant levels with the presence of control measures including ASHRAE 62.2 compliant mechanical ventilation.



Baseline Indoor Air Quality Field Study in Occupied New US Homes: Hot Humid and Mixed Humid Climates

Indoor Moisture Generation Enhancement

- Summary: additional testing and analysis in 15 homes to complete a moisture balance and enable internal moisture generation rates to be estimated.
- Impact: Simulation and lab home experiments using estimated value of 12 lbs/day result in fewer hours > 60% RH than data collected in occupied homes.
- Approach:
  - Collect data during peak cooling season to ensure relatively constant indoor RH and moisture content of materials/ furnishings.
  - Monitor condensate generation and conduct tracer gas testing to calibrate infiltration model (also monitor local wind speed?)
  - When combined with the protocol's measurements of air flows, temperature, and RH the enhancement enables estimation of average internal moisture generation (lbs/day) for the testing week.

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Baseline Indoor Air Quality Field Study in Occupied New US Homes: Cold and Marine Climates

Prime Recipient	Key Participants
PNNL PI: Dr. Jian Zhang PM: Cheryn Metzger	Team Members: WSU, Cadmus, Panasonic, NEEA and SWEEP Project Supporters: BPA, WAPA, Ecotope

- Summary: 32 homes in each of two climate regions (64 homes total) with varying house and ventilation characteristics, about half meeting ASHRAE 62.2 mechanical ventilation requirements
- Impact: About 42% of the country's housing stock is located in the selected climate zones (cold and marine).
- Project Goals:
  - Understand relationship between residential air flows (ventilation) and IAQ in the cold and marine climates
  - Quickly deploy data with codes and standards bodies as well as manufacturers

ADDITIONAL SLIDES

References

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Healthy Efficient New Gas* Homes (HENGH)

- Investigate impacts of 2008 building code that required MV
- Web-based survey of ventilation use and IAQ satisfaction
- Characterize MV system designs & installed performance (airflows)
- Monitor use of ventilation equipment; daily survey of activities
- Measure contaminant concentrations
  - CO_2, Est. $PM_{2.5}$, NO_2/NO_X, Aldehydes
- Target of 70 homes monitored for ~7 days, including weekend

*Focus on homes with gas appliances b/c funds from utility surcharge

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HENGH Survey Results

- More concern about OAQ than IAQ
- Homes with “fresh vent” more likely to be satisfied with IAQ
- Venting range hoods regarded as more effective than non-venting
- People report rational window use to manage IAQ
- Substantial dissatisfaction with thermal control
- More air cleaner use in homes with respiratory compromised people

Technical Advisory Committee

Peter Ashley	HUD	Vito Ilacque	EPA
Daniel Aubin	NRC Canada	Dave Jacobs	NCHH
Laureen Burton	EPA	Brian Lamb	WSU
David Cohan	DOE Codes	Shelly Miller	CU Boulder
Rich Corsi	UT Austin	Dustin Poppendieck	NIST
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Nicholas Hurst	EPA Indoor airPlus	Jonathan Wilson	NCHH