New Indoor Air Quality Standards for Homes Based on Cognition, Health, Sleep, and Productivity

February 1 & 2, 2017

Ty Newell, PhD, PE
Build Equinox
Urbana, IL 61802
www.buildequinox.com

BUILD EQUINOX

SOLUTIONS FOR A HEALTHY, COMFORTABLE, AND SUSTAINABLE LIFESTYLE

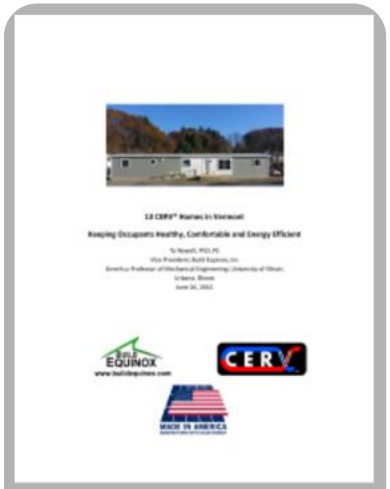
Mission

BUILD EQUINOX

Research & Education [1,2]*

Ben Newell
Ty Newell Alex Long

CERV
INTELLIGENT FRESH AIR VENTILATION
FRESH AIR
LIVE HEALTHIER LIVE LONGER
ENGINEERED AND MADE IN AMERICA
WITH SOLAR ENERGY
c UL us LISTED



VERMOD CERV Report

Develop solutions for healthy, comfortable and sustainable lifestyles….learning to live on our daily allowance of solar energy.

How do we live on a piece of land without spoiling it?

* References at end of presentation

BUILD EQUINOX
WWW.BUILDEQUINOX.COM

Build Equinox

- Build Equinox manufactures systems that automatically keep air fresh in residences
- “CERV” smart ventilators are manufactured in our facility in Urbana IL

100% Solar Powered Business!

BUILD EQUINOX
WWW.BUILDEQUINOX.COM

New IAQ Metrics - Outline

- Why are new IAQ metrics needed?
- Smart ventilation
- Energy cost versus cost of air quality
- New air quality metrics
  - Personal performance
  - Exposure
  - Basic statistics
- Field data
  - Comparing “leaky” homes to smart ventilated homes
  - Energy data
- Future Developments

ASHRAE President Visits Equinox House

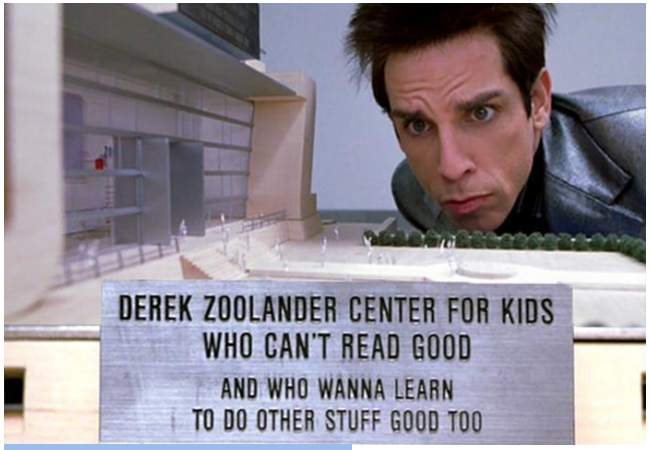
"…..a critical shift in thinking from a goal of **indoor environments that are acceptable** to the occupants to those that are **truly healthy and productive**…"

Bill Bahnfleth; 2013-2014 ASHRAE President

Equinox House

BUILD EQUINOX
WWW.BUILDEQUINOX.COM

Our Homes and Buildings are making us



Stupid

Sick

and, Tired

The cost of being stupid, sick and tired is tremendous

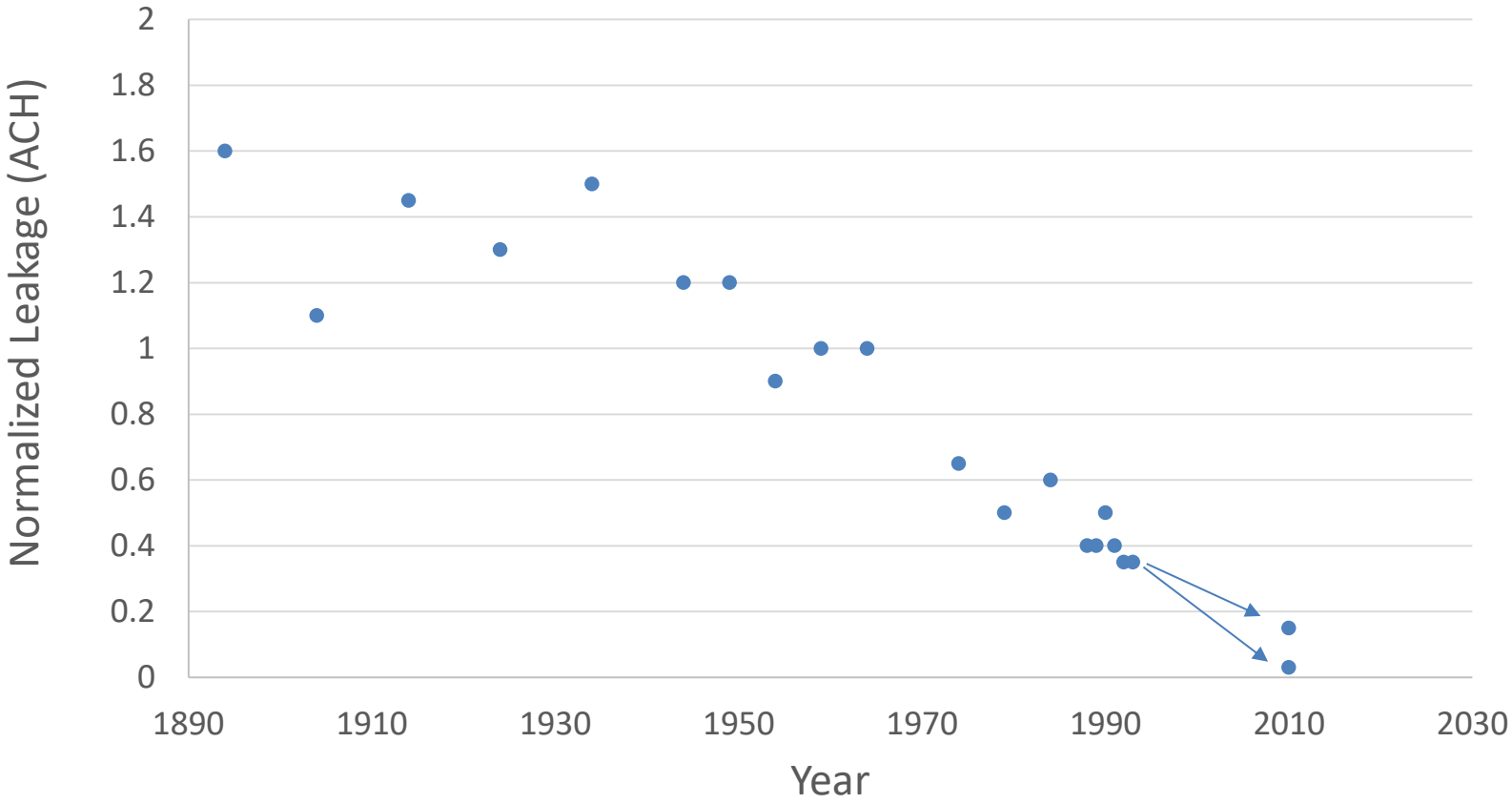
Health Cost

- Annual energy cost for 100M high performance residences = $160B/yr; $80B for people; ~$80B for climate
  - 4000kWh/person, 12cents/kWh, 325M people
- Annual cost of seasonal influenza is $87B/yr
  - Improved ventilation reduces contagion concentrations
- Asthma now afflicts nearly 10% of the population (~25% of households) for a total of $56B/yr total cost
  - Can we reduce asthma to 4% of populace where it used to be….or even more?
- 10% Decrease of Human Cognition ~ $1.5T/year
  - $50K per human value; estimated cognition decrease due to carbon dioxide concentration at typical ventilation levels (1100ppm, ~15-20cfm/person)

ASHRAE 62.2 is “Acceptable”…but

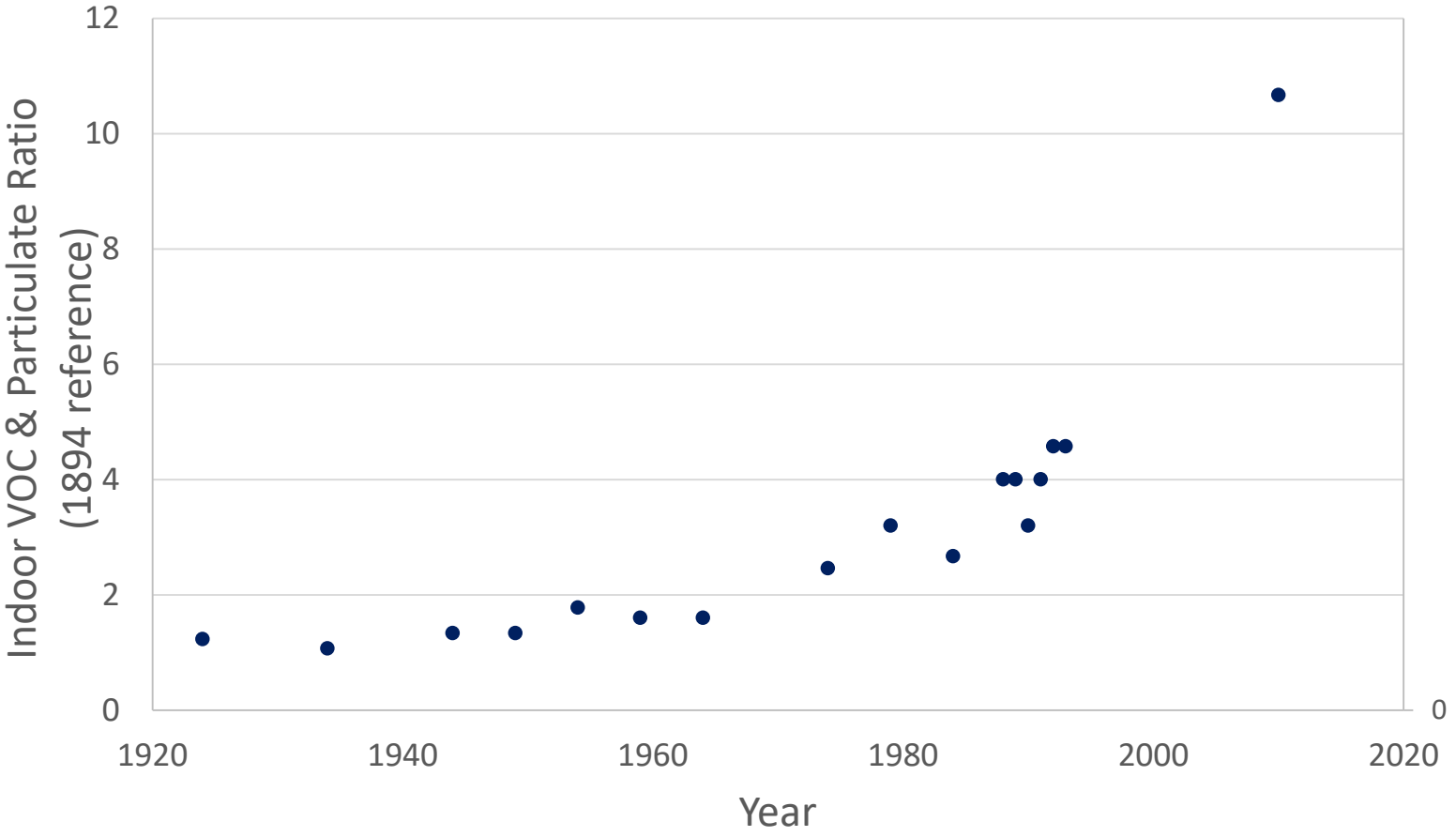
- ASHRAE 62.2 is an agreed upon MINIMUM ventilation standard. It is NOT an indoor air quality standard
- Based on odor dissatisfaction threshold, not pollution
  - 20% population dissatisfaction! [13]
- Does not account for higher pollution events/occupancy changes
- Nominal 20cfm/person will result in >1,000ppm CO2 concentration
- New studies show venting to 62.2 will result in significant reduction in health, cognition, and sleep quality
- Smart ventilation surpasses 62.2 standards that gets us to truly healthy and productive environments

Great Progress Sealing Homes



2010 data represents good construction (3ACH at 50Pa) and “Passive House” construction (0.6ACH at 50Pa)

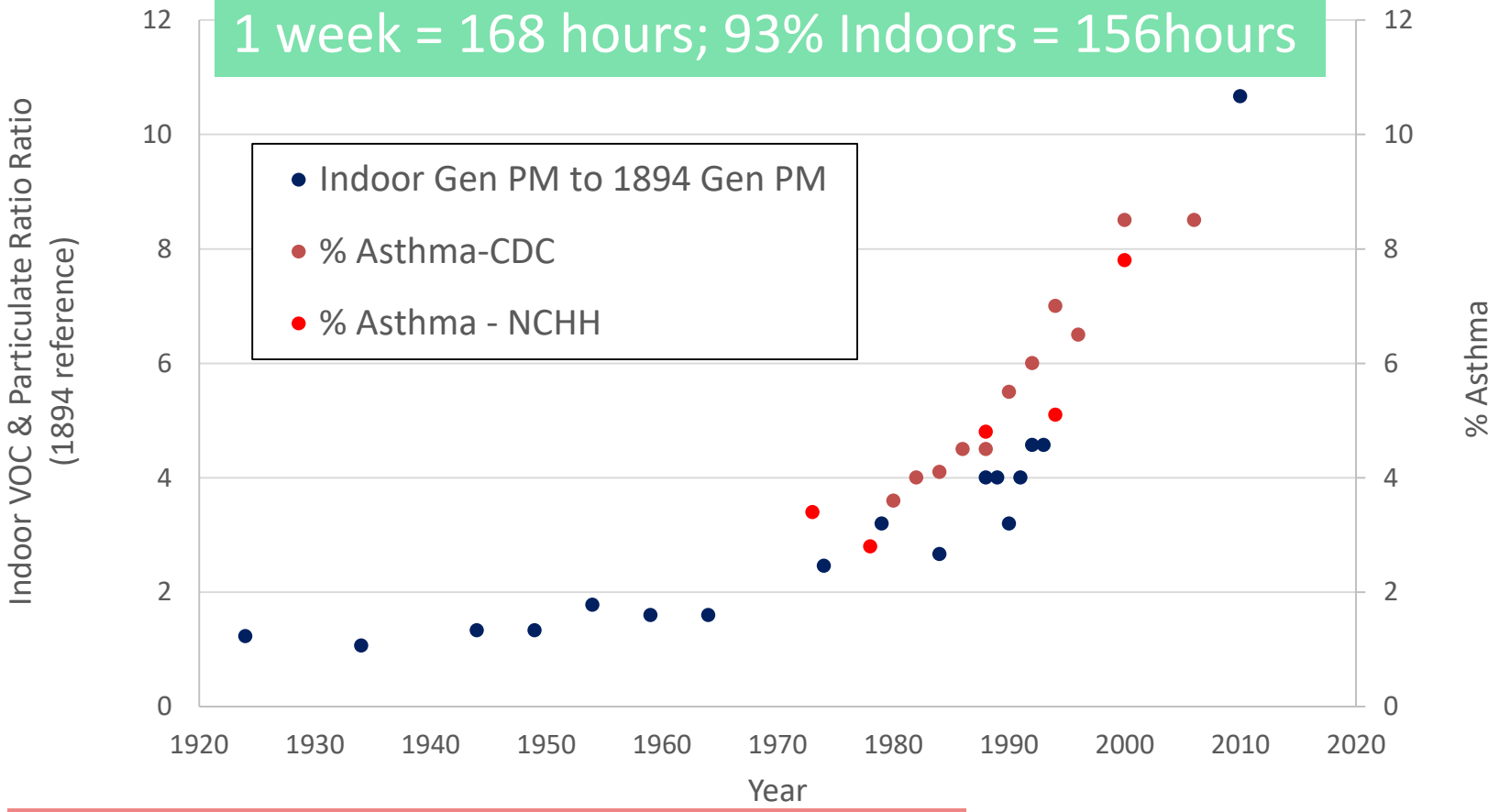
But, Homes Become Unhealthy



Unventilated homes

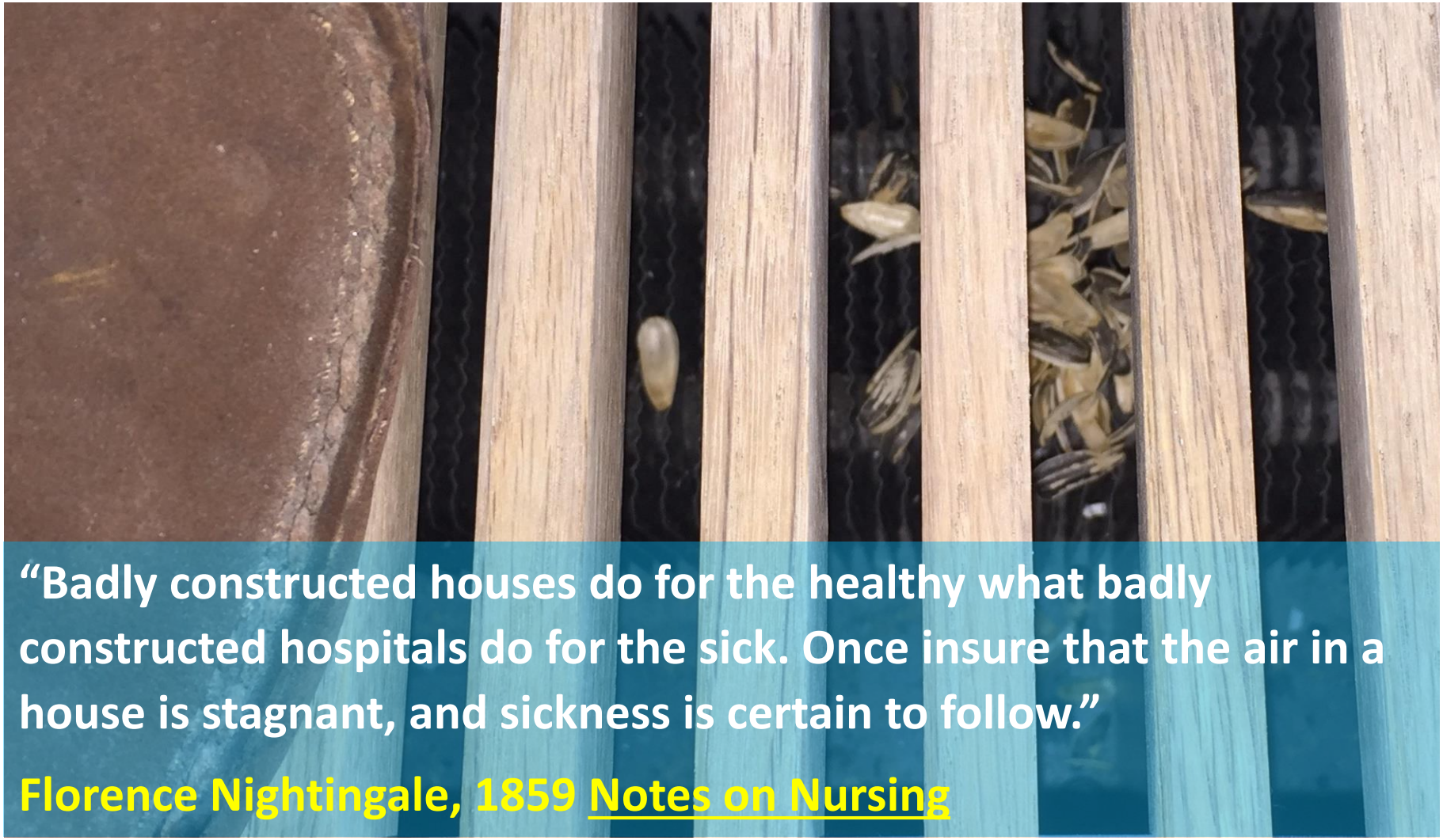
Why Has Asthma Increased?

1 week = 168 hours; 93% Indoors = 156hours



-68.7% at home, ~115hours/week
-18.2% other indoors, ~ 31hours/week
-5.5% in vehicle, ~9hours/week
-7.6% outdoors, ~13hours/week

[3,4,5,6,7]



"Badly constructed houses do for the healthy what badly constructed hospitals do for the sick. Once insure that the air in a house is stagnant, and sickness is certain to follow."

Florence Nightingale, 1859 Notes on Nursing

Air Supply Vent - Fresh Air?

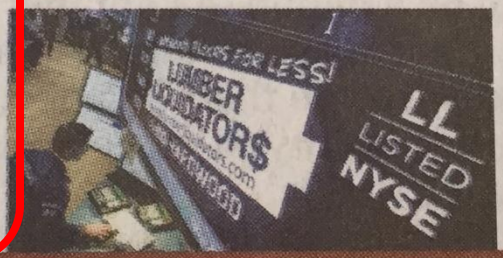
"To have pure air, your house be so constructed as that the outer atmosphere shall find its way with ease to every corner of it. House architects hardly ever consider this. The object in building a house is to obtain the largest interest for the money, not to save doctors' bills for the tenants." Florence Nightingale, 1859 Notes on Nursing

Company Spotlight

Lumber Liquidators sinks

Lumber Liquidators' shares plunged Monday after the Centers for Disease Control and Prevention said people exposed to certain types of the company's flooring are three times more likely to get cancer than the agency previously predicted.

The CDC said that its original study used an incorrect value for ceiling height. It now estimates the risk of cancer at six to 30 cases per 100,000 people. It previously estimated two to nine cases per 100,000 people.



Its recommendations will likely stay the same – that people take steps to reduce exposure.

Lumber Liquidators stopped selling Chinese-made laminate floors in May after a television news show reported that they contain high levels of the carcinogen formaldehyde. It also began providing customers with free air quality tests.

The company said Monday that it has strengthened its "quality assurance procedures," such as testing sample products.

Lumber Liquidators (LL) Monday's close: **$11.40**

52-WEEK RANGE
$11 — $70

Price-earnings ratio: **Lost money**
(Based on past 12-month results)

Price change	1-yr	3-yr*	5-yr*
LL	-83.2%	-42.1	-16.1

Smart Ventilation Verification

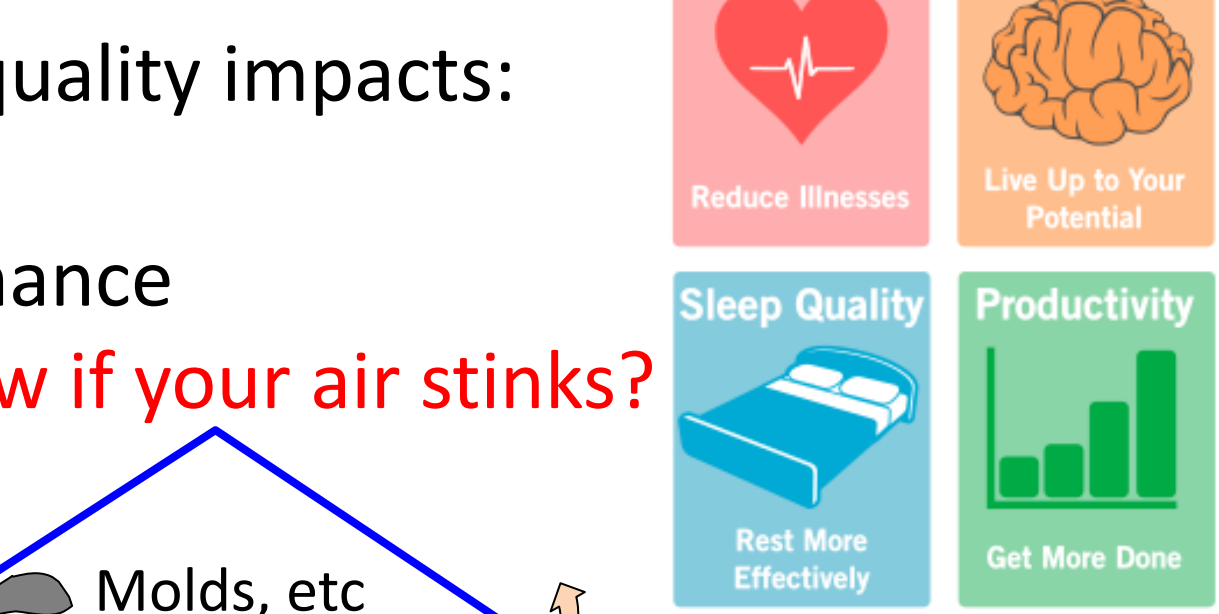
BUILD EQUINOX
WWW.BUILDEQUINOX.COM

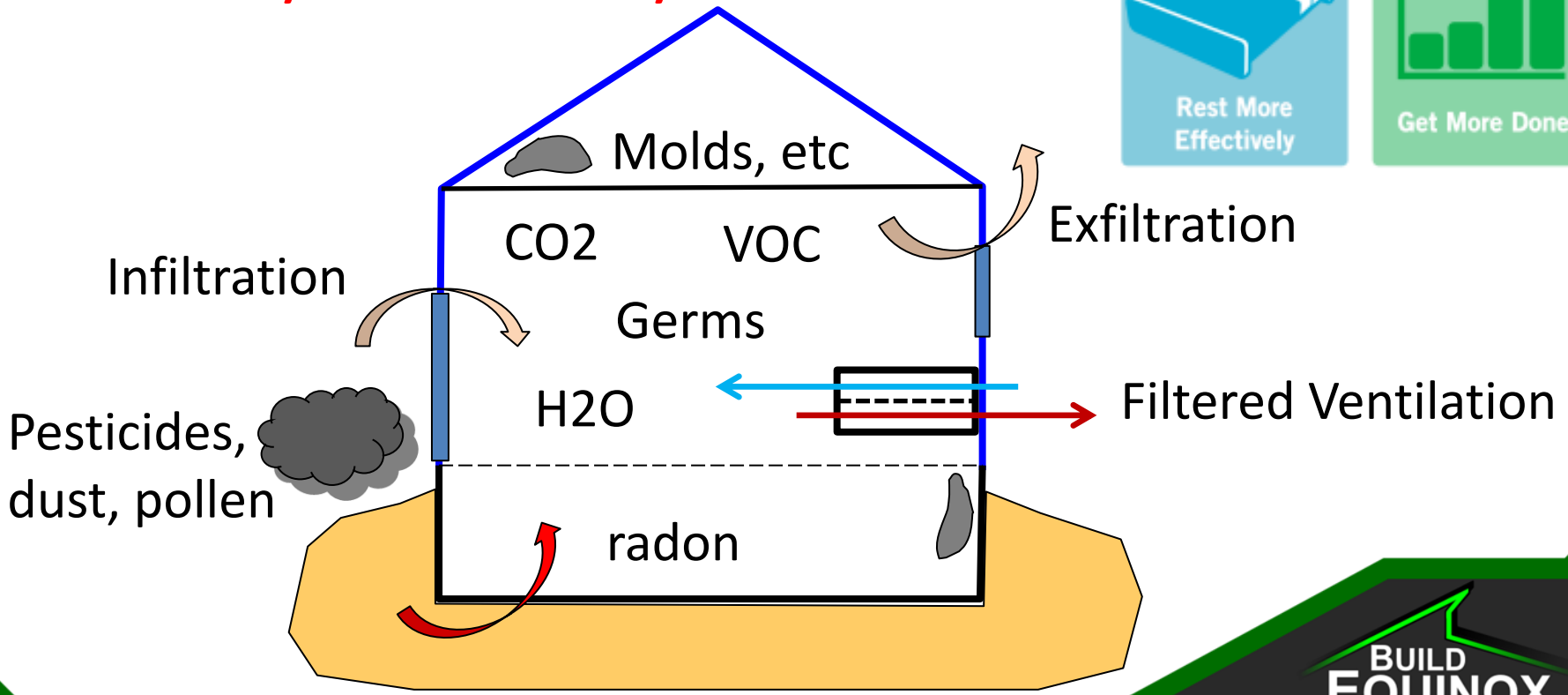
Fresh Air

Poor indoor air quality impacts:

- Health
- Human Performance

How do you know if your air stinks?





What is Smart Ventilation?

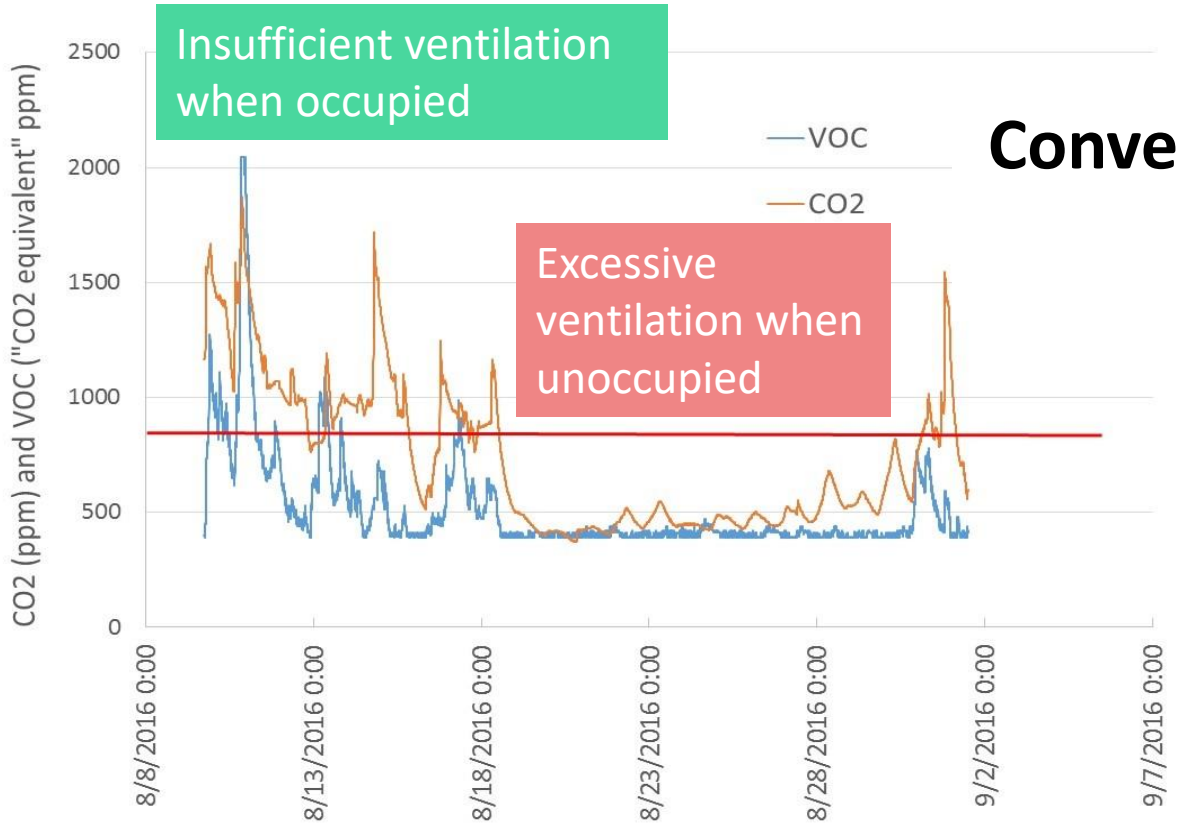
"Smart" ventilators [9]

- Measure indoor air pollutants to ventilate when needed
- Sense when outdoor conditions are nicer than indoors, and maximize "free" conditioning
  - Recharges home with fresh air
- Maintain high quality air throughout the entire house
- Achieve **both** increased energy efficiency and air quality above levels achieved with conventional ventilation systems
- Monitor and archive indoor air quality conditions over time

Smart ventilation systems allow us to define new sets of **indoor air quality metrics** providing us with information that quantifies our health and productivity

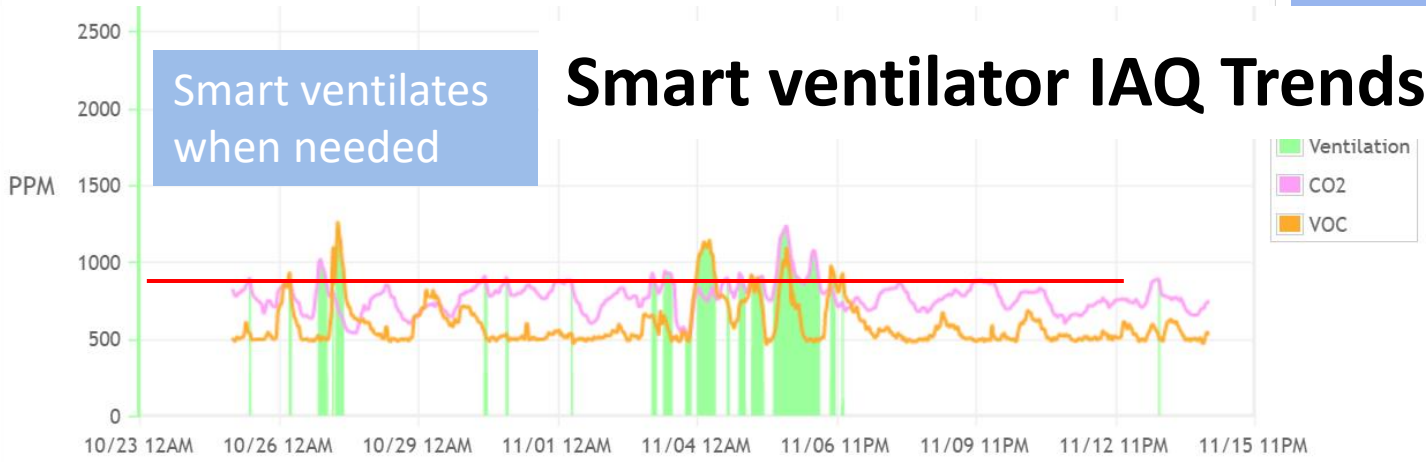
*It is evolving, with new research studies and technology

Conventional ventilator IAQ Trends



With today's sensors, automatic fresh air control improves our health and performance

Smart ventilator IAQ Trends

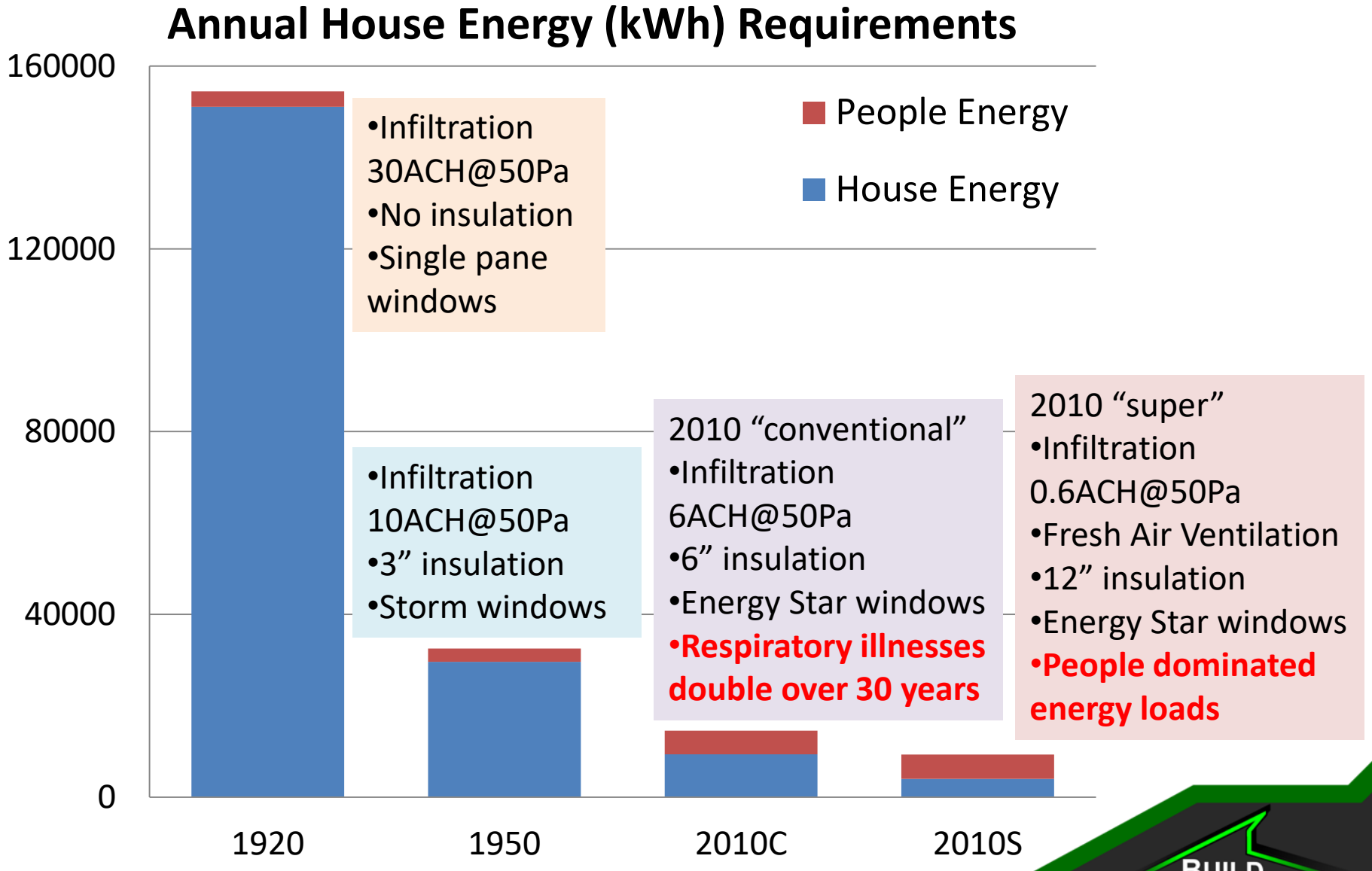


High Performance & Smart Ventilation

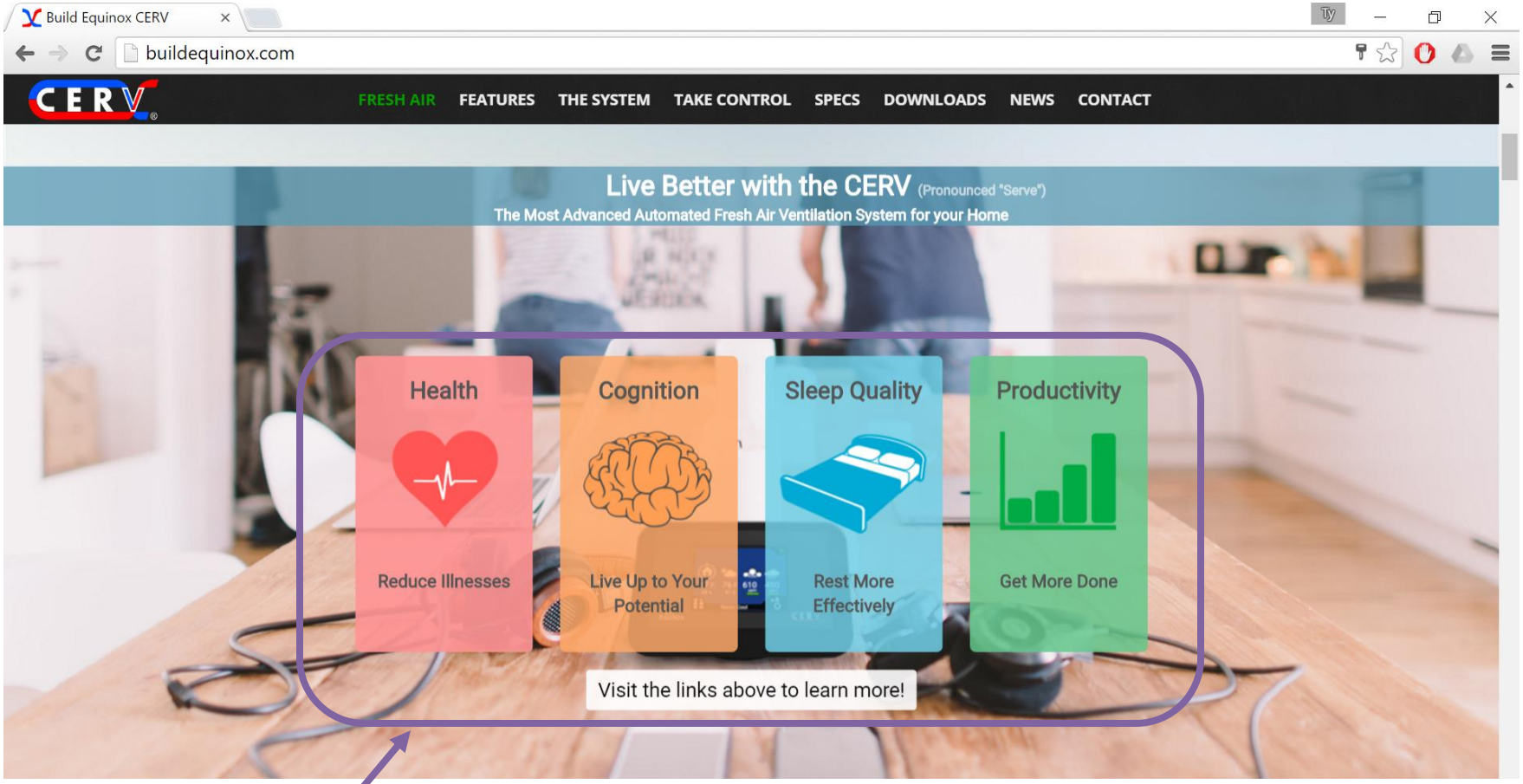
- Combining the most stringent housing standards with smart ventilation results in the healthiest, most productive and energy efficient residence

Vermod homes average 3,650kWh/occupant and 9kWh/sqft per year

History of House Energy



4 Important Papers



4 Reference papers on health, cognition, sleep and productivity [10,11,12,14]

BUILD EQUINOX
WWW.BUILDEQUINOX.COM

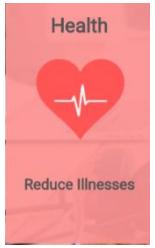
Indoor Air 2000; 10: 212–221
http://journals.munksgaard.dk/indoorair

INDOOR AIR
ISSN 0905-6947

Risk of Sick Leave Associated with Outdoor Air Supply Rate, Humidification, and Occupant Complaints

DONALD K. MILTON[1]*, P. MARK GLENCROSS[1,2] AND MICHAEL D. WALTERS[2]

Abstract We analyzed 1994 sick leave for 3,720 hourly employees of a large Massachusetts manufacturer, in 40 buildings with 115 independently ventilated work areas. Corporate records identified building characteristics and IEQ complaints. We rated ventilation as moderate (≈25 cfm/person, 12 ls^{-1}) or high (≈50 cfm/person, 24 ls^{-1}) outdoor air supply based on knowledge of ventilation systems and CO_2 measurements on a subset of work areas, of ventilation rates compared [moderate with approximately 12, and high with approximately 24 l/s-person] are at the upper end of rates seen in these facilities. That indicates that benefits continue to accrue when ventilation is increased above 10 l/s-person, and that experimental studies to validate and to determine mechanisms for these observational findings should be a priority for indoor air research.



4 Important Papers - Health

A Section 508–conformant HTML version of this article
is available at http://dx.doi.org/10.1289/ehp.1510037.

Associations of Cognitive Function Scores with Carbon Dioxide, Ventilation, and Volatile Organic Compound Exposures in Office Workers: A Controlled Exposure Study of Green and Conventional Office Environments

Joseph G. Allen,[1] Piers MacNaughton,[1] Usha Satish,[2] Suresh Santanam,[3] Jose Vallarino,[1] and John D. Spengler[1]

[1]Exposure, Epidemiology, and Risk Program, Department of Environmental Health, Harvard T.H. Chan School of Public Health, Boston, Massachusetts, USA; [2]Psychiatry and Behavioral Sciences, SUNY-Upstate Medical School, Syracuse, New York, USA; [3]Industrial Assessment Center, Center of Excellence, Syracuse University, Syracuse, New York, USA

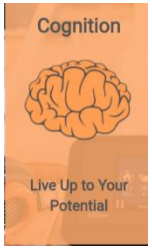
Background: The indoor built environment plays a critical role in our overall well-being because of both the amount of time we spend indoors (~90%) and the ability of buildings to positively or negatively influence our health. The advent of sustainable design or green building strategies reinvigorated questions regarding the specific factors in buildings that lead to optimized conditions for health and productivity.

Objective: We simulated indoor environmental quality (IEQ) conditions in "Green" and "Conventional" buildings and evaluated the impacts on an objective measure of human performance: higher-order cognitive function.

Methods: Twenty-four participants spent 6 full work days (0900–1700 hours) in an environmentally controlled office space, blinded to test conditions. On different days, they were exposed to

Bornehag et al. 2005; Hedge 2009; Hedge and Gaygen 2010; Nishihara et al. 2014).

The IEQ problems that arose from conventional buildings with a tight envelope contributed to the advent of sustainable design or "green" building rating systems [e.g., U.S. Green Building Council's (USGBC's) Leadership in Energy and Environmental Design (LEED®)]. These rating systems aim to reduce the environmental footprint of buildings and to improve occupant health by



4 Important Papers - Cognition

Indoor Air 2015
wileyonlinelibrary.com/journal/ina

INDOOR AIR
doi:10.1111/ina.12254

The effects of bedroom air quality on sleep and next-day performance

Abstract The effects of bedroom air quality on sleep and next-day performance were examined in two field-intervention experiments in single-occupancy student dormitory rooms. The occupants, half of them women, could adjust an electric heater to maintain thermal comfort but they experienced two bedroom ventilation conditions, each maintained for 1 week, in balanced order. In the initial pilot experiment (N = 14), bedroom ventilation was changed by opening a window (the resulting average CO_2 level was 2585 or 660 ppm). In the second experiment (N = 16), an inaudible fan in the air intake vent was either disabled or operated whenever CO_2 levels exceeded 900 ppm (the resulting average CO_2 level was 2395 or 835 ppm). Bedroom air temperatures varied over a wide range but did not differ between ventilation conditions. Sleep was assessed from movement data recorded on wristwatch-type actigraphs and subjects reported their perceptions and their well-being each morning using online questionnaires.

P. Strøm-Tejsen, D. Zukowska, P. Wargocki, D. P. Wyon

International Centre for Indoor Environment and Energy, Department of Civil Engineering, Technical University of Denmark, Kongens Lyngby, Denmark

Key words: Air quality; Ventilation; Windows; Sleep; Sleep quality; Performance.

P. Strøm-Tejsen
International Centre for Indoor Environment and Energy
Technical University of Denmark

4 Important Papers - Sleep

Int. J. Environ. Res. Public Health **2015**, *12*, 14709-14722; doi:10.3390/ijerph121114709

OPEN ACCESS

International Journal of
Environmental Research and Public Health
ISSN 1660-4601
www.mdpi.com/journal/ijerph

Article

Economic, Environmental and Health Implications of Enhanced Ventilation in Office Buildings

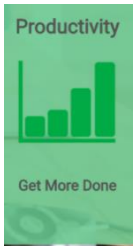
Piers MacNaughton [1,*], James Pegues [2], Usha Satish [3], Suresh Santanam [4], John Spengler [1] and Joseph Allen [1]

[1] Department of Environmental Health, Harvard T.H. Chan School of Public Health, Landmark 409 West, 401 Park Drive Boston, MA 02115, USA; E-Mails: spengler@hsph.harvard.edu (J.S.); jgallen@hsph.harvard.edu (J.A.)

[2] United Technologies Climate, Controls & Security, Syracuse, NY 13221, USA; E-Mail: James.F.Pegues@carrier.utc.com

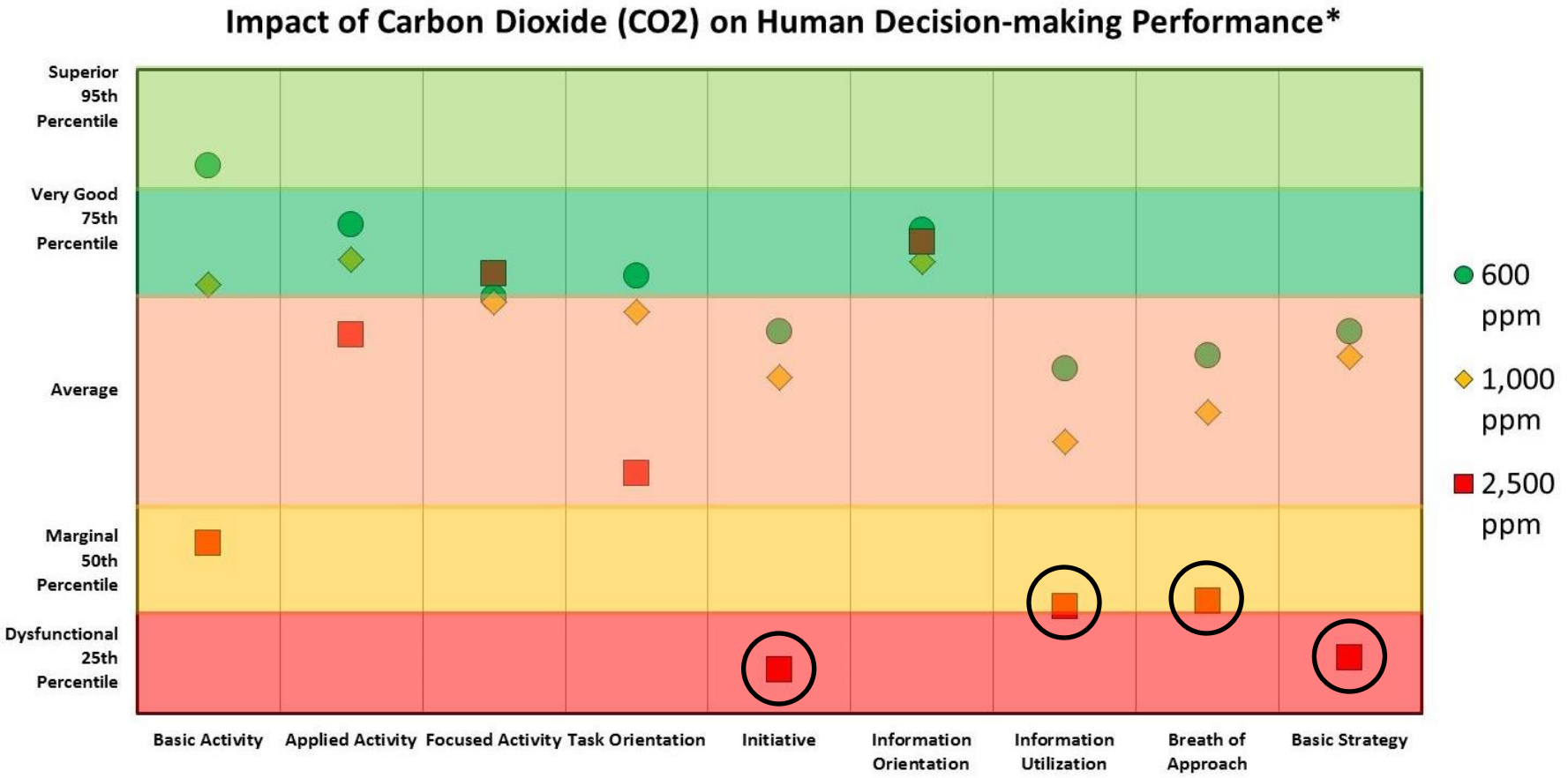
[3] Psychiatry and Behavioral Sciences, SUNY-Upstate Medical School, Syracuse, NY 13210, USA; E-Mail: satishu@upstate.edu

[4] Industrial Assessment Center, Biomedical and Chemical Engineering Department, Syracuse University, Syracuse, NY 13210, USA; E-Mail: ssantana@syr.edu



4 Important Papers - Productivity

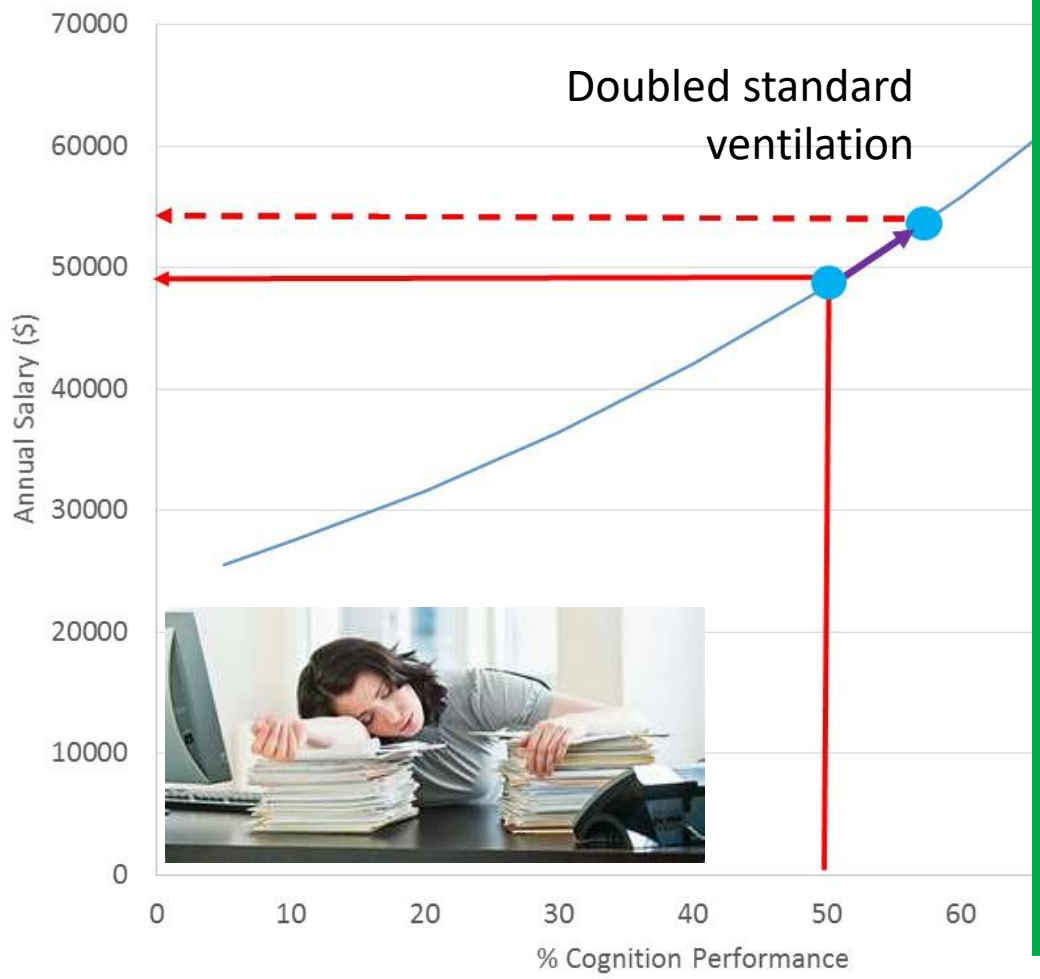
Carbon Dioxide (CO2) Impairs Cognitive Performance



* "Is CO2 Indoor Pollutant?", WIlliam Fisk, Usha Satish, Mark Mendel, Toshifumi Hotchi, and Douglas Sullivan, *ASHRAE Journal*, Vol. 55, No. 3, pp. 84-85, March 2013.

Strongly impairs: Initiative, Information Utilization, Breath of Approach, and Basic Strategy

Earnings vs Cognition Performance



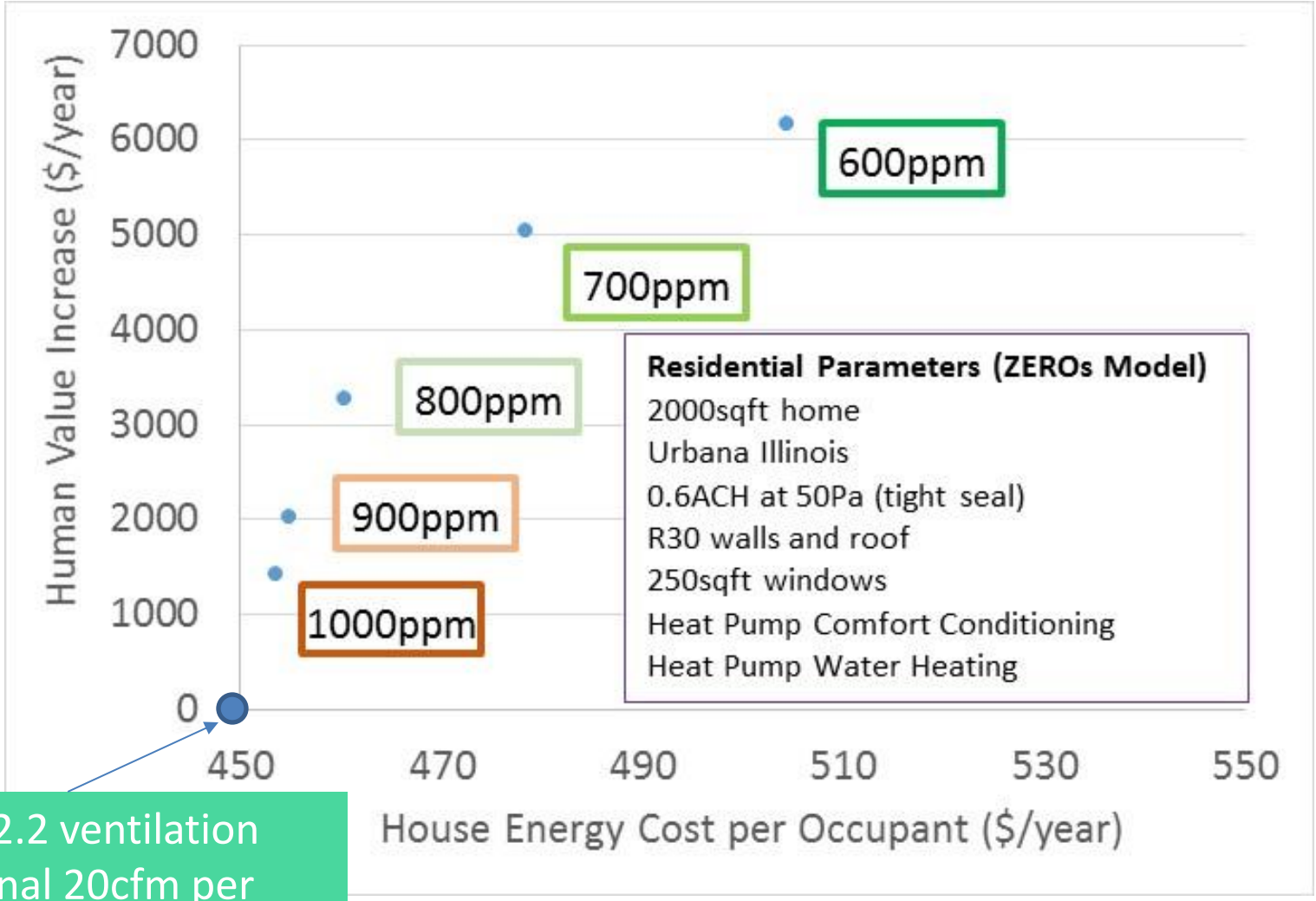
Earnings correlate with cognition performance (see “productivity” paper on BuildEquinox.com)

Cognition performance is directly linked to IAQ (see paper on “cognition” on BuildEquinox.com)

Doubling ASHRAE ventilation standards (20cfm to 40cfm per person) would increase productivity by $6500/person with an energy cost of less than $40/person

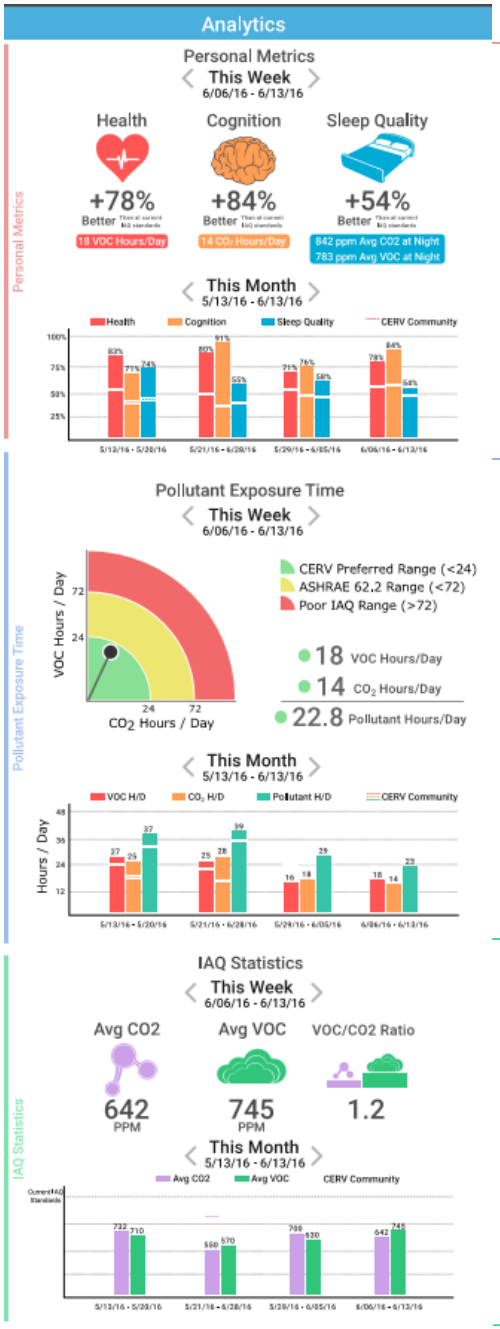
BUILD EQUINOX
WWW.BUILDEQUINOX.COM

Human Productivity $$ - Residential



ASHRAE 62.2 ventilation with nominal 20cfm per person of ventilation results in ~1100ppm CO_2

New IAQ Metrics



Personal Metrics: Immediate impact of pollutants on cognition and productivity

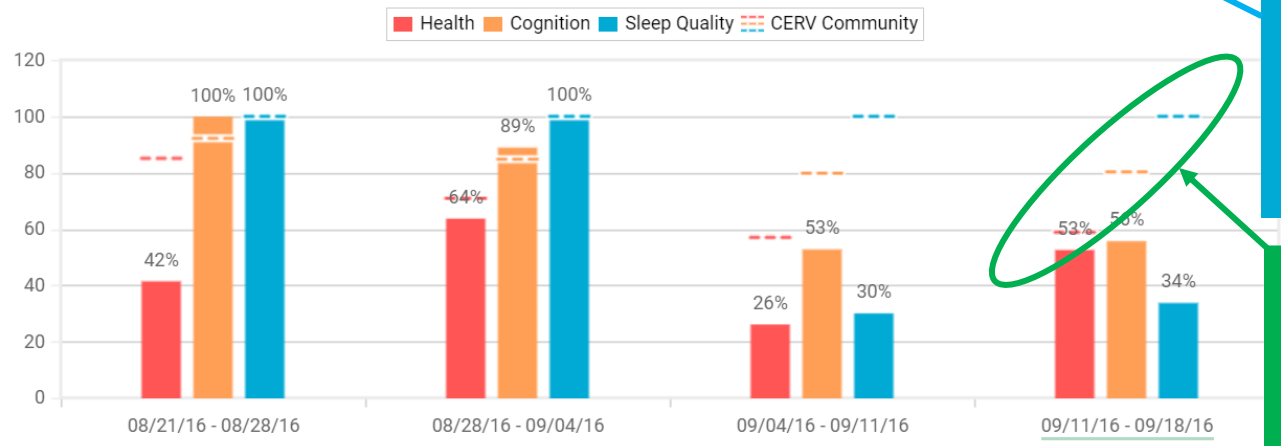
Pollutant Exposure Time: Accumulation monitoring of pollutants

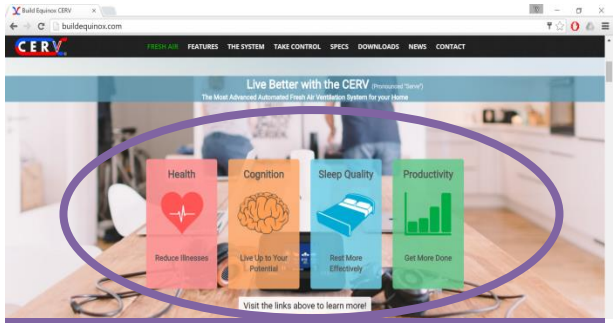
IAQ Statistics: Basic CO2 and VOC pollutant trends in your home

Your Performance

This Week
09/11/16 - 09/18/16

Health	Cognition	Sleep Quality
+52%	+55%	+33%
Better Than at current IAQ standards	Better Than at current IAQ standards	Better Than at current IAQ standards
CERV Community +58%	CERV Community +80%	CERV Community +100%





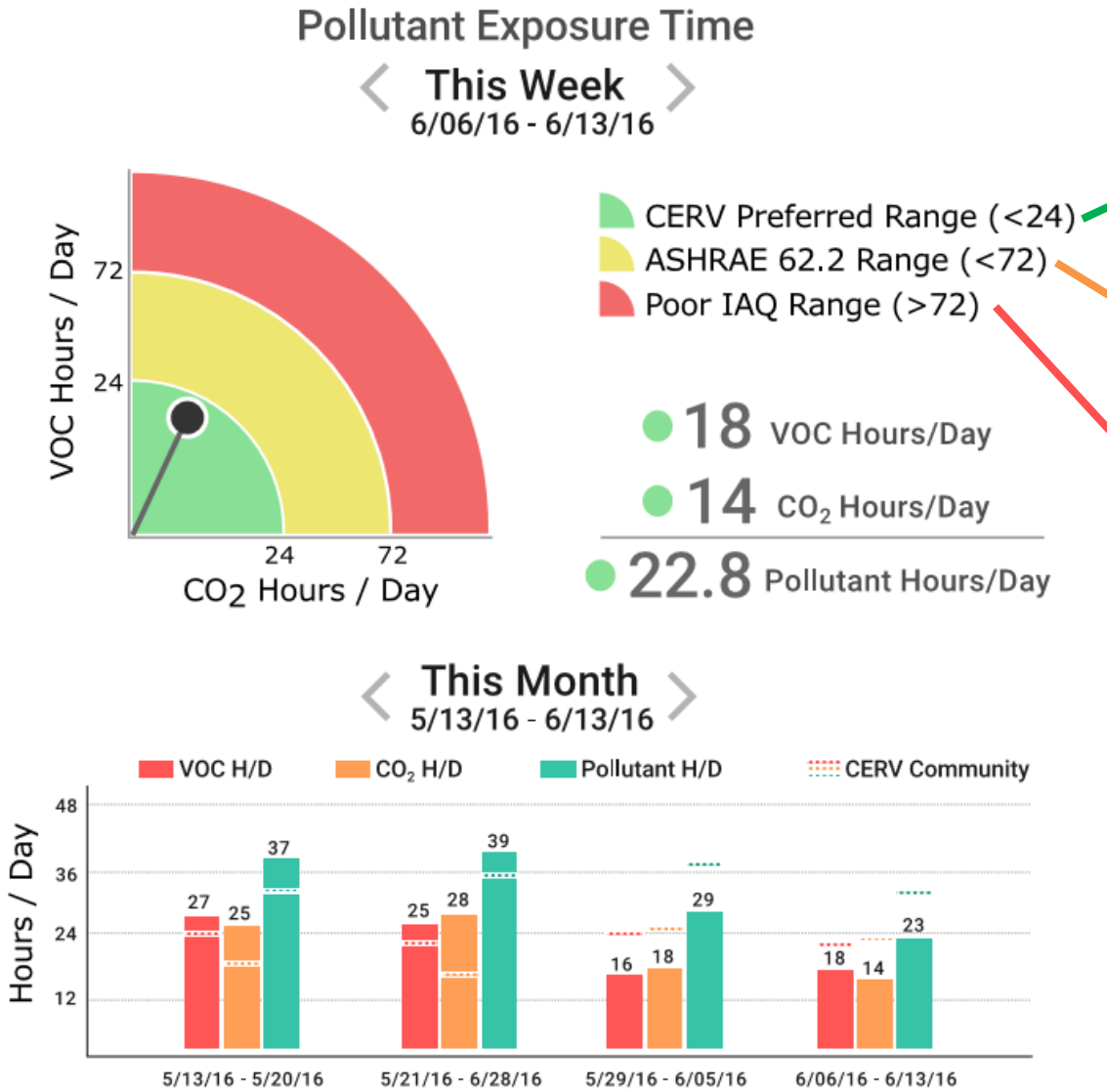
4 Reference papers on health, cognition, sleep and productivity on Build Equinox Website

Defined as IAQ from 10pm to 7am "Sleep hangover"

How do I compare with others?

BUILD EQUINOX
WWW.BUILDEQUINOX.COM

Pollutant Exposure Time



Energy efficient Smart Ventilation

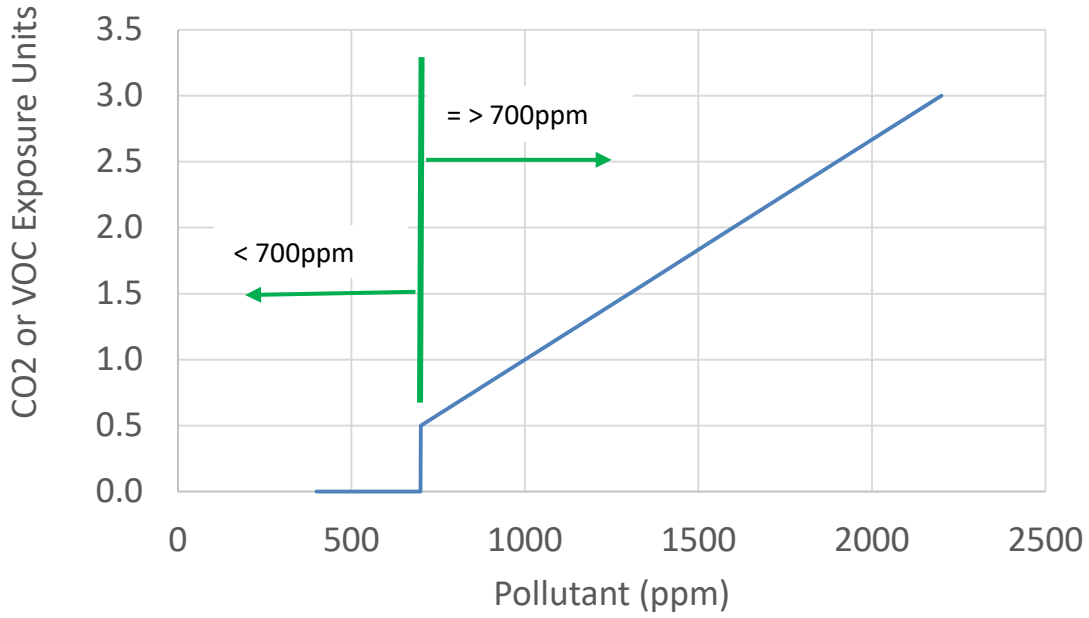
Likely IAQ due to human occupancy from ASHRAE 62.2 ventilation standards

Range exceeding ASHRAE ventilation levels

Weekly trends over the past month

Accumulated Health Impact

Pollutant Exposure



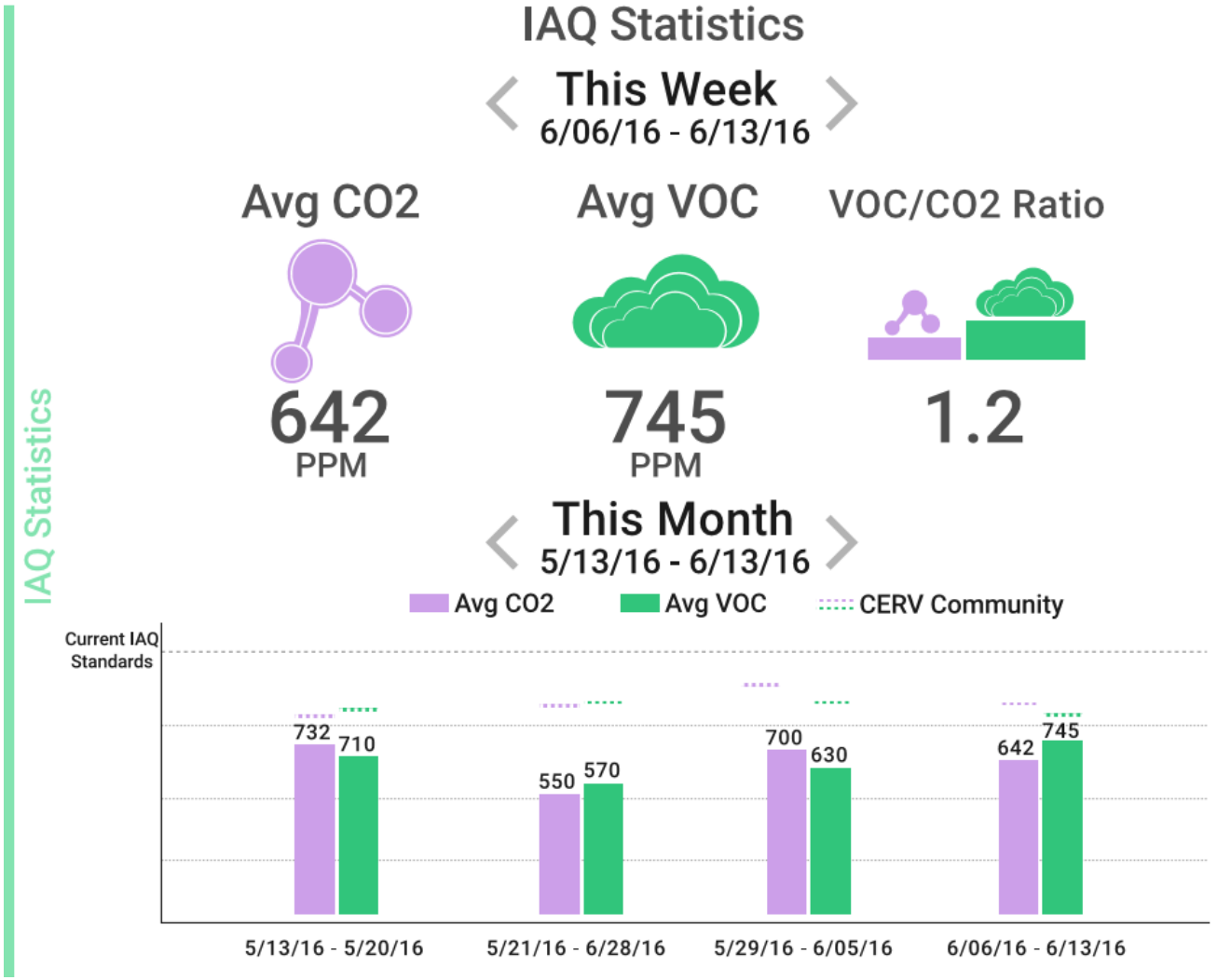
Exposure units are defined:

- Scale similar to "Olf"
- 1person in a room with 10 liters/sec (~20cfm) is 1 Olf (Olfactory) ~ 1000ppm CO2
- Current research indicates less significant impact with CO2 less than 700ppm, but may change with future research
- VOC is a soup of chemicals, and current scale assumes similar impact to CO2

CO2 or VOC Exposure Units = 0 for <700ppm

CO2 or VOC Exposure Units = (X ppm – 400)/(1000-400)

Sum (Exposure Units X Time Increment) = Exposure-hours



All electric homes:

VOC/CO2 < 1 indicates VOCs primarily human generated

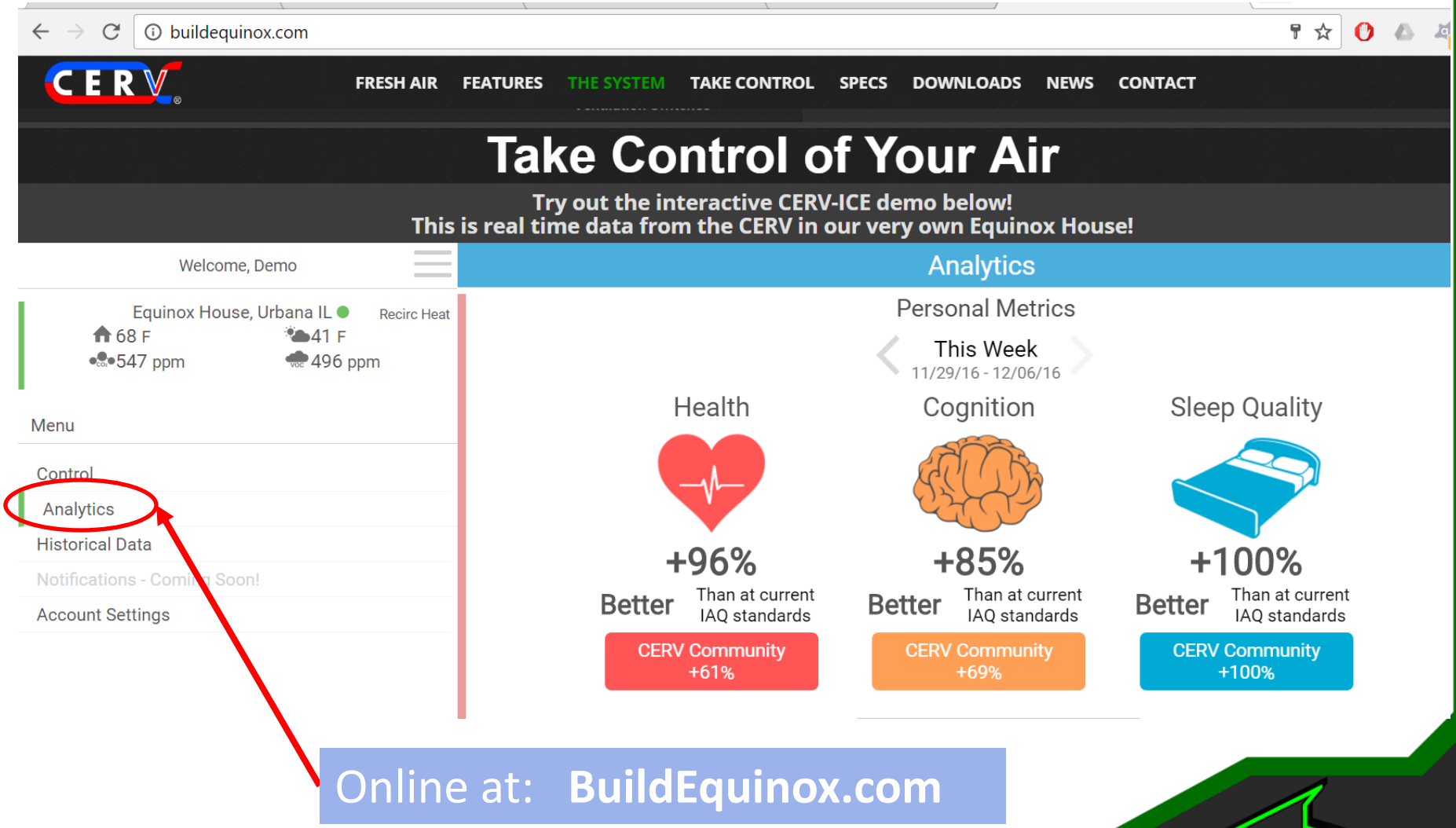
VOC/CO2 > 1 indicates additional sources of VOC emissions

Combustion homes: both <1 and >1

Weekly trends over the past month

Basic IAQ Statistics

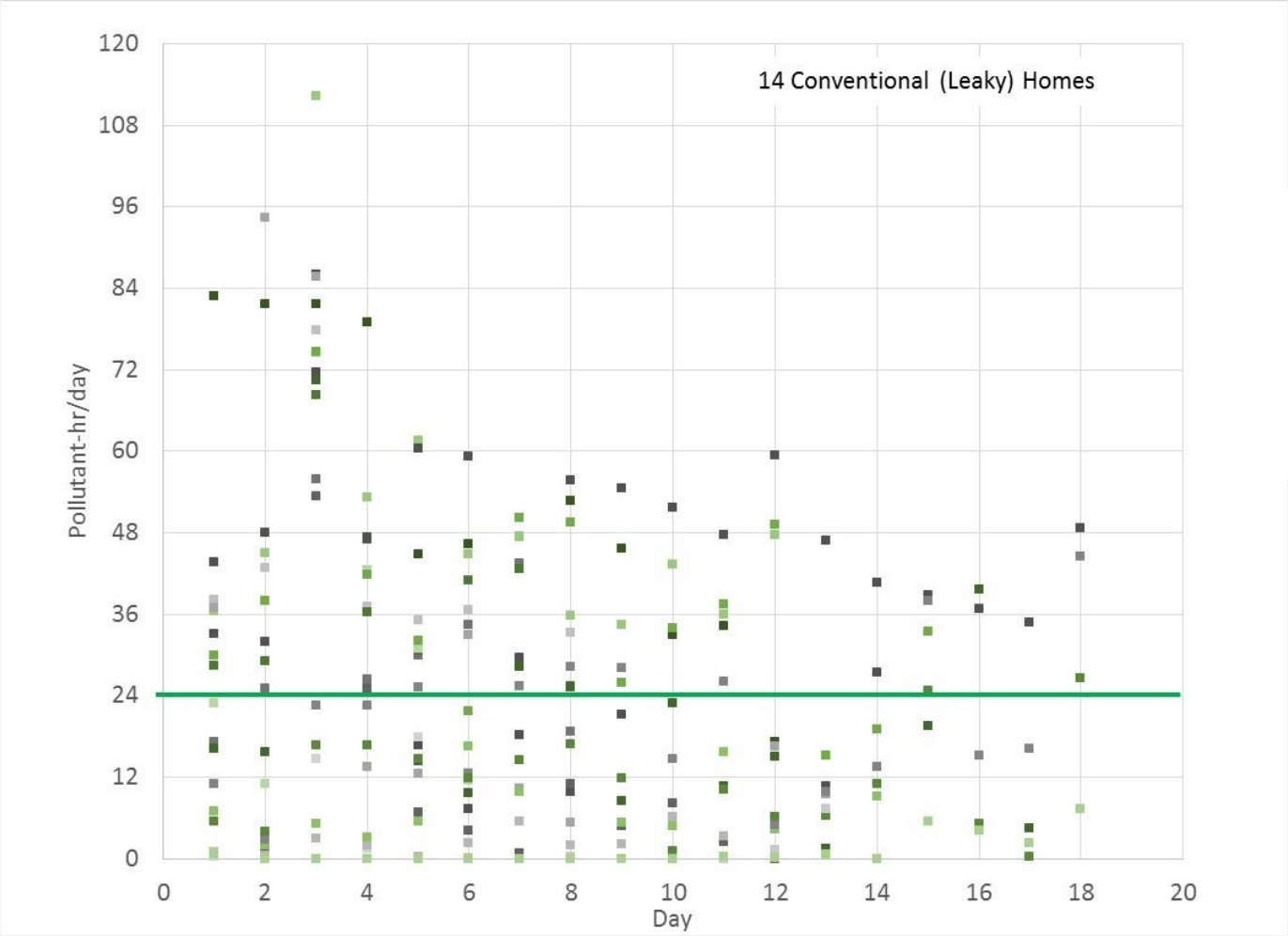
Watch Live IAQ Analytics



Online at: **BuildEquinox.com**

BUILD EQUINOX
WWW.BUILDEQUINOX.COM

Conventional “Leaky” Homes

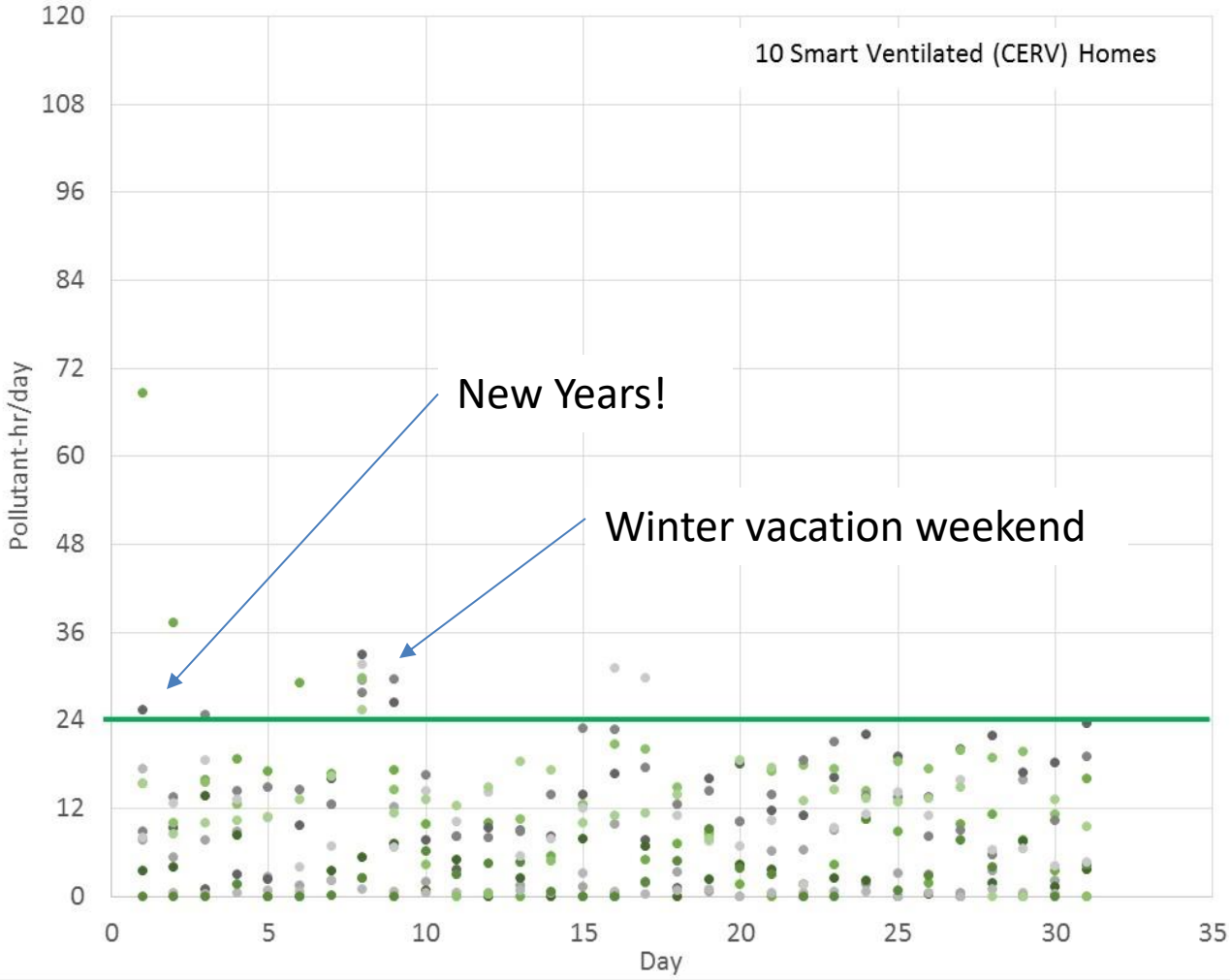


Various times of year

Homes in California, Colorado, Vermont, Minnesota, Illinois

~2 week assessment period with Build Equinox IAQ monitoring technology (Black Box IAQ)

Smart Ventilated (CERV) Homes

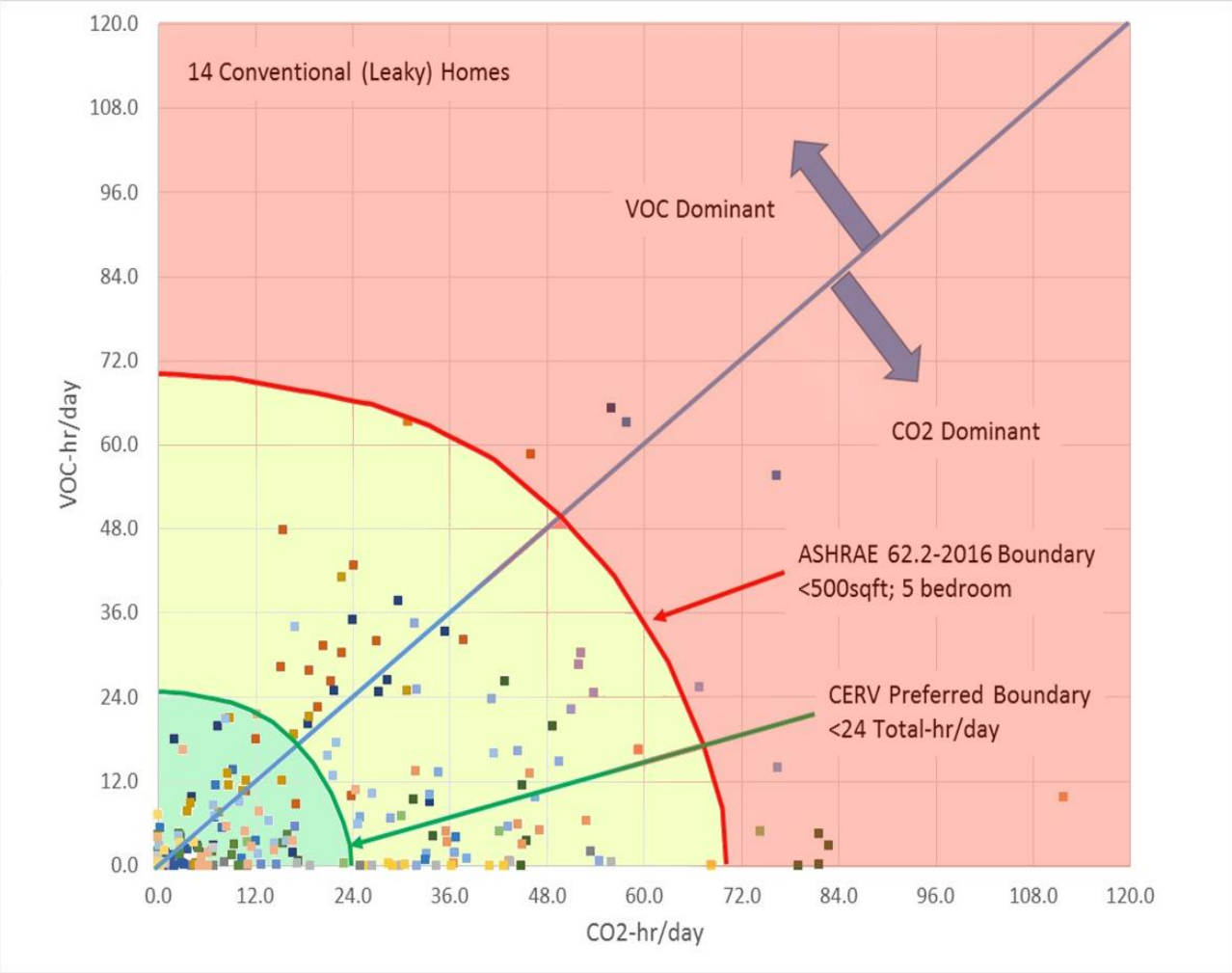


January data (closed house)

Homes in Oregon, Vermont, Colorado, South Carolina, Illinois

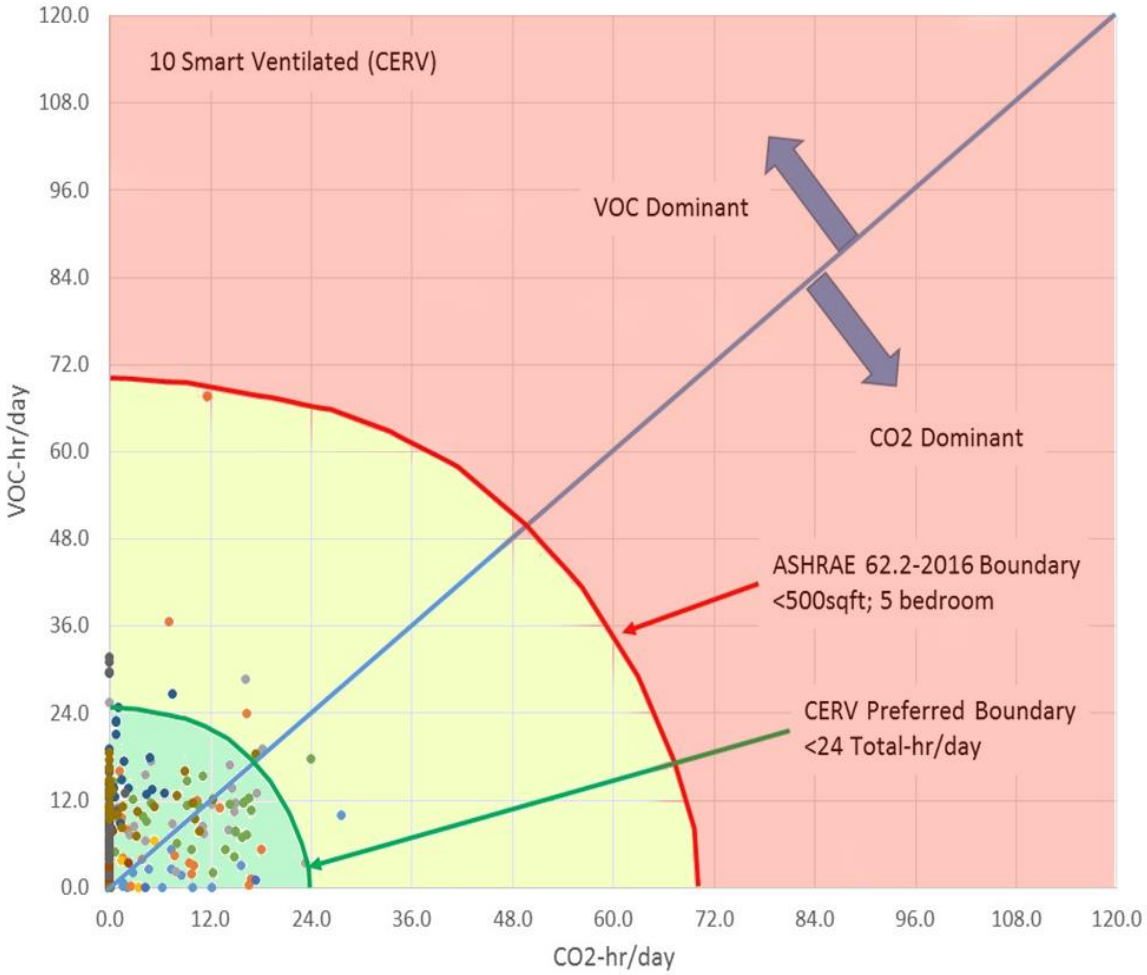
~4 week assessment period with CERV-ICE online monitoring (January 2016 data)

14 Conventional “Leaky” Homes



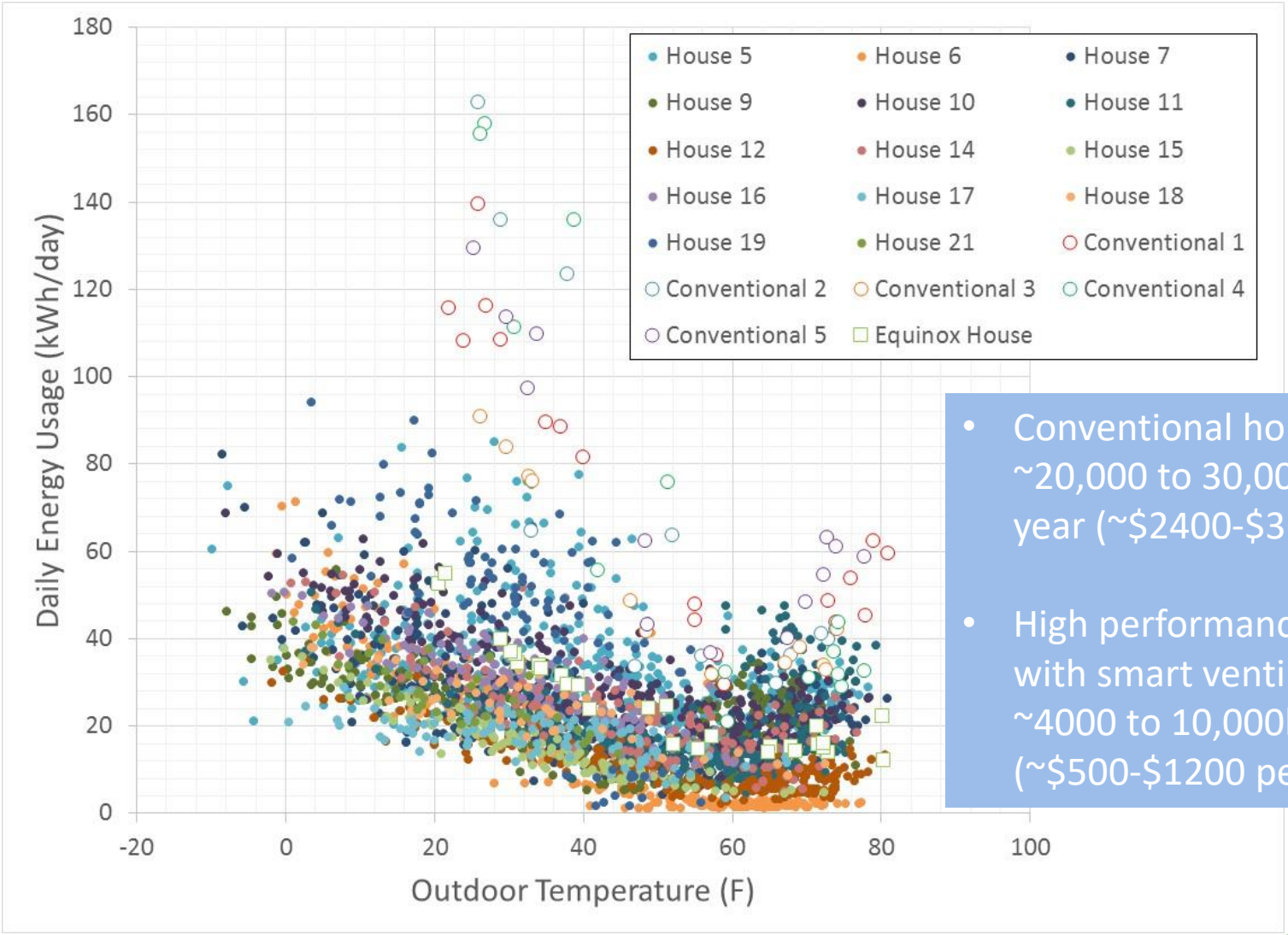
~2 week assessment period with Build Equinox IAQ monitoring technology (Black Box IAQ)

10 Smart Ventilated (CERV) Homes



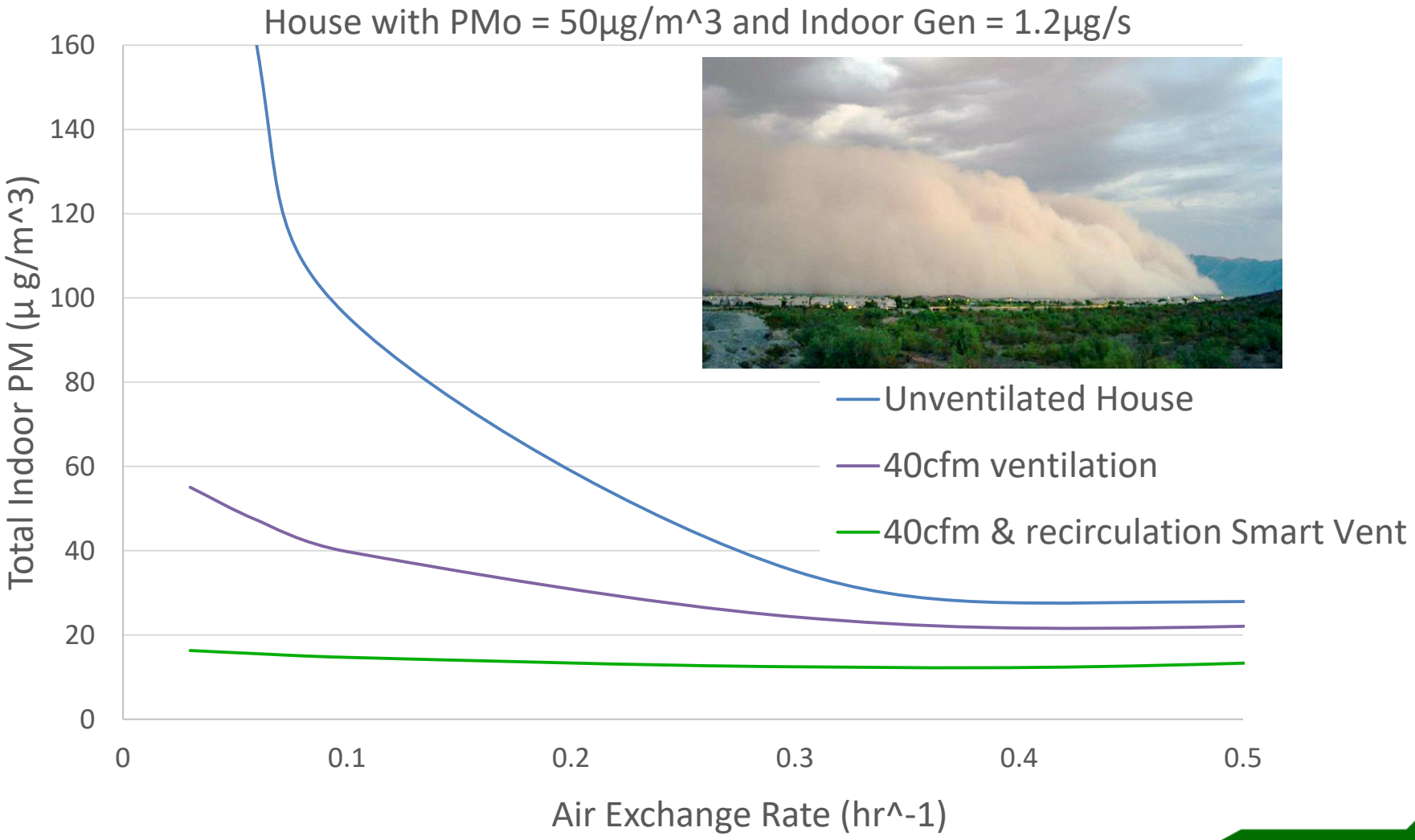
~4 week assessment period with CERV-ICE online monitoring (January 2016 data)

High Performance Homes vs Conventional

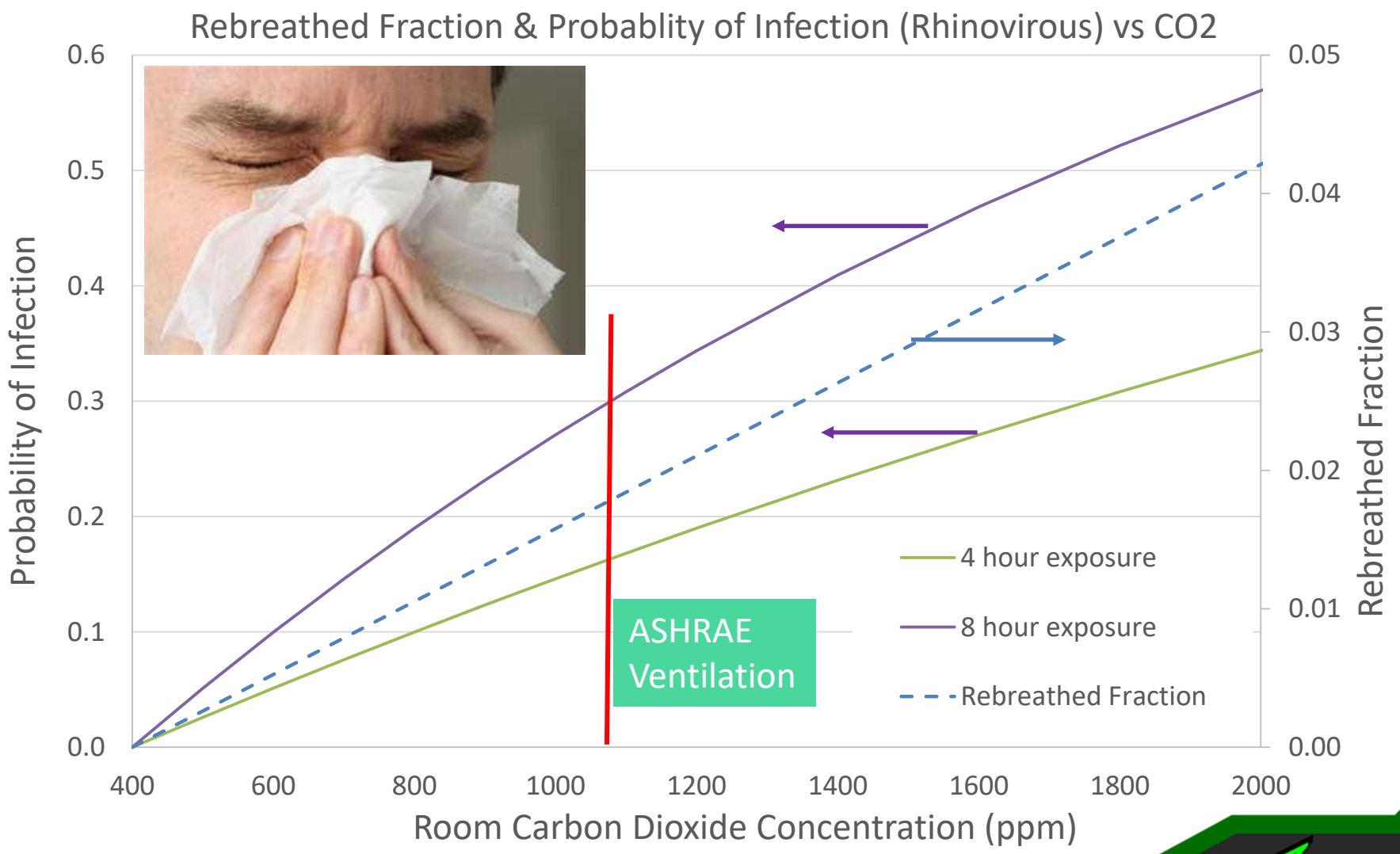


- Conventional homes use ~20,000 to 30,000kWh per year (~$2400-$3600 per year)
- High performance homes with smart ventilation use ~4000 to 10,000kWh per year (~$500-$1200 per year)

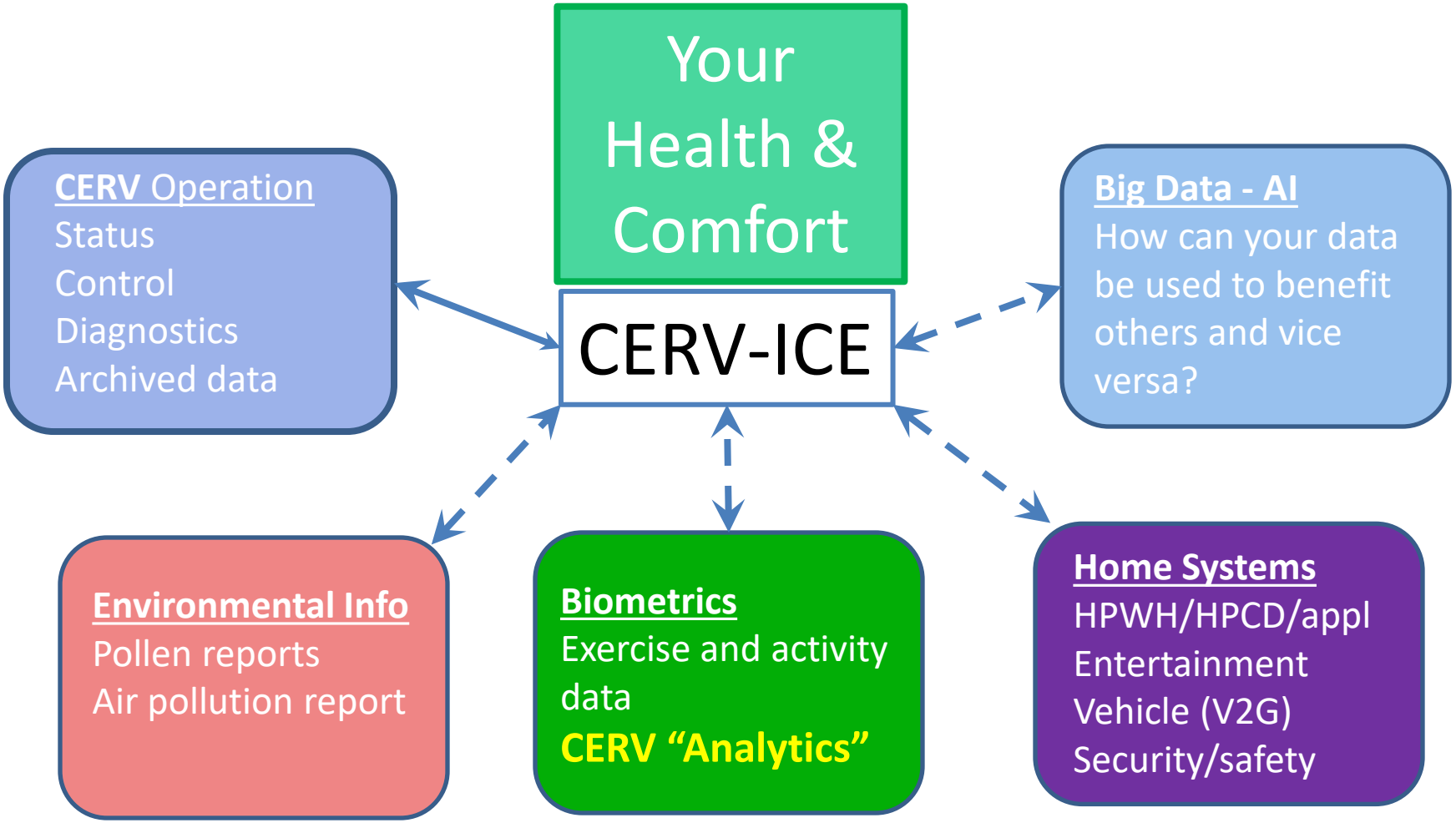
Upcoming Analytics - Particulate Management



Upcoming Analytics - Reducing Epidemics



The Future – Where We are Going



Summary

- The cost of poor IAQ at home and at work is much greater than the cost of energy (and associated ventilation) in efficient homes and buildings

- New IAQ metrics will help building occupants understand estimated impact of IAQ on their health, cognition and sleep
- Monitoring of accumulated pollutants will provide information for understanding future health effects of our indoor environments
- IAQ metrics provide a quantitative basis for comparing quality of construction, selection of materials, and occupant activities
- Basic Research is needed to continue defining interaction of pollutants on our health and productivity

THANK YOU!

References:

[1] T.Newell and B.Newell, 12 article NZEB design series, ASHRAE Journal, Sept 2010 – Aug 2011, available at BuildEquinox.com/publications

[2] T.Newell, "13 CERV® Homes in Vermont; Keeping Occupants Healthy, Comfortable and Energy Efficient"; Efficiency Vermont Report, June 2016, available at BuildEquinox.com/publications

[3] P. Ole Fanger, "What is IAQ?"; Indoor Air 2006; 16: 328–334, Technical University of Denmark

[4] M.Sherman, D Dickerhoff, "Air Tightness of U.S. Dwellings", ASHRAE Transactions, Jan 1998

[5] L.J.Akimbami, "The State of Childhood Asthma; 1980-2005", Advance Data from Vital and Health Statistics, No 381, CDC, US Dept of Health and Human Services, Dec 2006

[6] D.E. Jacobs, J.Wilson, S.L. Dixon, J. Smith, and A. Evens, "The Relationship of Housing and Population Health: A 30-Year Retrospective Analysis", Environmental Health Perspectives, Vol 117, No 4, April 2009

[7] N.E.Klepeis, W.C. Nelson, W.R. Ott, J.P. Robinson, A.M. Tsang, P.Switzer, J.V. Behar, S.C. Hern, W.H. Engelmann, "The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants", J Exposure Analysis and Environmental Epidemiology, Vol 11, pp231-252, 2001

[8] A.F. Rudd, J.W. Lstiburek, K. Ueno, "Residential Dehumidification Systems Research for Hot Humid Climates September 1, 2001—December 30, 2003", NREL Report, NREL/SR-550-36643, Feb 2005

[9] I. Walker, M. Sherman, B. Less,"Houses are Dumb Without Smart Ventilation", LBNL paper LBNL-6747E, May, 2014

[10] Joseph G. Allen, Piers MacNaughton, Usha Satish, Suresh Santanam, Jose Vallarino, and John D. Spengler; "Associations of Cognitive Function Scores with Carbon Dioxide, Ventilation, and Volatile Organic Compound Exposures in Office Workers: A Controlled Exposure Study of Green and Conventional Office Environments";Env Health Perspectives; Oct 2015

[11] DK Milton, PM Glencross, and MD Walters; "Risk of Sick Leave with Outdoor Air Supply Rates, Humidification, and Occupants Complaints"; Indoor Air; Vol 10, pp212-221; 2000

[12] P. Strøm-Tejsen, D. Zukowska, P. Wargocki, D. P. Wyon; "The effects of bedroom air quality on sleep and next-day performance", Indoor Air; doi:10.1111/ina.12254; 2015

[13] Seichi Konzo; The Quiet Indoor Revolution; Small Homes Council-Building Research Council, University of Illinois, Urbana, IL 1992

[14] Piers MacNaughton, James Pegues, Usha Satish, Suresh Santanam, John Spengler, and Joseph Allen; "Economic, Environmental and Health Implications of Enhanced Ventilation in Office Buildings"; Int. J. Environ. Res. Public Health 2015, 12, 14709-14722; doi:10.3390/ijerph121114709