New IAQ Metrics to Avoid Being Stupid, Sick and Tired

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March 8 & 9, 2017
Mission

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?

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100% Solar Powered Business!

Research & Education [1,2]
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
Our Homes and Buildings are making us Stupid, Sick, and Tired.

The cost of being stupid, sick and tired is staggering....
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 and colds is $127B/yr
  – Influenza = $87B/y; Non-influenza viral infections = $40B/y [15,16]
  – 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 [10, 11, 12, 14]
- Smart ventilation surpasses 62.2 standards that gets us to truly healthy and productive environments
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
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 = 156 hours

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

Poor indoor air quality impacts:
• Health
• Human Performance

How do you know if your air stinks?

- radon
- CO2
- VOC
- H2O
- Molds, etc
- Exfiltration
- Infiltration
- Germs
- Pesticides, dust, pollen
- Filtered Ventilation
- radon

Health: Reduce Illnesses
Cognition: Live Up To Your Potential
Sleep Quality: Rest More Effectively
Productivity: Get More Done

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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
Insufficient ventilation when occupied

Smart ventilates when needed

Excessive ventilation when unoccupied

With today’s sensors, automatic fresh air control improves our health and performance
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.
4 Reference papers on health, cognition, sleep and productivity [10,11,12,14]
Risk of Sick Leave Associated with Outdoor Air Supply Rate, Humidification, and Occupant Complaints

DONALD K. MILTON¹*, P. MARK GLENCROSS¹,² AND MICHAEL D. WALTERS²

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 CO₂ 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.
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

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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 IEQ conditions in conventional or green buildings. At the end of each workday, participants completed a battery of computer-based tasks designed to assess various higher-order cognitive functions.

These results suggest that the IEQ conditions of green buildings can have positive effects on cognitive function, which may contribute to improved productivity and overall health in the workplace.


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...
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.

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

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

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Carbon Dioxide (CO2) Impairs Cognitive Performance

Impact of Carbon Dioxide (CO2) on Human Decision-making Performance*


**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
Human Productivity $$ - Residential

ASHRAE 62.2 ventilation with nominal 20cfm per person of ventilation results in ~1100ppm CO2
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

How do I compare with others?

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?
Accumulated Health Impact

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

Pollutant Exposure Time

This Week
6/06/16 - 6/13/16

CERV Preferred Range (<24)
ASHRAE 62.2 Range (<72)
Poor IAQ Range (>72)

18 VOC Hours/Day
14 CO₂ Hours/Day
22.8 Pollutant Hours/Day

This Month
5/13/16 - 6/13/16

VOC H/D, CO₂ H/D, Pollutant H/D, CERV Community

Weekly trends over the past month
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

Exposure units are defined:

- Scale similar to “Olf”
- 1 person 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
Basic IAQ Statistics

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
Watch Live IAQ Analytics

Online at: 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 Homes

~4 week assessment period (January 2016 data)

January data (closed house)

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

New Years!

Winter vacation weekend
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)
History of House Energy

Annual House Energy (kWh) Requirements

- **1920**
  - Infiltration: 30ACH@50Pa
  - No insulation
  - Single pane windows

- **1950**
  - Infiltration: 10ACH@50Pa
  - 3” insulation
  - Storm windows

- **2010 “conventional”**
  - Infiltration: 6ACH@50Pa
  - 6” insulation
  - Energy Star windows

- **2010 “super”**
  - Infiltration: 0.6ACH@50Pa
  - Fresh Air Ventilation
  - 12” insulation
  - Energy Star windows
  - Respiratory illnesses double over 30 years
  - People dominated energy loads

- **2010S**
  - People Energy
  - House Energy
High Performance Homes vs Conventional

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

House with PMo = 50µg/m^3 and Indoor Gen = 1.2µg/s

- Unventilated House
- 40cfm ventilation
- 40cfm & recirculation Smart Vent

Total Indoor PM (µg/m^3)

Air Exchange Rate (hr^-1)
Upcoming Analytics - Reducing Epidemics

Rebreathed Fraction & Probability of Infection (Rhinovirus) vs CO2

- Probability of Infection vs Room Carbon Dioxide Concentration (ppm)
- Rebreathed Fraction vs Room Carbon Dioxide Concentration (ppm)

- 4 hour exposure
- 8 hour exposure
- Rebreathed Fraction

ASHRAE Ventilation
The Future – Where We are Going

Your Health & Comfort

PREVENTilation

CERV Operation
Status
Control
Diagnostics
Archived data

Big Data - AI
How can your data
be used to benefit
others and vice
versa?

Environmental Info
Pollen reports
Air pollution report

Biometrics
Exercise and
activity data
CERV “Analytics”

Home Systems
HPWH/HPCD/appl
Entertainment
Vehicle (V2G)
Security/safety
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:


