Why We Ventilatte

Max Sherman
Lawrence Berkeley National Lab
ASHRAE Distinguished Lecturer

ASHRAE BIO

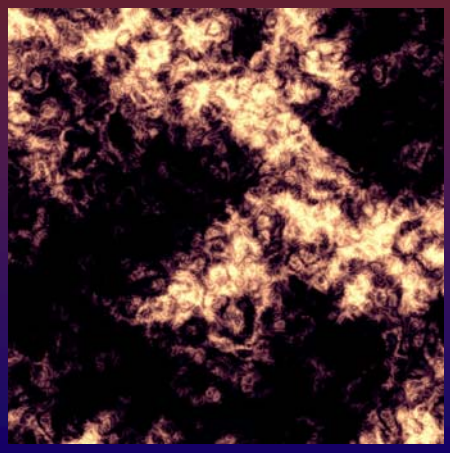
- Distinguished Lecturer
- Exceptional Service Award
- Board of Directors; TechC
- Chair of committees:
  - 62.2; Standards Committee
  - TC 4.3; TC 2.5
- Holladay Distinguished Fellow

OVERVIEW

- What is Ventilation? What is IAQ?
- Why *do* we ventilate? Why don't we?
- When will we learn?
- How can we be smart about setting standards?
- What is the role of ventilation in buildings

Who Are You?

- Engineers (ASHRAE Members & not);
- architects,
- contractors,
- reps,
- builders,
- vendors,
- code officials



WHAT IS VENTILATION

- Medicine: To Exchange Air In the Lungs
- Latin: *Ventilare*, "to expose to the wind"
- Today: To Bring In Outdoor Air And Replace Indoor Air Of The Occupied Space
- Long History

HISTORY OF STANDARDS

- Contaminants require ventilation
  - From cave-man to euro-man
- Rates and design based on expert judgments
  - From cave-man to euro-man
- Science is latecomer
  - Need to find what we are ventilating for

Early Codes and Standards

- 1631 King Charles & Windows
- 4 cfm/p 1836 Tredgold "Parliament Stinks"
  - Steady rise as research continues
- 30 " 1895 ASVE Contagion-based
- 30 " 1925 22 US State Codes
- 1927 UBC Requires 1/8 Windows

Silly English did not know that 2 cfm= 1 l/s

ASHRAE Standards History

- ASHRAE 62-73 Was 5 cfm/person
  - 15-20 cfm/p recommendation
- ASHRAE 62-81 Was 5 cfm/person
  - But 15 cfm, *if smoking allowed*
- ASHRAE 62-89
  - 15 cfm/p assumed moderate smoking
  - 0.35 ACH for houses

Residential 62

- 62-89 residential section was very vague
  - Failed attempt to improve it in famous "62-89R"
- Separate 62.2 committee formed in 1997
  - Much gnashing ensued
- 62.2-2003 was first version
  - Many changes since
- Latest version is 62.2-2013

Why Do We Ventilate Today?

Sustainable	Not Sustainable
Improves Comfort	Reduces Comfort
Reduces Exposure to Contaminants	Increase Exposure to Contaminants
Saves Energy	Costs Energy
Control Moisture	Causes Moisture Problems
Improved Durability	Reduces Durability

WE VENTILATE FOR COMFORT

- Thermal Comfort (IEQ not IAQ)
  - Prevents overheating by venting excess heat
  - Air movement makes us feel cooler
  - Ventilative cooling is another topic
- Odor Control
  - Not all odors are bad: personal differences
  - Occupants are best "sensors" –can take actions
  - *Most* odors not controlled by constant ventilation

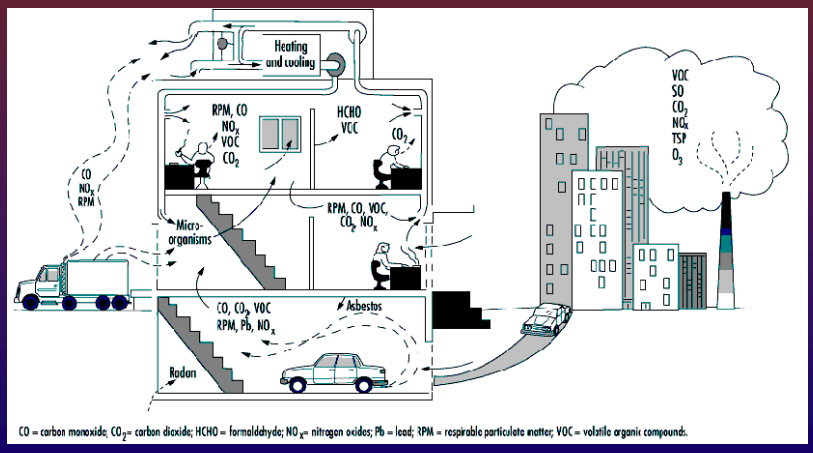
One Odor Matters: US!

- People Emit "Human Bioeffluents"
  - CO_2 is only surrogate
- Daily Hygiene of Western World
  - 5 cfm adapted (occupants)
  - 15 cfm unadapted (visitors)
- Dominates In High-Density Spaces
- Sets Floor Otherwise

VENTILATE FOR HEALTH

- Occupants not usually good sensors
  - So, we must design healthy buildings
- Key Questions:
  - What are the important contaminants?
  - How do we measure harm from them?
  - How do we mitigate that harm?

CONTAMINANT SOURCES



CO = carbon monoxide; CO_2 = carbon dioxide; HCHO = formaldehyde; NO_x = nitrogen oxides; Pb = lead; RPM = respirable particulate matter; VOC = volatile organic compounds.

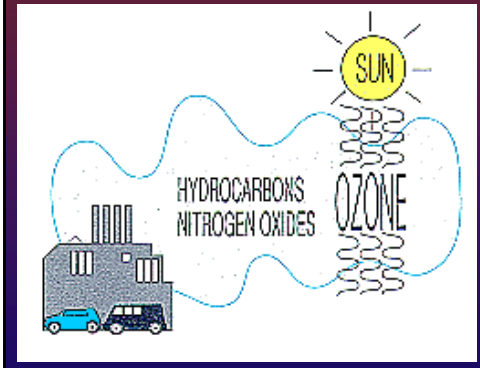
BUT NOT FOR….

- We do NOT ventilate for contagion control
  - Maybe in hospitals but not in homes or offices
- We do NOT ventilate to supply "fresh air"
  - <2% of 62.2 rates needed to supply oxygen for people
- We do NOT ventilate to *supply* anything

Ventilation is about chronic pollutant removal

Local Exhaust is about acute source removal

OZONE



- Usually Lower Indoors
- Highly Reactive
  - Reacts w/ almost anything
- Can Be Mitigated by
  - Envelope Performance
  - Closed Windows
  - Pressure Management
  - Activated Carbon

COMBUSTION

- Lots of Pollutants
  - NO_x, SO_x, CO_x
  - H_2O
  - Ash & Soot
  - Other Stuff
- Outdoors
- Indoors worse if not vented

NAAQS: CRITERIA POLLUTANTS

- Lead: A Lesser Airborne Contaminant Of Concern
  - Still some local issues
- SO_2: From High-Sulfur Coal In Power Plants
  - Acid Rain is a local phenomena
- CO, NO_2: Mostly From Combustion
- Ozone: Photochemically Produced From (Auto) Combustion By-Products
- Particulates: PM2.5 *(mass below 2.5μ)*

BIOLOGICAL

- Dust Mite, Pets
- Mold, Fungi
- Allergies
- Asthma

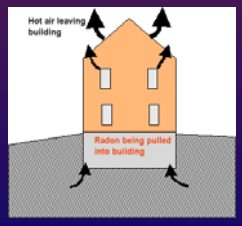
Mostly moisture control

Toxic Air Contaminants

- Activities
  - Cleaning
  - Painting
  - Pesticides
  - Hobbies
  - Office
- Residues Linger
- Entrainment

BUILDING EMISSIONS

- Volatile Organic Compound (VOC)
  - Formaldehyde
- Radon
  - Soil Gas
- Particles
- Others



WHAT SOURCES MATTER?

- Hazards Analysis
  - Identify likely contaminates of concern
  - Compare measured concentrations to standards
- Harm (Risk) Analysis
  - What is the harm done from these hazards
  - What should be the focus of mitigation efforts

Conduct Hazard Analysis

- Study includes 77 published studies of measured concentrations indoors; focus on US homes
  - 67 relevant to long term concentrations
  - 10 relevant to short term concentrations
- 267 chemicals were included: criteria pollutants, VOCs, SVOCs, and metals
- 97 chemicals had relevant health standard or metrics for comparison

Comparing Concentrations to Health Standards

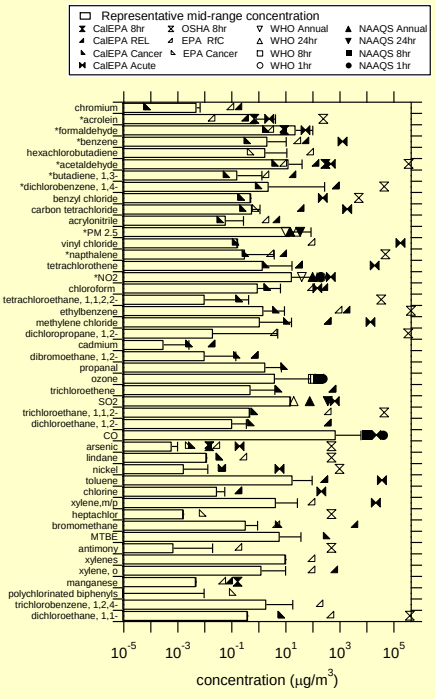
- Criteria Pollutants
  - US EPA- NAAQS (1hr, 8hr, 24hr, annual)
  - WHO (1hr, 8hr, 24hr, annual)
- HAPs/TACs
  - Cancer Health Standards
    - California EPA - Unit Risk Estimates
    - US EPA - Unit Risk Estimates
  - Non-Cancer Health Standards
    - California EPA-Reference Exposure Levels (1hr, 8hr, annual)
    - US EPA – Reference Concentrations (annual)

Note: ACUTE vs. CHRONIC

- Acute exposures involve strongly intermittent sources and short-term effects
- Chronic exposures caused by low level, but continual sources and have long-term effects
- Ventilation standards control
  - Acute exposures by source control or local exhaust
  - Chronic exposures by general ventilation

Identifying Chronic Health Hazards

- Non-Cancer
  - Direct comparison to published values
- Cancer
  - Cancer "REL" set to a cancer risk that correspond to a lifetime incremental risk of 1 in 10^5 assuming 70 years of continuous exposure



Top 10 Chronic IAQ Hazards

Priority Hazards

- acetaldehyde,
- acrolein,
- benzene,
- 1,3-butadiene,
- 1,4-dichlorobenzene,
- formaldehyde,
- naphthalene,
- NO_2,
- $PM_{2.5}$.

Not listed

- Carbon Tetrachloride
- Ozone
- Radon
- Tobacco Smoke

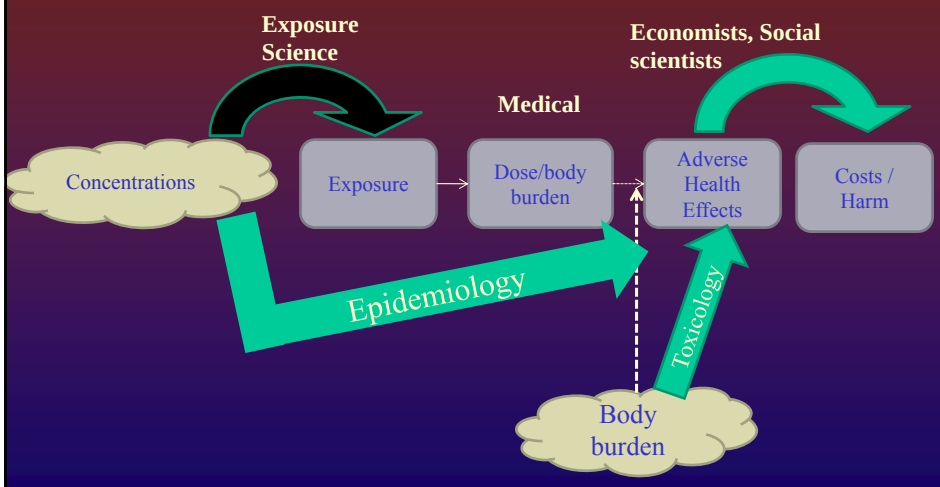
Contaminant Standards Questionable

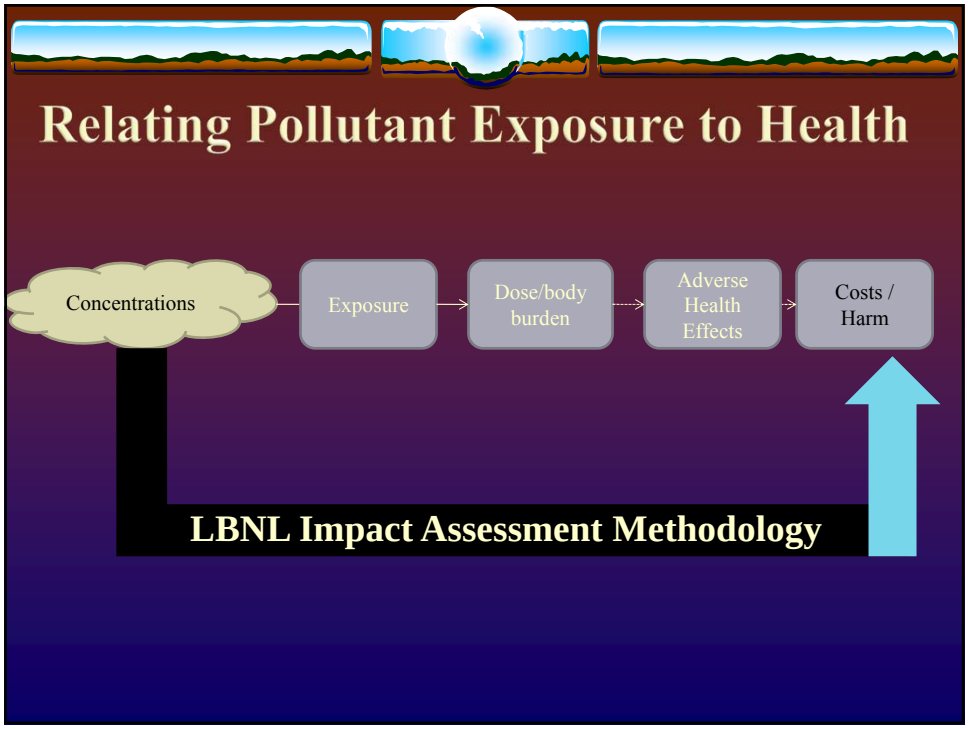
- Based on expert opinions backed by data
- But are political decisions
  - Costs & benefits; practicalities; good as can be
- Do not use same health impact criteria
  - So, can't be compared or "traded"
- Need level playing field
  - to get total cost/harm from contaminants

"Obvious" Approach

- Find out what harm (cost) a given exposure has.
  - Using a common metric
- Would allow trade-offs, and comparisons
  - Design optimization
- But not as easy to do as it is to say
  - interdisciplinary

Many Disciplines Involved





Costs of Adverse Health Effects

- Disability Adjusted Life Years (DALYs)

$$DALY = YLL + YLD$$

- YLL = Years lost to premature death
- YLD = Equivalent years lost to disability
- DALY valued at roughly $50,000 - $160,000
- Non-Fatal Stroke: ~9.5–13 DALYs
- PM2.5 Mortality: ~1.2-10 DALYs

32

Indoor Concentrations → DALYs

- Annual DALYs lost per person=
  - Criteria Pollutants

$$\Delta concentration * \frac{\partial Disease\_Incidence}{\partial concentration} * \frac{\partial DALYs}{\partial Disease}$$

  - Single component gas phase pollutants (Huijbregts)

$$inhaled\_mass * \frac{\partial DALYs}{\partial inhaled\_mass}$$

Criteria Pollutant Approach

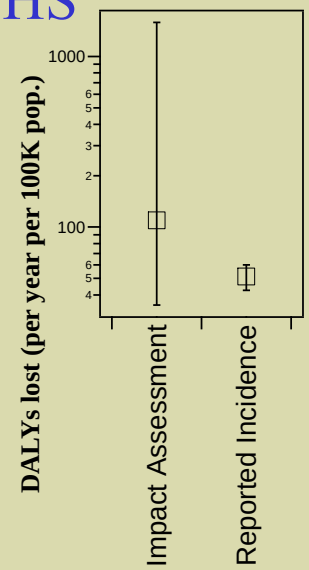
- Concentration-Response functions
  - Relate increased exposure to disease incidence
  - Derived from epidemiology studies

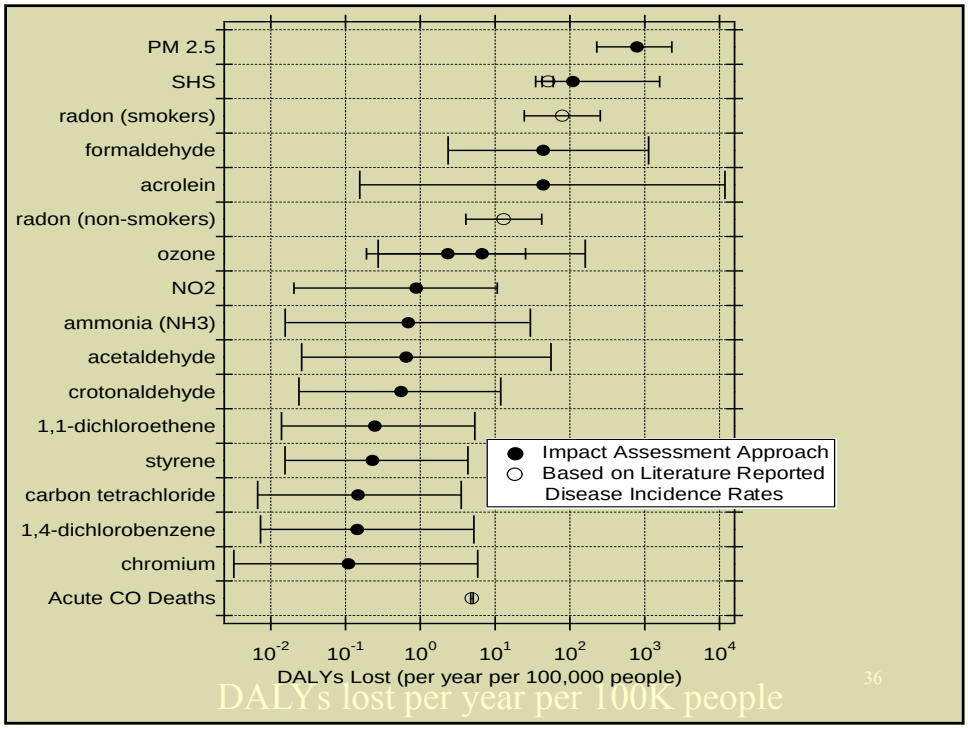
$$\frac{\partial \text{Disease incidence}}{\partial \text{concentration}} * \Delta \text{concentration} = -[y_o(\exp(-\beta \Delta C_{exposure})-1)]$$

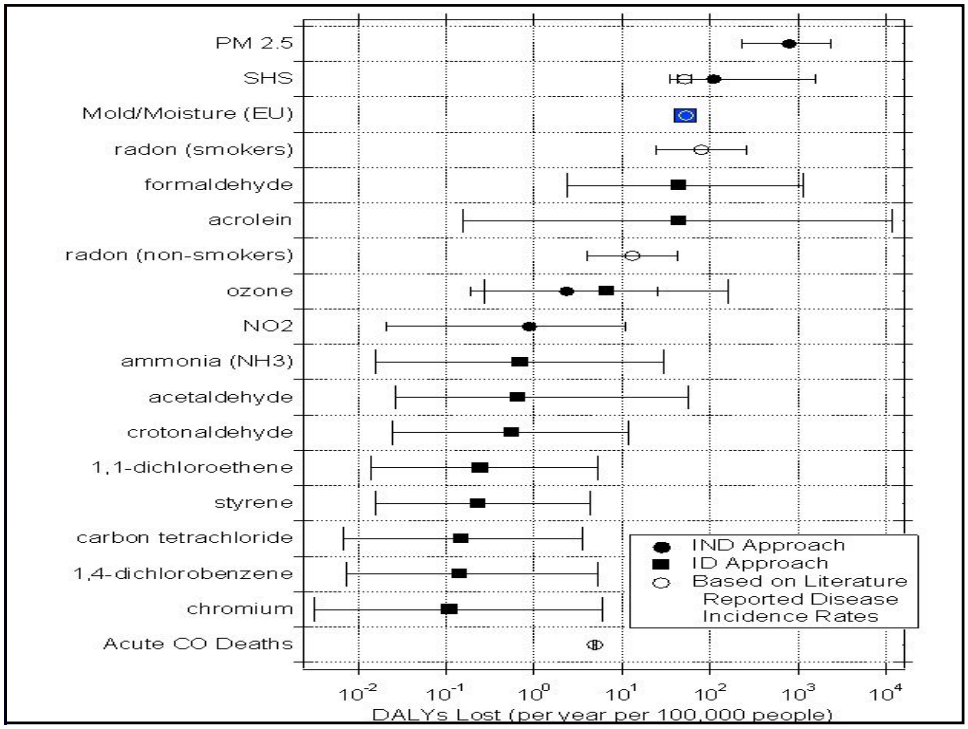
- DALYs per incidence of disease (Various)
- Exposure concentrations (Logue et al. 2011)

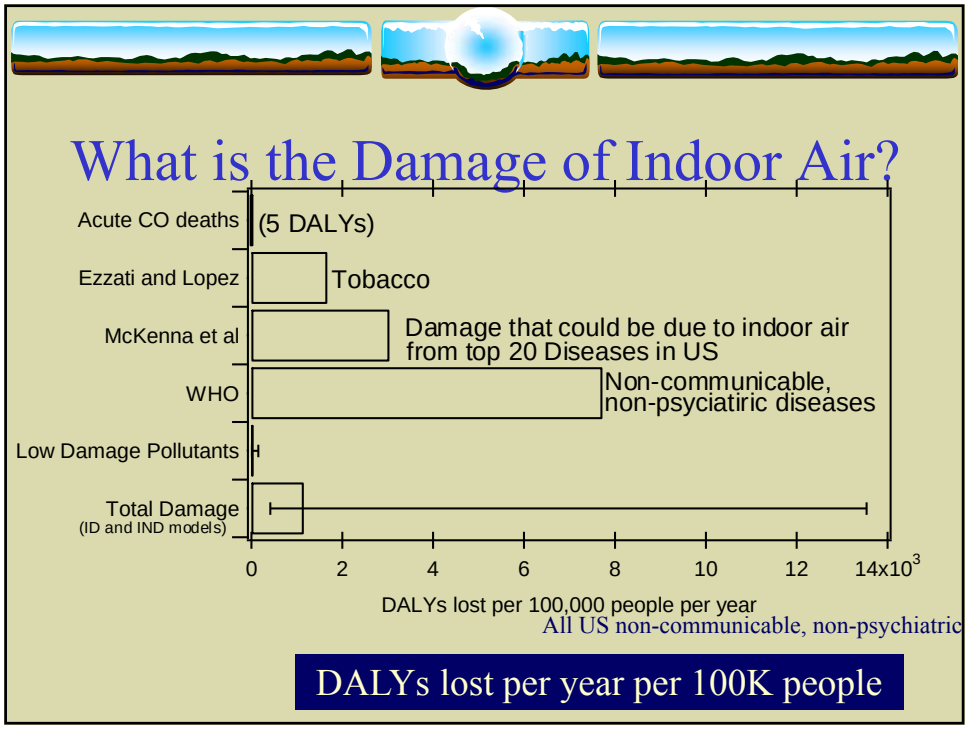
Checking Methodology: SHS

- Applied to concentrations of secondhand smoke components
- Determined damage associated with reported health impact of SHS by EPA
- Results help assess uncertainty of other indoor pollutant impacts

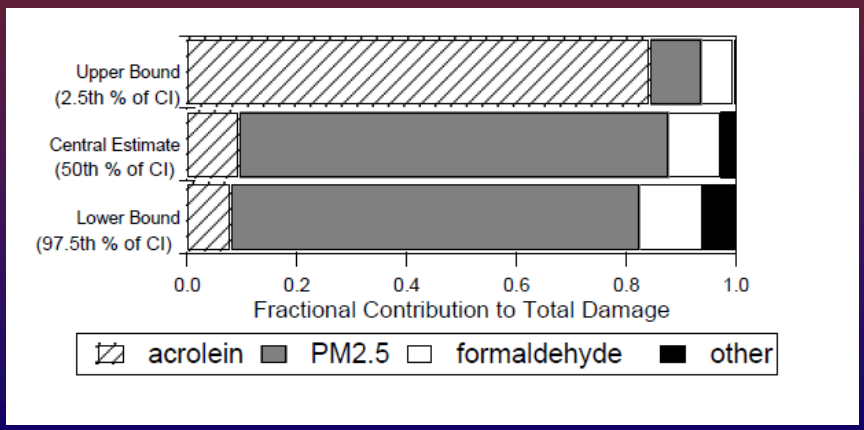





PM 2.5
SHS
Mold/Moisture (EU)
radon (smokers)
formaldehyde
acrolein
radon (non-smokers)
ozone
NO2
ammonia (NH3)
acetaldehyde
crotonaldehyde
1,1-dichloroethene
styrene
carbon tetrachloride
1,4-dichlorobenzene
chromium
Acute CO Deaths
IND Approach
ID Approach
Based on Literature Reported Disease Incidence Rates
10^-2 10^-1 10^0 10^1 10^2 10^3 10^4
DALYs Lost (per year per 100,000 people)


What is the Damage of Indoor Air?
Acute CO deaths
(5 DALYs)
Ezzati and Lopez
Tobacco
McKenna et al
Damage that could be due to indoor air from top 20 Diseases in US
WHO
Non-communicable, non-psyciatiric diseases
Low Damage Pollutants
Total Damage
(ID and IND models)
0 2 4 6 8 10 12 14x10^3
DALYs lost per 100,000 people per year
All US non-communicable, non-psychiatric
DALYs lost per year per 100K people

What Pollutants are the main risk drivers? (excludes SHS and radon)



EQUIVALENCE

- Trade-offs allow smart design
- Equivalence allows health trade-offs
  - Implicit or Explicit
- How do we get there ?
  - Philosophy for enabling innovation

Study Results

1. PM2.5 is most significant indoor health hazard
   - Can have significant outdoor source
2. Product of combustion are 2nd most
   - Acrolein is biggest chronic contributor
   - Least studied of important compounds
3. Formaldehyde is 3rd most
   - Even though it meets WHO standards

…not counting smoking or Radon or acute

Control Approaches (> Std 62)

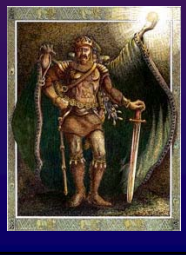
1. Particle filtration (PM2.5)
   - Ventilation may not handle particles well
2. Combustion control (Acrolein et al)
   - Do not let products of combustion into space
3. Low emitting materials (HCHO mostly)
4. Then dilution ventilation (>human odor needs)
   - *We don't know what we don't know*

A Word on Equivalence

- Uses science to
- Health/IAQ Equivalence: equivalent harm
  - Ultimate objective of IAQ standards
  - DALY is good metric, but don't have enough info
- Ventilation Equivalence: equivalent exposure
  - Assumes generic contaminant of unknown harm
  - Embodied in ASHRAE 62.2

FOR MORE INFORMATION

- Residential Building Systems Group
  - http://homes.lbl.gov
- Air Infiltration and Ventilation Center (AIVC)
  - http://www.aivc.org
- ASHRAE
  - http://www.ashrae.org



CURRENT ASHRAE STANDARDS

- 62.1-2010: Non Residential
  - Users Manual and companion guideline
- 62.2-2010: Residential
  - Users Manual and companion guideline
- Guideline 10: Indoor Environmental Quality

The Latest Tool for Good IAQ

ASHRAE's Indoor Air Quality Guide

- Practical guidance on achieving good IAQ in commercial buildings
- Joint effort of ASHRAE, AIA, BOMA, US EPA, SMACNA, USGBC
- 200 page book, 500 page CD
- Available now