

METRICS

What do we need to know in order
to add air distribution into
ASHRAE Standard 62.2?

Max Sherman

OBJECTIVES

- To define some potential metrics that can be used to evaluate air distribution
 - But, first we need to look at implied metrics for acceptable Indoor Air Quality
- Suggest some approaches to evaluate metrics
 - Simulation
 - Experiment

Max's Metric Mantra:

Metrics must be
meaningful and
measurable

Pre-Metric: Acceptable IAQ

- Frames discussion of metrics
- Won't discuss this quantitatively, but operationally it should
 - Limit **damage**
 - Caused by **contaminants** of concern
 - To which people are exposed over some **time period**

Types of “DAMAGE”

- Comfort
 - Unpleasant Odors, Irritation (*covered by 62.2*)
 - Acoustics, lighting, thermal, etc. (*not covered*)
- Health
 - Reduced physiological functioning
 - Tissue damage
 - Increased susceptibility to disease

Contaminants of Concern

- Compounds and specifics: *Bjarne*
- Whole-house ventilation looks at what?
 - Acute Mortality/Morbidity: No
 - E.g. we don't control phosgene with 62.2
 - Reduction in life-expectancy: Yes
 - E.g. carcinogenesis, mutagenesis, toxic loads
 - Reduction in quality of life: Yes
 - E.g. hours of discomfort, minor disease etc.

Timed Exposure

- Delay in absorption of contaminant
 - Important for short-term exposure
- Body can repair/adapt sometimes; e.g.
 - 10 ppm CO for 400 hours: small impact
 - 400 ppm CO for 10 hours: death
- But not others; e.g.
 - Irreparable tissue damage
 - Risk increases during exposure

Damage Equation:



- Linear ($n=1$) for many cumulative risks
 - Most cancer, metals, stable (e.g. DDT)
- $n=3$ for Chlorine
 - Typical of oxidants, poisons
- $n \gg 1$ represents a threshold
 - Time above threshold is important
- Linear approximation good if little variation

$D \cdot (C/C_c)^n$

IAQ METRICS

- Peak concentration of contaminant
 - Good for high exposure levels/acute effects
 - Good for threshold-dominated contaminants
 - Focus on short-term dose
- Average concentration (e.g. linearized)
 - Good for cumulative exposures
 - Good for steady exposures above thresholds
 - Focus on long-term dose

Average Concentration It is

- Highly variable emission rates
 - Not well controlled by continuous ventilation
 - Need source control (e.g. exhaust ventilation)
- Contaminants of concern
 - Must be above thresholds to be “of concern”
 - Are the ones we expect to control with whole-house ventilation
- Metric is then long-term average concentration: DOSE

How Do We Get Concentration

- Depends on
 - Sources & sinks
 - Volumes
 - Ventilation & air transport
- Linked by Continuity Equation
- Need to proceed generically
 - No pollutant specifics (i.e. a tracer gas)
 - Ignore species-specific interactions

CONTINUITY EQUATION

- Locally Covariant Derivation

- Good everywhere

- Even near black holes

$$J_{\mu} \cdot \partial^{\mu} C_T = \Lambda_T$$

- Steady state, single zone expression:

- S=emission rate (e.g. cfm)

- Q= ventilation (e.g. cfm)

$$C_o = S_o / Q_o$$

Getting Back to Distribution

- Air distribution is only relevant when it is not a single well-mixed zone.
 - Can't get too crazy (e.g. CFD)
 - Need to relate it to the simple result
- We use a multizone continuity equation
 - But we can assume the zones are well mixed
 - Need matrix formulation of continuity equation

MATRIX EQUATION

- Local Zonal Description

- Matrix of flows
- Independent sources
- Zonal concentrations

$$\underline{V} \cdot \underline{C} + \underline{Q} \cdot \underline{C} = \underline{S}$$

- Pseudo-Steady State

- Matrix inverse
- Represents averages

$$\underline{C} = \underline{Q}^{-1} \cdot \underline{S}$$

MATRIX NOTATION

- For N zones: N rows & N columns
- Sum of all entries gives single zone value
- Diagonal element is total for zone
- Off-diagonal elements of Q matrix are (negative of) flow between zones
 - Ask about Volume matrix if you dare

$$Q_o \equiv \sum_{i,j} Q_{ij}$$

Dose is our IAQ Metric

- A person can only be in one zone at a time
 - So, we define an activity variable.
- Source strength may vary zonally.
 - So, we define a source fraction for each zone
- Distribution impacts are relative
 - So, we define a relative dose v. perfect mixing

How Should We Use Metric

1. Evaluate Metric for distribution system of interest
2. Evaluate Metric for distribution in reference case (e.g. 62.2 default)
3. Adjust total rate by ratio to increase or decrease depending on system
 - Could be tabulated like in 62.1

DOSE

- d is dose
- \underline{s} is fractional source strength
- \underline{a} is fractional time spent in each zone

$$d = \underline{a} \cdot \underline{\underline{D}} \cdot \underline{s}$$

- $\underline{\underline{D}}$ is Distribution Matrix

$$\underline{\underline{D}} = Q_0 \underline{\underline{Q}}^{-1}$$

DISTRIBUTION MATRIX

- Couples emission in one zone to exposure in all other zones; e.g.
 - All entries the same (1) for fully mixed
 - Matrix diagonal for isolated zones
- ***Independent*** of sources, activities, etc
- So, we could base final metric on it
 - If we define activity/source distribution

3-Zone Example (PFT data)

- Q Matrix=>
 - m^3/hr
 - $Q_0=726 \text{ m}^3/\text{hr}$

653	-291	0
-130	448	-206
-17	-23	292

- D Matrix =>
 - Dimensionless
 - $D_0=9.54$

1.30	0.88	0.62
0.43	1.97	1.39
0.11	0.21	2.63

Metric Choices

- Need to determine how to use the Distribution Matrix in a way that does not depend on knowing activity/sources.
- What is appropriate for a standard?
 - Best case?
 - Worst case?
 - Typical case?
 - What is that??

Extreme Metrics

- The best and worst cases of the metric will be when the contaminant of concern is emitted in a single zone
- Worst case: Highest value in matrix; e.g. someone generates contaminants and lives in same zone: **2.63** in example
- Best case: lowest value: e.g. live in most isolated room: **0.11** in example

Distributed Distribution

- Assume sources are fully dispersed and activity is spread between all zones

$$d = D_o / N^2$$

- $d=1.06$ in example
- Tends toward perfect mixing result because of source distribution and activity patterns

Inactivity Patterns

- Suppose sources were distributed but someone spent all their time in the worst zone
- Relative dose would then be from the row of Distribution Matrix with highest sum.
- From example
 - 0.93, 1.26, 0.98
 - RMS mean=1.07

Deviation from Perfection

- Suppose we have no clue on activity patterns or source distributions
- We can measure the “distance” from perfect mixing using RMS deviation

$$d = 1 + \frac{1}{N} \sqrt{\sum_{i,j} (D_{ij} - 1)^2}$$

- $d=1.80$ for example case

Which Metric Option?

- Fully distributed sources & activities (1.06)
 - Air distribution effect will be minimal
- Worst zone; distributed sources (1.26)
 - Is reasonable? (RMS=1.07)
- Clueless: (1.80)
 - Robust, but semi-empirical; conservative
- Worst case: (2.63)
 - Appropriate for minimum standard?

METRICS ARE WORTHLESS

Unless you can measure them, of course

- Direct Field Measurement
 - Measure response in real configuration
 - Can really only be done with tracer gas
- Simulation
 - More practical; allows parametrics
 - But must be believable
 - See “Direct Field Measurement” above

HOW TO MAKE THE MEASUREMENTS

The diagnostics necessary to
measure air distribution effects

TWO TRACER APPROACHES

- Simplified for the Metric of Choice; e.g.
 - Inject tracer in reference source pattern
 - Sample in reference activity pattern
- Complete Characterization
 - Measure all flows to/from zones
 - Can be used to compare metrics
 - And derive simplified approach
 - Can be used to verify simulations

TRACER CONTINUITY

- Same Continuity equation, but
 - this time we know concentrations
 - and are looking to determine the flows
- Unfortunately, no direct solution
 - N^2 unknowns, but only N equations
 - Need to get more information

$$\underline{V} \cdot \underline{C} + \underline{Q} \cdot \underline{C} = \underline{S}$$

THREE APPROACHES

- Time Series in Non-steady State
 - Fit time series data over changing conditions (e.g. decay) to solve differential equation
- Series (Single-Tracer) Steady-state Tests
 - N tests are done one at a time
- Simultaneous Multi-Tracer Tests
 - Use N tracer gases to run simultaneous tests (e.g. inject one in each zone)

TIME SERIES

- Fit data to=>
 - To find eigenvalues
 - “A”s are relevant air change rates
 - N of the them; C_{ij} are their eigenvectors
 - Slowest is whole-building air change rate
 - Quickest determines uncertainty
 - This approach never works in real buildings
 - Mixing issues obscure vital information
 - **KIDS: DON'T DO THIS AT HOME**
- $$C_i(t) = \sum_j C_{ij} e^{-A_j t}$$

MIXING KILLS

- In all real experiments mixing will obscure short-term information with noise
- Don't differentiate---INTEGRATE
- Even in single-zone situations, fitting decay data is inferior to integrating under the curve
- In multizone situations it is much worse
 - Alternative approaches are needed

MULTIPLE EXPERIMENTS

- Do N different experiments & integrate/average
 - inject in N independent ways
 - E.g. in 1 zone different zone each experiment
- Add to Matrix equation
 - Can be inverted now

$$\underline{\underline{V}} \cdot \underline{\underline{C}} + \underline{\underline{Q}} \cdot \underline{\underline{C}} = \underline{\underline{S}}$$

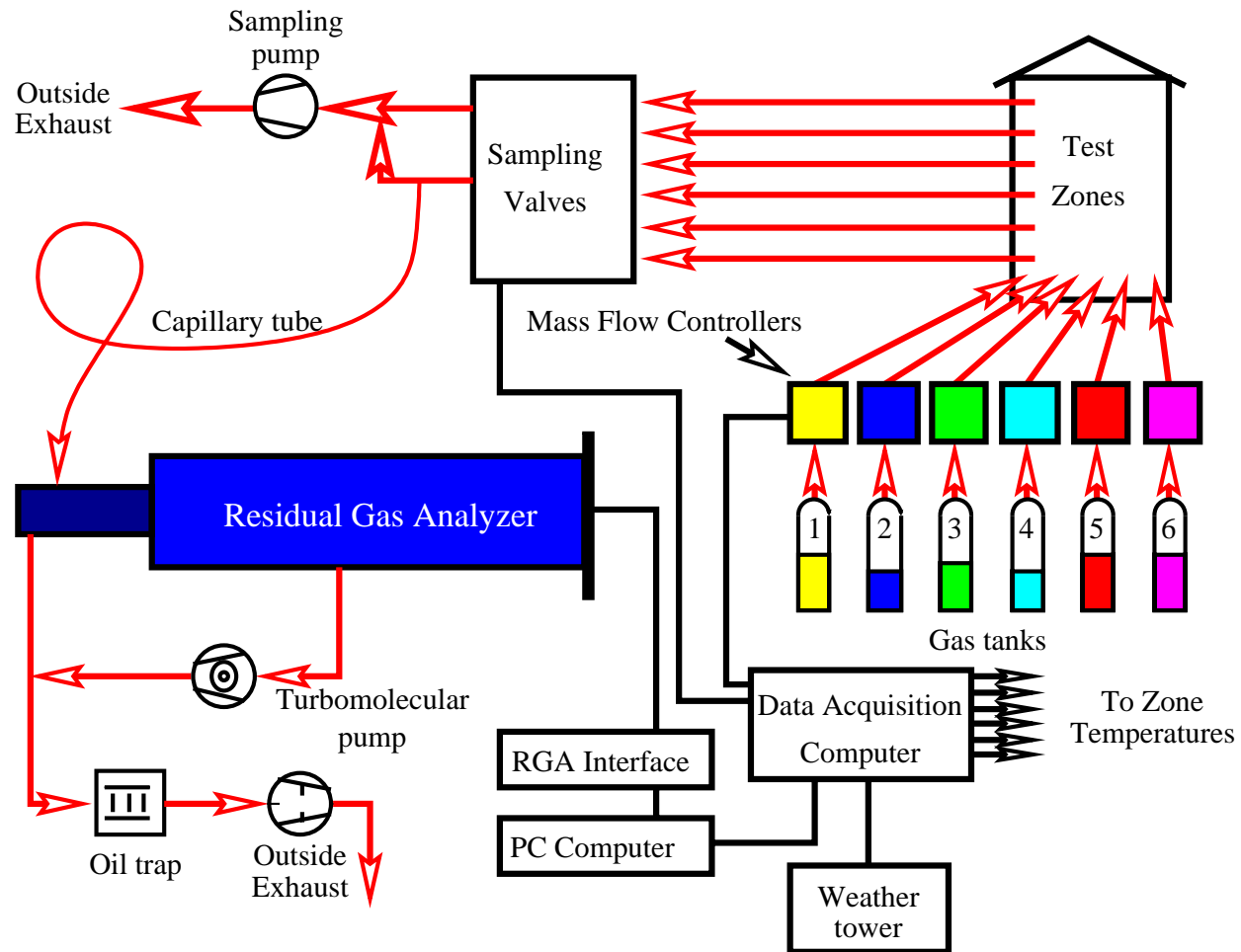
$$\underline{\underline{Q}} = (\underline{\underline{S}} - \underline{\underline{V}} \cdot \underline{\underline{C}}) \cdot \underline{\underline{C}}^{-1}$$

SERIES OR PARALLEL

- Series Option
 - Can be done with one tracer gas
 - Very sensitive to changes in air flows
- Parallel (MultiTracer) Option
 - Can accurately find average flow
 - Takes less time
 - LBL's MTMS uses this approach

MTMS

MULTI-TRACER GAS MONITORING SYSTEM



Gas lines are in red, electrical lines are black

WHAT TO DO NOW?

- Some discussion on options for Metrics
- Measurement of possible metrics in real buildings for various real systems
 - LBL & BSC planning on doing so this year
- Simulate wider variety of options
 - Significant differences between systems????
 - Field diagnostics even needed????
- Implement in 62.2 as appropriate

DISCUSSION