The Promise and Problems of Performance-Based Ventilation

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Premises

- Indoor air quality is defined by response to exposures from indoor and outdoor sources, so (ideally) should know which exposures matter and how they interact
- Exposures can be controlled in several ways
  - Source reduction (in some cases, to some degree)
  - Ventilation (general and local)
  - Air treatment (removal/transformation of contaminants)
- Ventilation differs from other controls because of its perceived generality – removes "all" air contaminants
- Selected controls don't change the definition of IAQ (i.e., performance-based *ventilation* is ultimately performance-based IAQ control)

How much to ventilate?

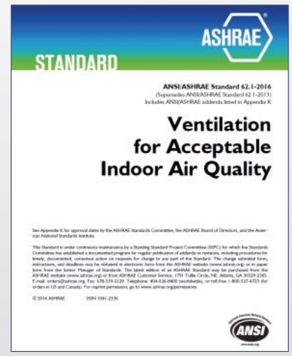
- Goals
  - Safety/health (no "harmful" exposures)
  - Comfort (perception)
  - Performance (various definitions)
- Current status
  - Safety is not negotiable, sets floor
  - Comfort can be determined directly, widely accepted
  - Quantification of performance is elusive, but promises large benefits

Perception vs. Performance

- Perception
  - Subjective response to conditions
  - Metric: percent dissatisfied
  - Predominant approach to thermal environment and indoor air quality
  - Well studied for a long time, including interactions

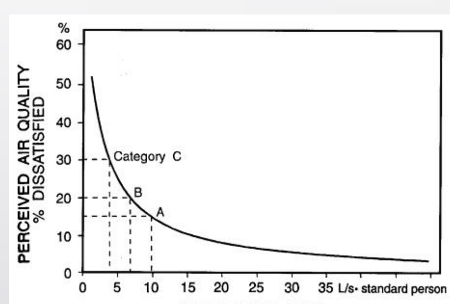
PAQ Example – ASHRAE Standard 62.1-2016 *Ventilation for Acceptable Indoor Air Quality* (non-residential)

- Acceptable indoor air quality (safety + perception)
    - *"No known contaminants at harmful concentrations as determined by cognizant authorities"*
    - *"A substantial majority (80% or more) of the people exposed do not express dissatisfaction"*



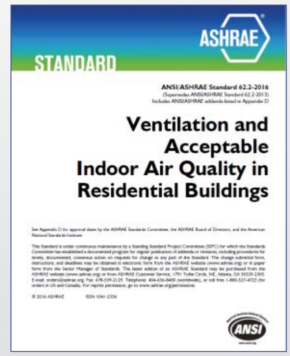
PAQ Example – ASHRAE Standard 62.1-2016

- Prescriptive rates for most spaces
    - Occupant: 5-10 cfm/pers (2.5 – 5 L/s-pers)
    - Building: 0.06-0.18 cfm/ft2 (0.3 – 0.9 L/s-m2)
    - Typical total: 6 – 17 cfm/pers (2.8-8.5 L/s-pers)
- "IAQ Procedure" may lead to different results, doesn't change criteria



PAQ Example – ASHRAE Standard 62.2-2016 *Ventilation and Acceptable Indoor Air Quality in Residential Buildings*

- Acceptable indoor air quality – similar, but not identical to 62.1
  - *"A substantial majority of occupants express no dissatisfaction with respect to odor and sensory irritation"*
  - *"Not likely to be contaminants at concentrations that are known to pose a health risk"*


STANDARD
ASHRAE
ANSI/ASHRAE Standard 62.2-2016
Ventilation and Acceptable Indoor Air Quality in Residential Buildings
ANSI

PAQ Example – ASHRAE Standard 62.2-2016

$$Q_{tot}\left[L/s\right] = 0.15 A_{floor}\left[m^2\right] + 3.5\left(N_{br} + 1\right)$$

- Calculate based on 0.15 L/s-m^2 floor area and 3.5 L/s-pers
- Tabulated ventilation rates based on of floor area, number of bedrooms, assumed # of occupants
- Credit for infiltration up to 2/3 of requirement with blower door test

$$Q_{fan} = Q_{tot} - \left(Q_{inf} \cdot A_{ext}\right)$$

TABLE 4.1b (SI) Ventilation Air Requirements, L/s

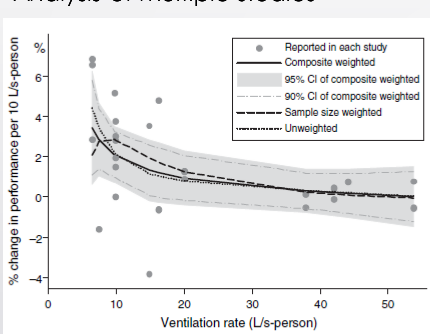
	Bedrooms				
Floor Area, m^2	1	2	3	4	5
<47	14	18	21	25	28
47–93	21	24	28	31	35
94–139	28	31	35	38	42
140–186	35	38	42	45	49
187–232	42	45	49	52	56
233–279	49	52	56	59	63
280–325	56	59	63	66	70
326–372	63	66	70	73	77
373–418	70	73	77	80	84
419–465	77	80	84	87	91

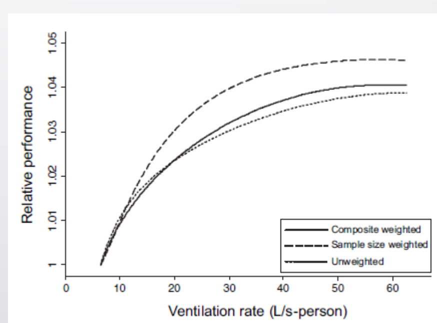
Perception vs. Performance

- Performance
  - Objective (less subjective?) measure of outcome
    - Task performance
    - Quality of work
    - Absenteeism
    - Disability/mortality (incidence of illness, DALY, QALY…)
  - Potential for monetization, cost-benefit analysis
  - Probably brings increased capital and/or operating costs (e.g, if ventilation increases above minimum standard values, there *may* be increased energy use and cost)

Examples – Ventilation and Task Performance

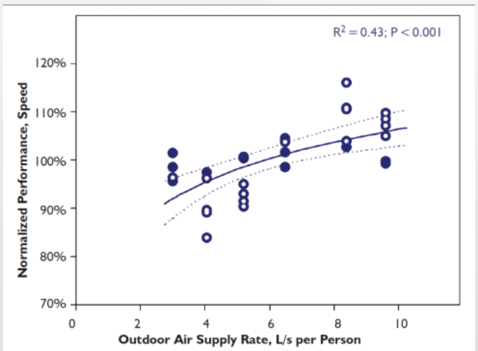
Analysis of multiple studies

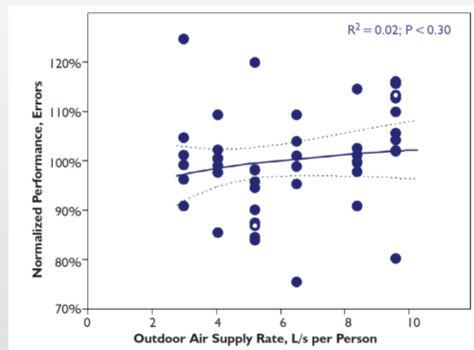




Seppänen, O., W. Fisk, and Q. Lei. 2006. Ventilation and Performance of Office Work. Indoor Air 16:28-36.

Examples – Performance on School Work

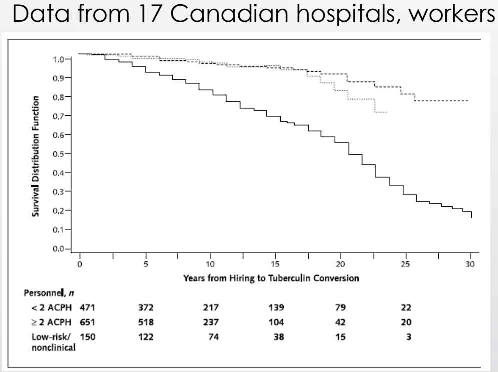


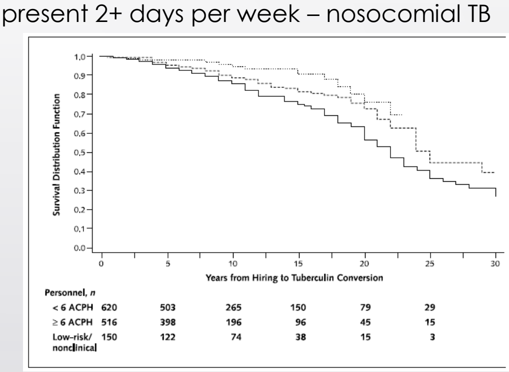


Wargocki, P. and D. Wyon. 2006. Indoor Environmental Effects on the Performance of School Work by Children. Final Report, ASHRAE Research Project 1257.

Examples – Incidence of Infection

Data from 17 Canadian hospitals, workers present 2+ days per week – nosocomial TB





Menzies, D., A. Fanning, L. Yuan, J.M. Fitzgerald. 2000. Hospital Ventilation and Risk for Tuberculous Infection in Canadian Health Care Workers. Ann. Internal Medicine 133(10):779-789.

Examples – Monetized Benefits

Based on 1 year of data involving 3,720 employees of a US company, 40 buildings, 115 independently ventilated work areas, 12-24 L/s-pers

Table 8 Potential Economic Benefits of Increased Ventilation

Outcome	Annual Cost (Saving) per 100 Corporate Employees	Annual Cost (Savings) per 100 Full-time US Workers (1997 Dollars)
Ventilation Costs		
2500cfm/100 workers×$3.22/cfm/year*	$8,050	$8,050
Sick Leave Costs		
Sick leave avoided (150 days per 100 workers)†	($48,000)	($24,444)
Net Savings	($39,950) ~5:1	($16,394) ~2:1

* An increase of 25 cfmp (11.8 ls^{-1}) priced at the average cost of increased outdoor air supply in the buildings studied
† Costs of sick leave were estimated at $20.37 per hour for full-time workers, on the basis 1997 data on the employer cost per hour for all full-time workers in the U.S. (U.S. Department of Commerce, 1998)

2017$ -1997$
1.51:1.00

Milton, D., P.M. Glencross, and M. Waters. 2000 Risk of Sick Leave Associated with Outdoor Air Supply Rate, Humidification, and Occupant Complaints. Indoor Air 10:212-221.

Problems, #1 - Metrics

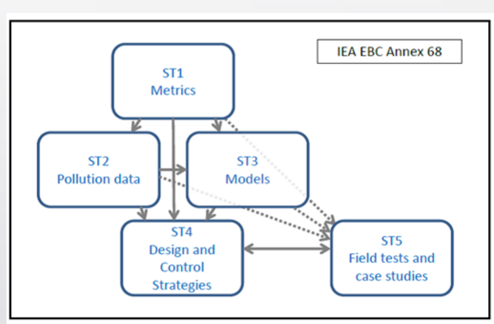
- Multiple hazards, sources, exposure pathways (not all airborne)
  - Gases
    - Building materials, human activities, outdoor air
  - Particulates
    - Human activities, outdoor air
  - Bio-contaminants
    - Infected humans (pathogens), humans, pests (allergens), fungi
- Discussions of metrics tend to narrow to chemical pollutants associated with building (asset focus) and not address biological pollutants (occupant focus)

Metrics (continued)

- Insufficient knowledge of dose-response
  - No clear consensus yet on target indoor pollutants
  - Interactions suspected to be important but not well understood
  - PM may be carriers for both chemical and microbial hazards
  - Multi-hazard approach in future
- Other problems with quantification
  - What is best response variable
  - Uncertainty – productivity, infection rate, chronic impact

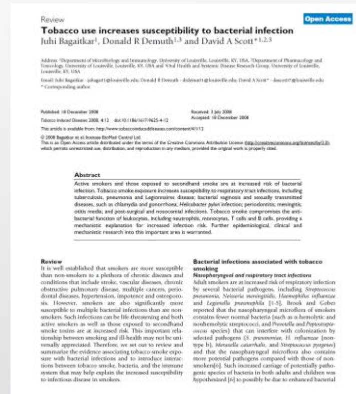
Example – IEA EBC Annex 68 – Indoor Air Quality Design and Control in Low-energy Residential Buildings

- Subtask 1: Defining the Metrics
  - Comprehensive survey of major pollutant types
  - Pollutants of concern for low energy building – compare multiple sources
  - ELV and DALY approach to metrics for (mainly) chemical pollutants, not biological
  - "Aggregation" for ELV is high-select, e.g., MAX(C_i/ELV_i), DALY are summed
- Good, but limited step in the right direction



Real-Life Aggregation: Particulate + Chemical + Biological Interaction

- ETS - Particulate matter and chemicals
- Infection - Pathogens
- *"Tobacco smoke exposure increases susceptibility to <u>respiratory tract infections</u>, including tuberculosis, pneumonia and Legionnaires disease; bacterial vaginosis and <u>sexually transmitted diseases</u>, such as chlamydia and gonorrhoea; Helicobacter pylori infection; periodontitis; meningitis; otitis media; and <u>post-surgical and nosocomial infections</u>."*


Review

Open Access

Tobacco use increases susceptibility to bacterial infection

Juhi Bagaitkar[1], Donald R Demuth[1,3] and David A Scott*[1,2,3]

Abstract

Active smokers and those exposed to secondhand smoke are at increased risk of bacterial infection. Tobacco smoke exposure increases susceptibility to respiratory tract infections, including tuberculosis, pneumonia and Legionnaires disease; bacterial vaginosis and sexually transmitted diseases, such as chlamydia and gonorrhoea; Helicobacter pylori infection; periodontitis; meningitis; otitis media; and post-surgical and nosocomial infections. Tobacco smoke compromises the anti-bacterial function of leukocytes, including neutrophils, monocytes, T cells and B cells, providing a mechanistic explanation for increased infection risk. Further epidemiological, clinical and mechanistic research into this important area is warranted.

Review

Bacterial infections associated with tobacco smoking

Nasopharyngeal and respiratory tract infections

Problems 2 – Limitations of Ventilation

- Ventilation does not inherently deliver good indoor air quality
  - Self-exposure to local, resuspended PM
  - SVOCs
  - Infection by fomite
  - Short range exposure – "large" droplets, bedding
  - Sources remain in place
- Wide variation in actual ventilation with occupant control
- Not sufficient by itself

Problems 3 – Limitations of Alternatives to Ventilation

- Particulate filters
  - Well-understood, but filters can be sources of indoor pollution
- Gas-phase filters
  - Cost, reliability, secondary contaminant production
  - Standardization, application data needed
- Microbial control (e.g., UVGI)
  - Unresolved concerns similar to gas-phase, but significant progress in recent years
- Contaminant specificity is good, but must know what is being targeted

Conclusions/Recommendations

- Comfort-health/safety status quo is fine as a baseline
- Potential of performance approach justifies development
- Different metrics needed for different occupancies

- Needs
  - IAQ definitions that are sufficiently complete and usable
  - Multi-modal approach to meeting goals
    - Source control
    - Hygiene
    - Ventilation
    - Filters/air cleaners
  - Consensus

Conclusions/Recommendations

- A broad coalition of stakeholders is needed to fill gaps, integrate and translate research results, develop consensus
  - Scientific societies
  - Professional associations
  - Healthcare
  - Governmental organizations
  - Facility management organizations
  - ...
  - *AIVC should be involved*
- Who will take the lead?