ASHRAE Region VI CRC
Track III: Session 1
Ventilation & IAQ Fundamentals

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Learning Objectives

- Outline the basic aspects of indoor air quality and how ventilation promotes quality
- Understand the ventilation fundamentals under ASHRAE 62.1-2004
- Identify ways to achieve LEED points through increased ventilation rates

Agenda

- **Fundamentals**
  - Indoor air quality and sick building syndrome
  - Role of ventilation and determining ventilation rates
- **Ventilation requirements**
  - ASHRAE Standard 62.1 2004
- **LEED NC Version 2.2 Credit**

What is Acceptable IAQ?

- Standard 62: “Air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction.”

Sick Building Syndrome

Definition: A cluster of non-specific, subjective health complaints and symptoms of discomfort or irritation experienced by a significant number of building occupants and that tend to go away when these individuals leave the building.

Symptoms include:

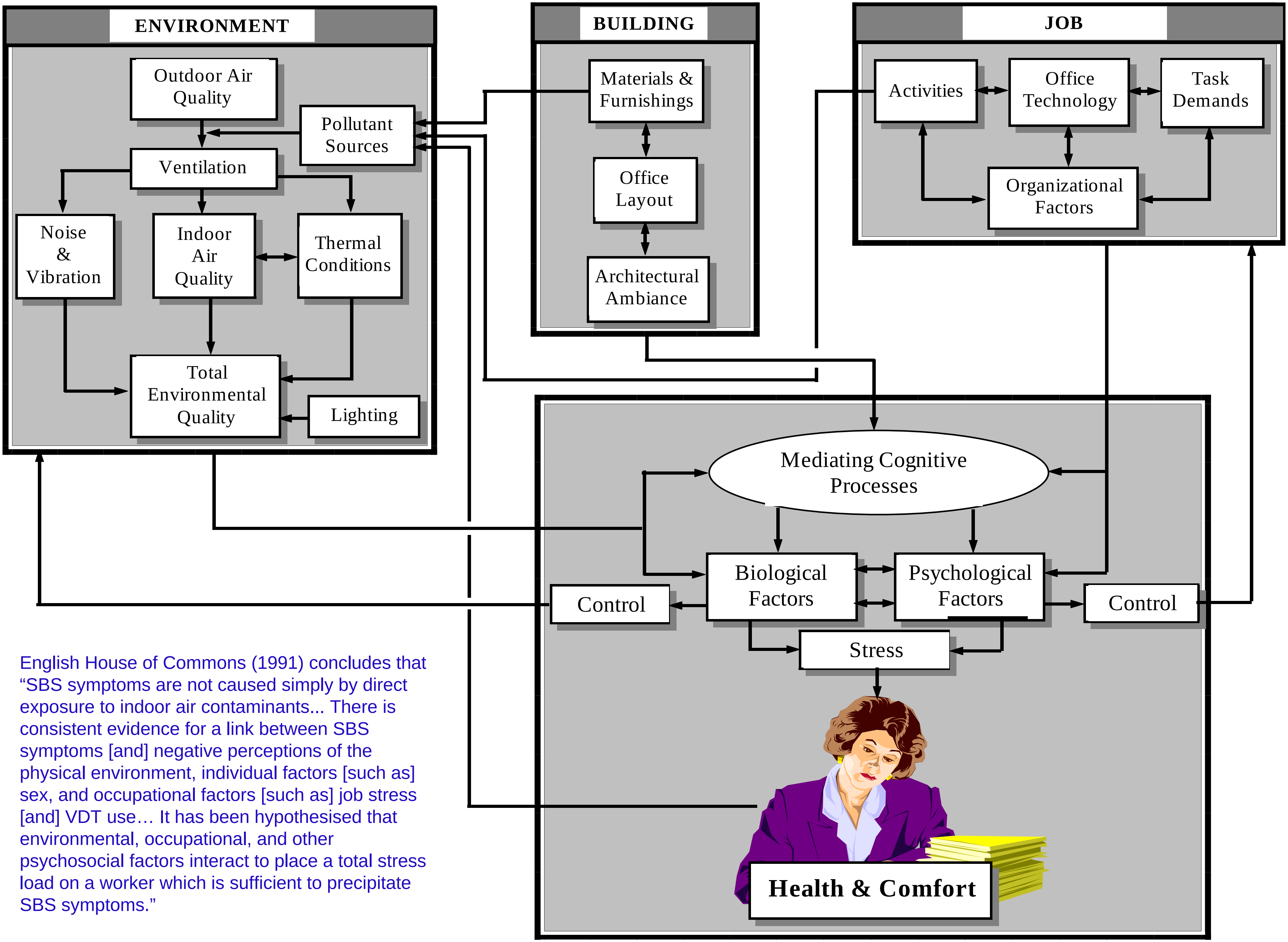
- **headaches**
- **irritation of eyes, nose, and throat**
- **dizziness**
- **difficulty concentrating**

What are the Causes of SBS? Why now?

Various theories including one or more of:

- **increased sensitivities and expectations of workers**
- **new indoor pollutants (VOCs)**
- **reduced ventilation due to energy crunch**
- **increased complexity of HVAC systems**
- **cost cutting in design, construction, maintenance**

- **No one really knows!!**

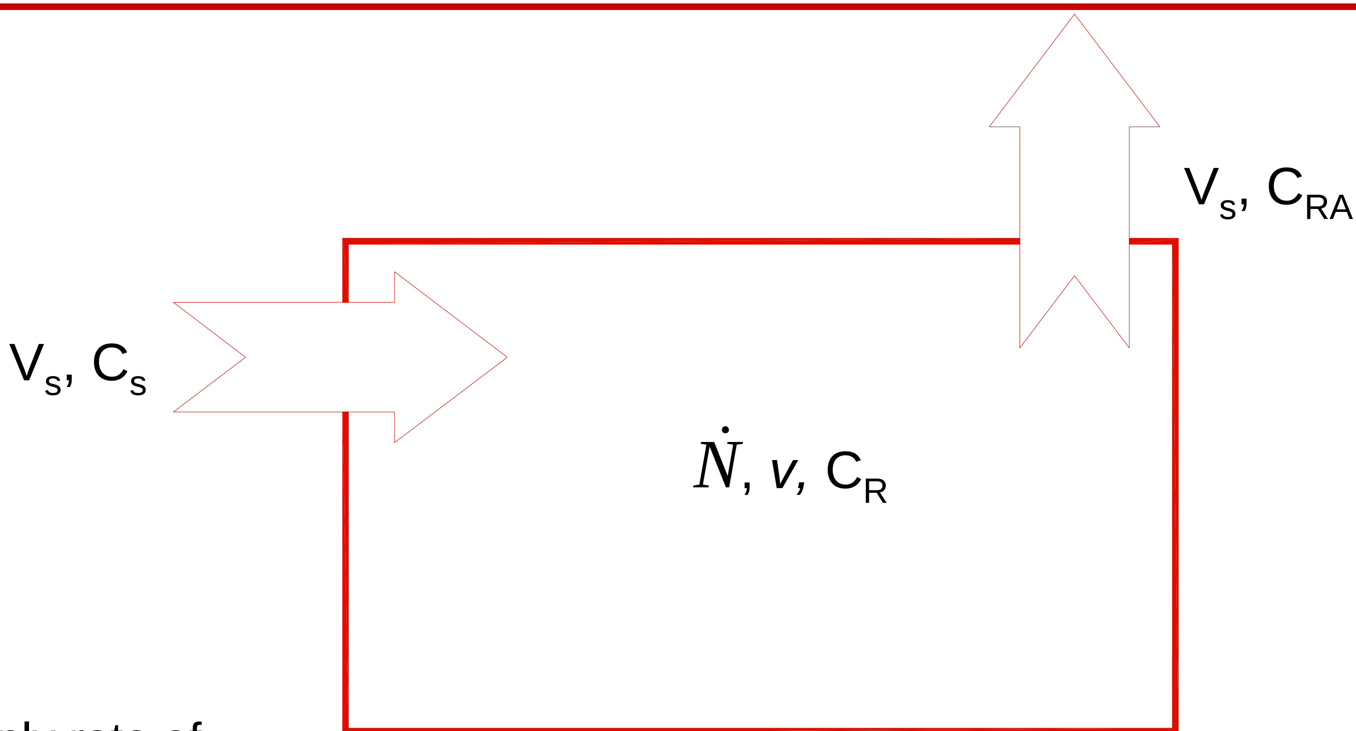


English House of Commons (1991) concludes that "SBS symptoms are not caused simply by direct exposure to indoor air contaminants... There is consistent evidence for a link between SBS symptoms [and] negative perceptions of the physical environment, individual factors [such as] sex, and occupational factors [such as] job stress [and] VDT use… It has been hypothesised that environmental, occupational, and other psychosocial factors interact to place a total stress load on a worker which is sufficient to precipitate SBS symptoms."

Effect of Pollutants on People

Σ	**Cumulative**	**1+2=3**
⇔	**Independent**	**1+2=2**
	Synergistic	**1+2=4**
	Antagonistic	**1+2=1**

Dilution Ventilation

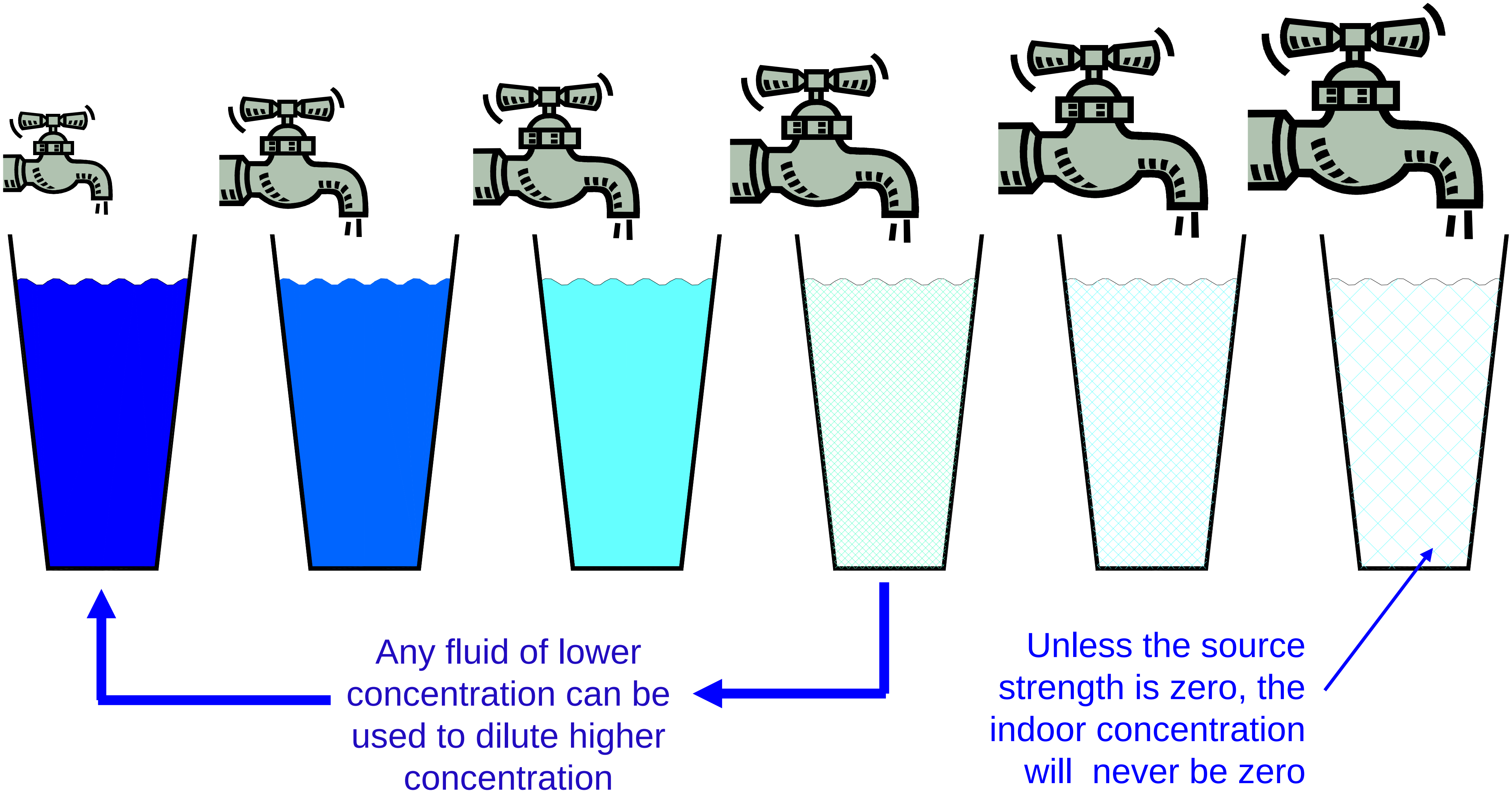


$$V_s = \frac{\dot{N}}{E_V (C_R - C_s)}$$

- V_s: Supply rate of ventilation air
- $\dot{N}$: Source strength of pollutant in space
- C_s: Concentration of pollutant in supply air
- E_V: Ventilation effectiveness
- C_R: Concentration of pollutant in room (at breathing level)

Understanding Dilution

Two important concepts:



The role of ventilation and determining ventilation rates

- Perception of air quality is a function of many factors, only one of which is the concentration of indoor contaminants.
- Dilution (ventilation) is nevertheless essential since not all pollutant sources can be eliminated
- There is still much to learn about the nature of indoor contaminants, source strengths, and maximum acceptable concentrations for non-industrial workplaces.
- Until more research is done, ventilation rates must be determined largely based on experience; as such, rates must be recognized as no more than rules-of-thumb.

How Much Ventilation is Enough?

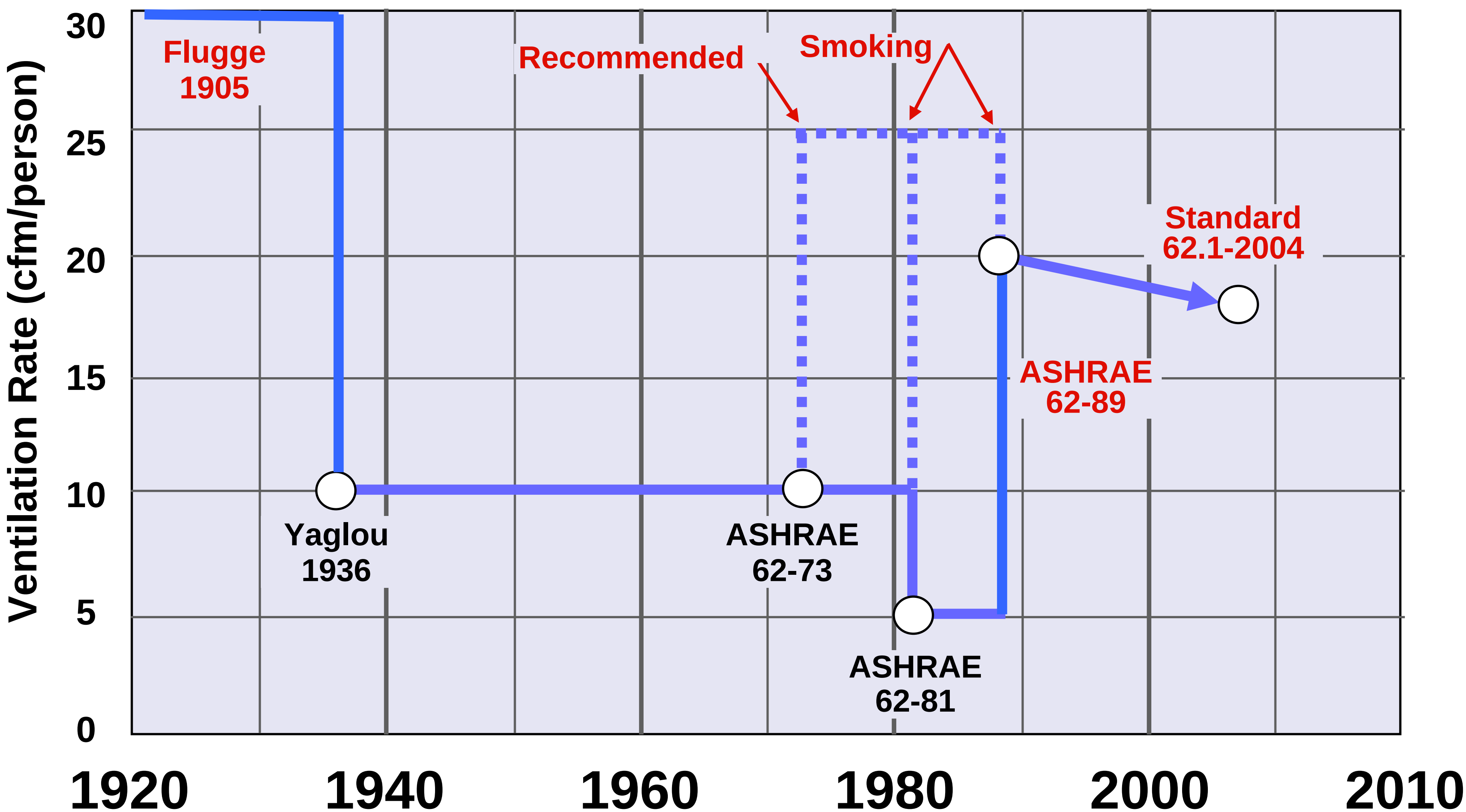
- **Depends on goal**
  - Ventilation for minimum health?
    - Harmful contaminants from indoor sources
    - Disease transmission
  - Ventilation for x% occupant satisfaction?
  - Ventilation for x% visitor first impression?
  - Ventilation for maximum productivity?
  - Ventilation for maximum life cycle cost?
- **What’s appropriate for a Code??**

How Much Ventilation is Enough for any of these goals?

- **We really don't know…**
- **Limited data from:**
  - Chamber studies
    - Mostly limited to body odor
  - Epidemiological studies
    - Mostly observational rather than experimental
    - Many potential confounding factors
    - Rates not always accurately measured
  - Anecdotal and Empirical "Evidence"

Historical Perspective

Ventilation Rates in Offices

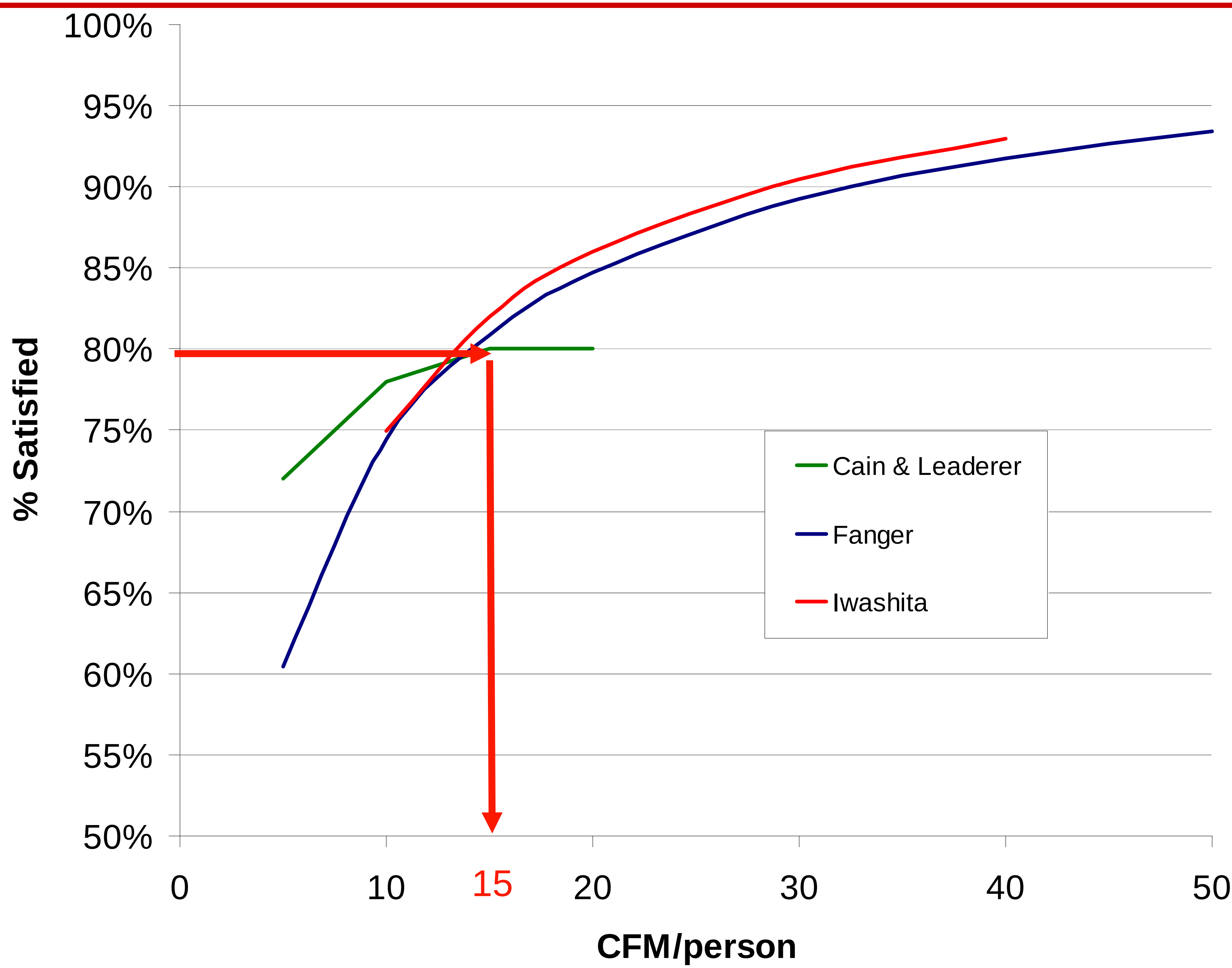


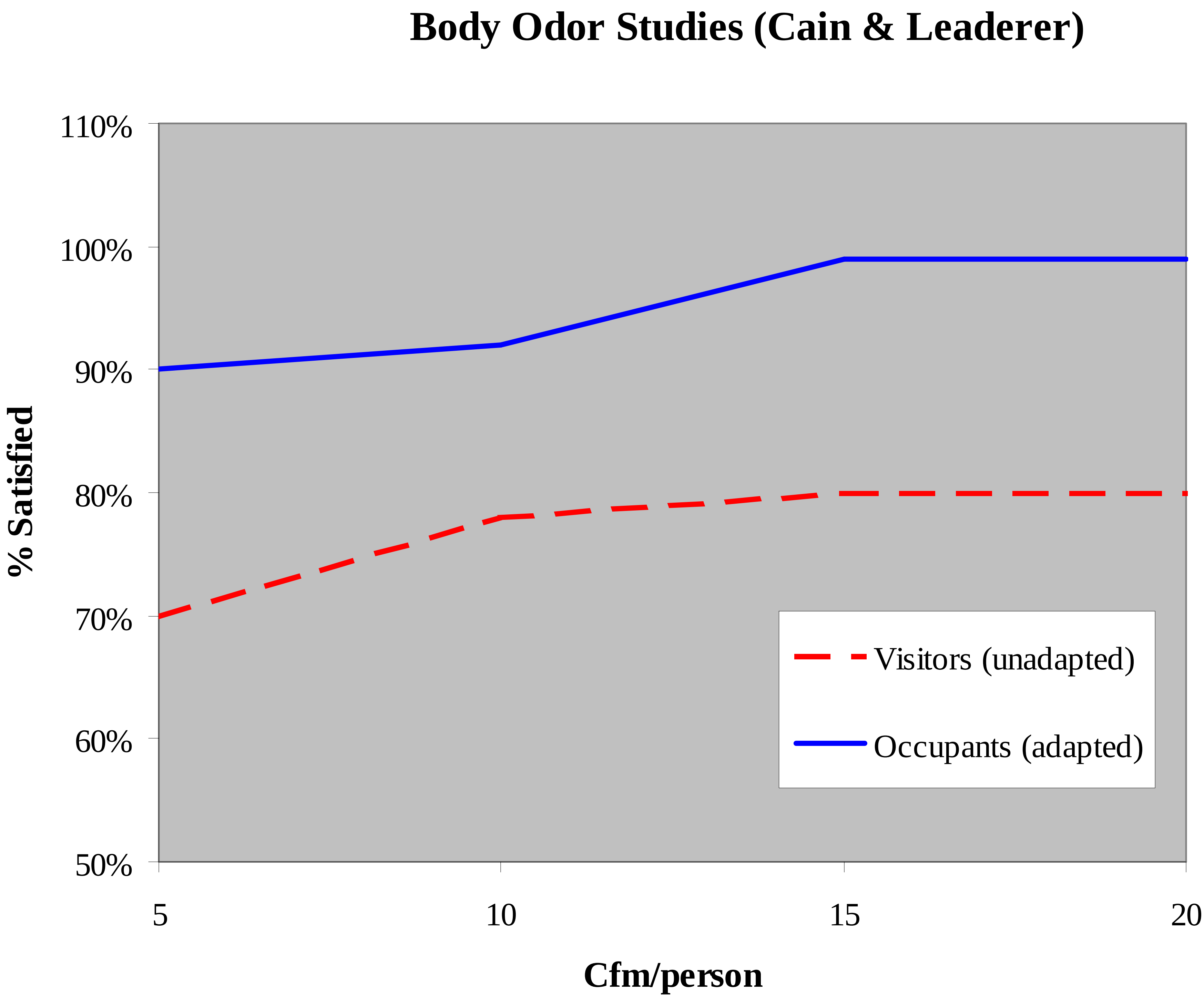
Rationale for 62.1-2004 Rates

- **Explicitly recognizes building as a source of indoor air pollutants**
  - Followed lead of European standards
- **Explicitly accounts for ventilation efficiency**
- **Many more studies to guide rate selection**
  - Almost exclusively offices
- **Still consider historical rates as a guide**
- **Rates still largely based on judgment of the 62 Project Committee, not explicit science**

Chamber Body Odor Studies

Impact of ventilation rate on "visitors"




Body Odor Studies (Cain & Leaderer)
110%
100%
90%
80%
70%
60%
50%
% Satisfied
5
10
15
20
Cfm/person
Visitors (unadapted)
Occupants (adapted)

Standard 62.1-2004
Ventilation Rate Procedure

Breathing Zone Outdoor Air Ventilation Rate, CFM

People Component

Building Component

$$V_{bz} = R_p P_z + R_a A_z$$

- R_p: Minimum CFM/Person
- P_z: Number of People
- R_a: Minimum CFM/sqft
- A_z: Floor Area

Ventilation System Efficiency

$$V_z = \frac{V_{bz}}{E_z} \qquad V_{ot} = \frac{\sum\limits_{\text{all spaces}} V_z}{E_V}$$

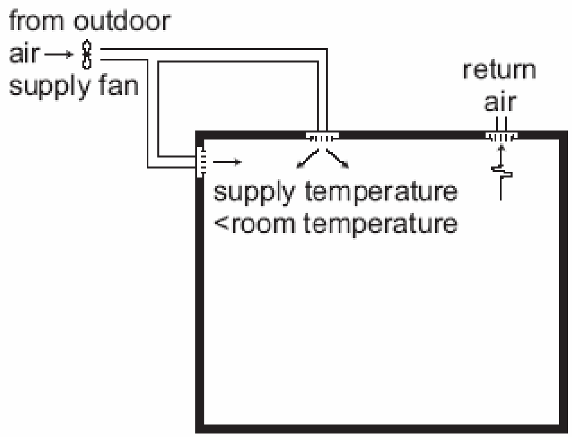
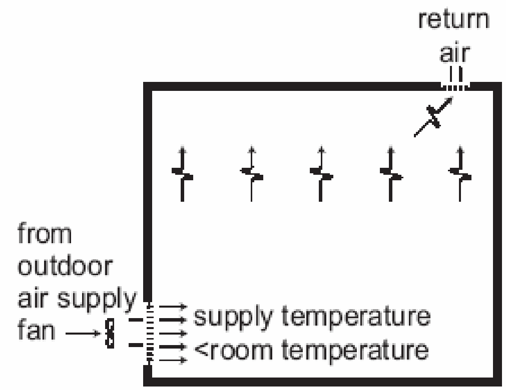
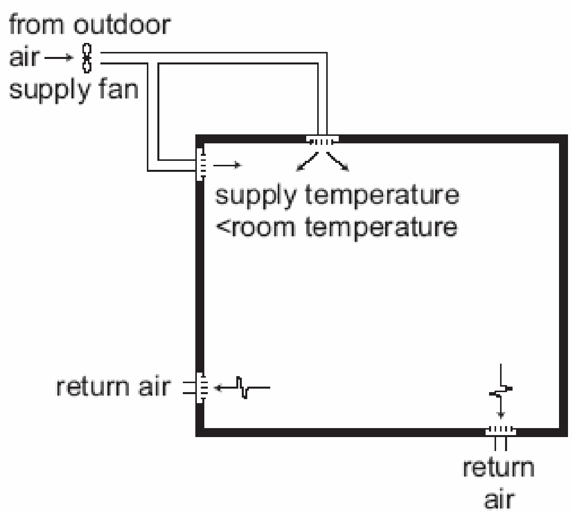
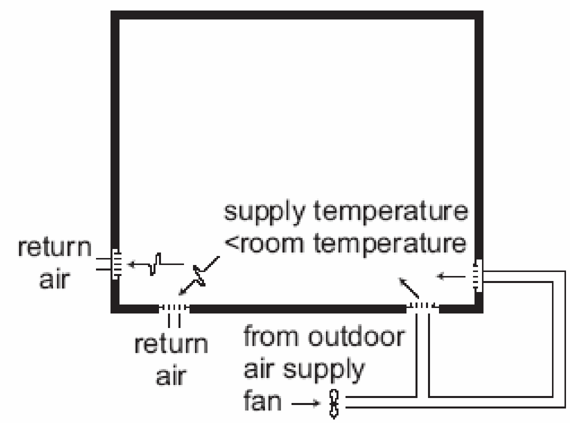
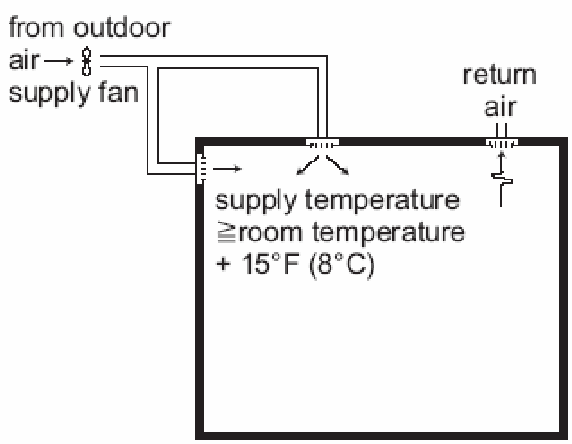
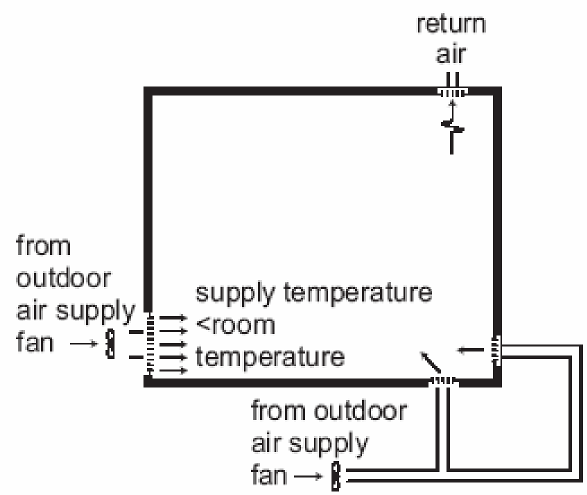
V_{bz} = Design outdoor air rate to breathing zone

V_z = Design outdoor air rate to space

E_z = Zone air distribution (air change) effectiveness

V_{ot} = Total outdoor air at ventilation system intake

E_V = System ventilation efficiency (ventilation system effects)

<table>
<tr><th>AIR DISTRIBUTION CONFIGURATION & E_z</th><th>TYPICAL ARRANGEMENT</th><th>AIR DISTRIBUTION CONFIGURATION & E_z</th><th>TYPICAL ARRANGEMENT</th></tr>
<tr><td>Ceiling supply of cool air
E_z=1.0</td><td>
</td><td>Floor supply of cool air and ceiling return provided low velocity displacement ventilation achieves unidirectional flow and thermal stratification
E_z=1.2</td><td>
</td></tr>
<tr><td>Ceiling supply of warm air and floor return
E_z=1.0</td><td>
</td><td>Floor supply of warm air and floor return
E_z=1.0</td><td>
</td></tr>
<tr><td>Ceiling supply of warm air 8°C (15°F) or more above space temperature and ceiling return.
E_z=0.8</td><td>
</td><td>Floor supply of warm air and ceiling return
E_z=0.7</td><td>
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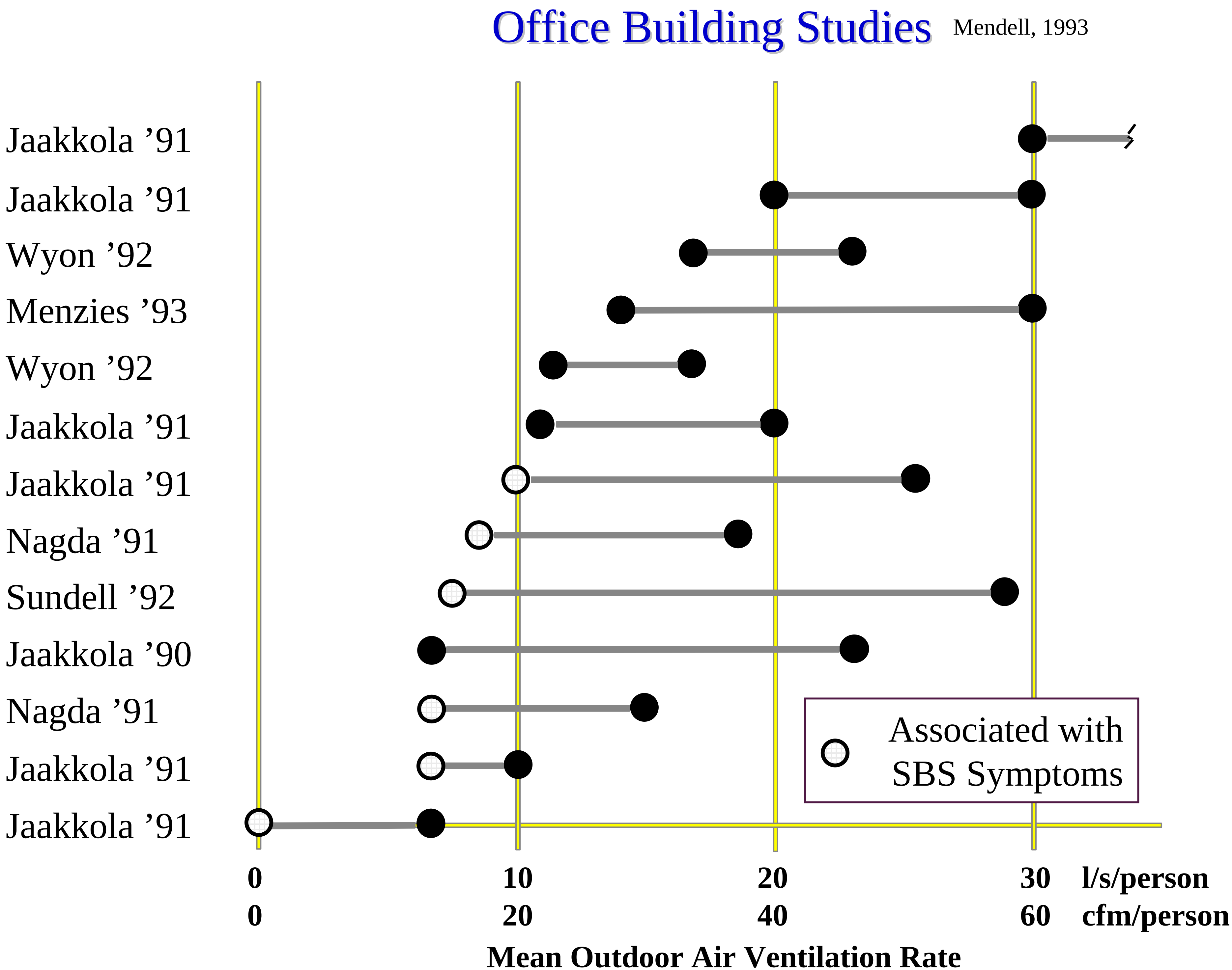

Office Building Studies
Mendell, 1993
Jaakkola '91
Jaakkola '91
Wyon '92
Menzies '93
Wyon '92
Jaakkola '91
Jaakkola '91
Nagda '91
Sundell '92
Jaakkola '90
Nagda '91
Jaakkola '91
Jaakkola '91
Associated with SBS Symptoms
0 10 20 30 l/s/person
0 20 40 60 cfm/person
Mean Outdoor Air Ventilation Rate

How to Determine the People and Building Component Rates?

- **Start with offices for which most data is available**
  - Studies based mostly on total outdoor air rate at intake
  - Few studies on building component and all European
  - Data predominantly support 62-89/01 rate of 20 cfm/person
- **Use "adapted" rate for people component**
  - Met philosophy of "code minimum"
  - Occupants are the target of standard
  - Addressed concerns about over-ventilating dense spaces
- **Back-calculate building rate from total rate and occupant rate, adjusted for efficiency**
- **Use judgment to determine rates for other occupancies based on office component rates**

Determining Ventilation Rates

Office Buildings

~5 cfm/person
(adapted)

~5 people/1000 ft²
(typical)

~0.06 cfm/ft²
(EUR)

Total OA Flow rate at air intake, cfm

$$V_{ot} = \frac{R_P P_D D + R_B A_B}{E_V}$$

~20 cfm/person
(Mendell)

~0.8 for heating
(Fisk)

People Component

Occupant Component

CATEGORY	R_P	DISCUSSION
0	0 cfm (0 L/s) per person	Applies to spaces where the ventilation requirements are assumed to be so dominated by building related sources, due to the typically very low and transient nature of the occupancy, that the occupant component may be ignored. Examples include storage rooms and warehouses.
1	5 cfm (2.5 L/s) per person	Applies to spaces where primarily adults are involved in fairly passive activities similar to sedentary office work.
2	7.5 cfm (3.5 L/s) per person	Applies to spaces where occupants are involved in higher levels of activity (though not strenuous), thereby producing higher levels of bioeffluents, or are involved in activities associated with increased contaminant generation. Examples include lobbies and retail stores.
3	10 cfm (5 L/s) per person	Applies to spaces where occupants are involved in more strenuous levels of activity (though not at an exercise-like level), or are involved in activities associated with even higher contaminant generation. Examples include most classrooms and other school occupancies.
4	20 cfm (10 L/s) per person	Applies to spaces where occupants are involved in very high levels of activity, or are involved in activities associated with very high contaminant generation. Examples include beauty salons, dance floors, and exercise rooms. Hair sprays, shampoos, etc., are considered occupant-related rather than building-related.

Building Component

Building Component

CATEGORY	R_a	DISCUSSION
1	0.06 cfm/ft^2 (0.3 L/s-m^2)	Applies to spaces where building related contaminants are generated at rates similar to office spaces. Examples include conference rooms and lobbies.
2	0.12 cfm/ft^2 (0.6 L/s-m^2)	Applies to spaces where building related contaminants are generated at rates significantly higher than those for offices. Examples include typical classrooms and museums.
3	0.18 cfm/ft^2 (0.9 L/s-m^2)	Applies to spaces where building related contaminants are assumed to be generated at an even higher rate. Examples include laboratories and art classrooms.
4	0.30 cfm/ft^2 (1.5 L/s-m^2)	These last two categories apply to three unusual spaces, all in the Sports and Entertainment category, for which there is no people-based ventilation requirement (R_p = 0). For that reason, and because of their unique natures, the building ventilation requirements are elevated to five to eight times the base rate.
5	0.48 cfm/ft^2 (2.4 L/s-m^2)	

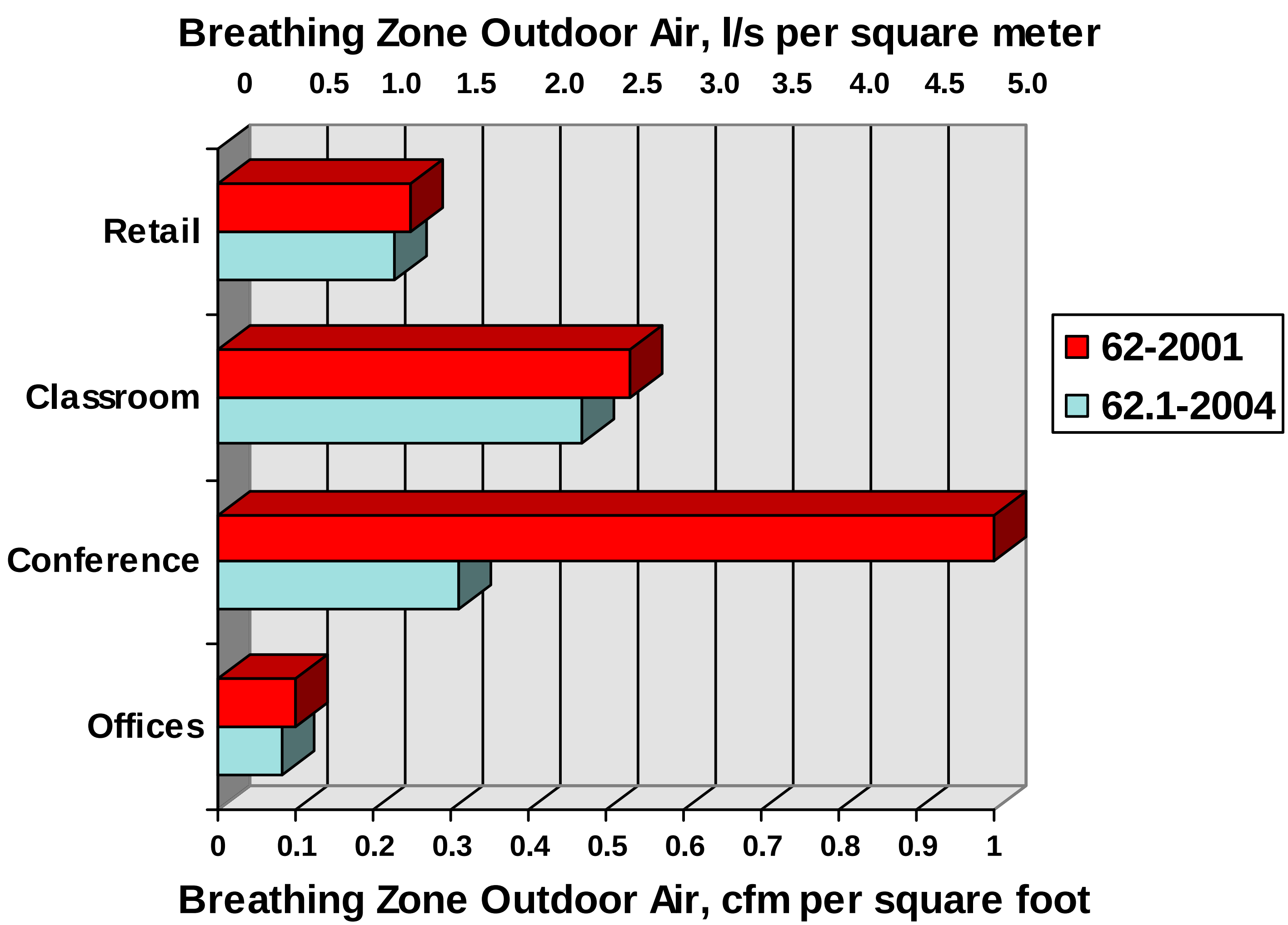
Example

62n Ventilation Rates

	Prescriptive Ventilation Requirement		Guideline Occupancy Assumptions		Ventilation Requirements at Guideline Occupancy and Typical System Efficiency		
Occupancy Category	People R_P cfm/person	Building R_B cfm/ft^2	Density people/ 1000 ft^2	Diversity Factor	System Efficiency	Outdoor air cfm/person	Outdoor air cfm/ft^2
Office space	5.0	0.06	5	1	0.8	21.3	0.11
Retail sales floor	7.5	0.12	15	1	1.0	15.5	0.23
General classrooms	10.0	0.12	35	1	0.8	16.7	0.59
Conference rooms	5.0	0.06	50	1	1.0	6.2	0.31

Breathing Zone

Outdoor Air Rate Comparison



Accounting for Multiple Space Effects

- **Two methods:**
  - Simple: Use default E_v from Table 6.3; or
  - Complex: Calculate E_v from Appendix A

Recommended for Single Duct Systems such as VAV Reheat Systems

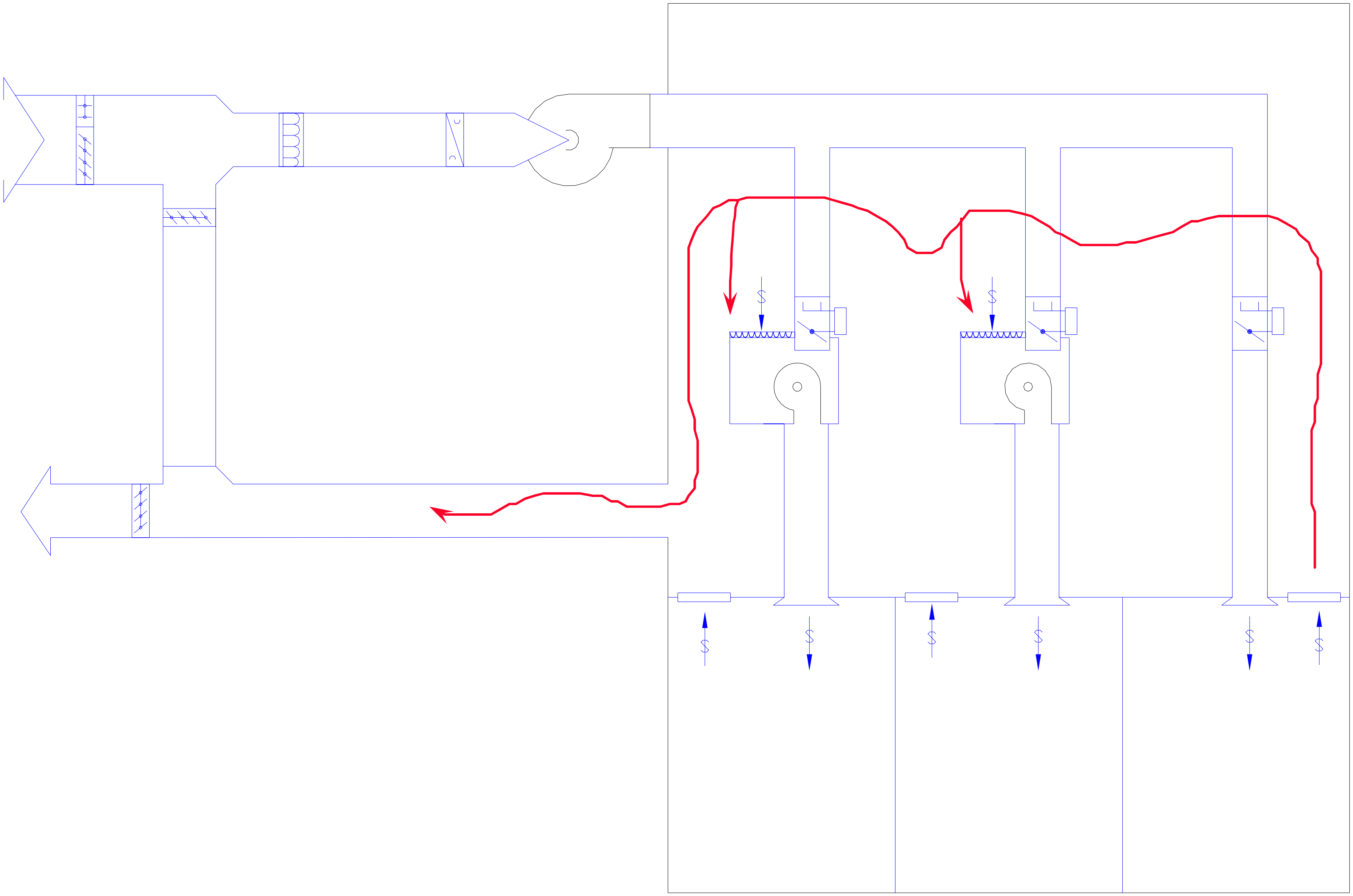
Recommended for Systems with multiple return air paths such as Fan-powered VAV and Dual Duct Systems

Table 6.3 Default Efficiencies

Max (Z_P)	E_V
≤ 0.25	**0.9**
≤ 0.35	**0.8**
≤ 0.45	**0.7**
≤ 0.55	**0.6**
> 0.55	**Use Appendix G**

$Z_p = V_{oz}/V_{pz}$

Multiple Zone Systems with Multiple Recirculation Paths

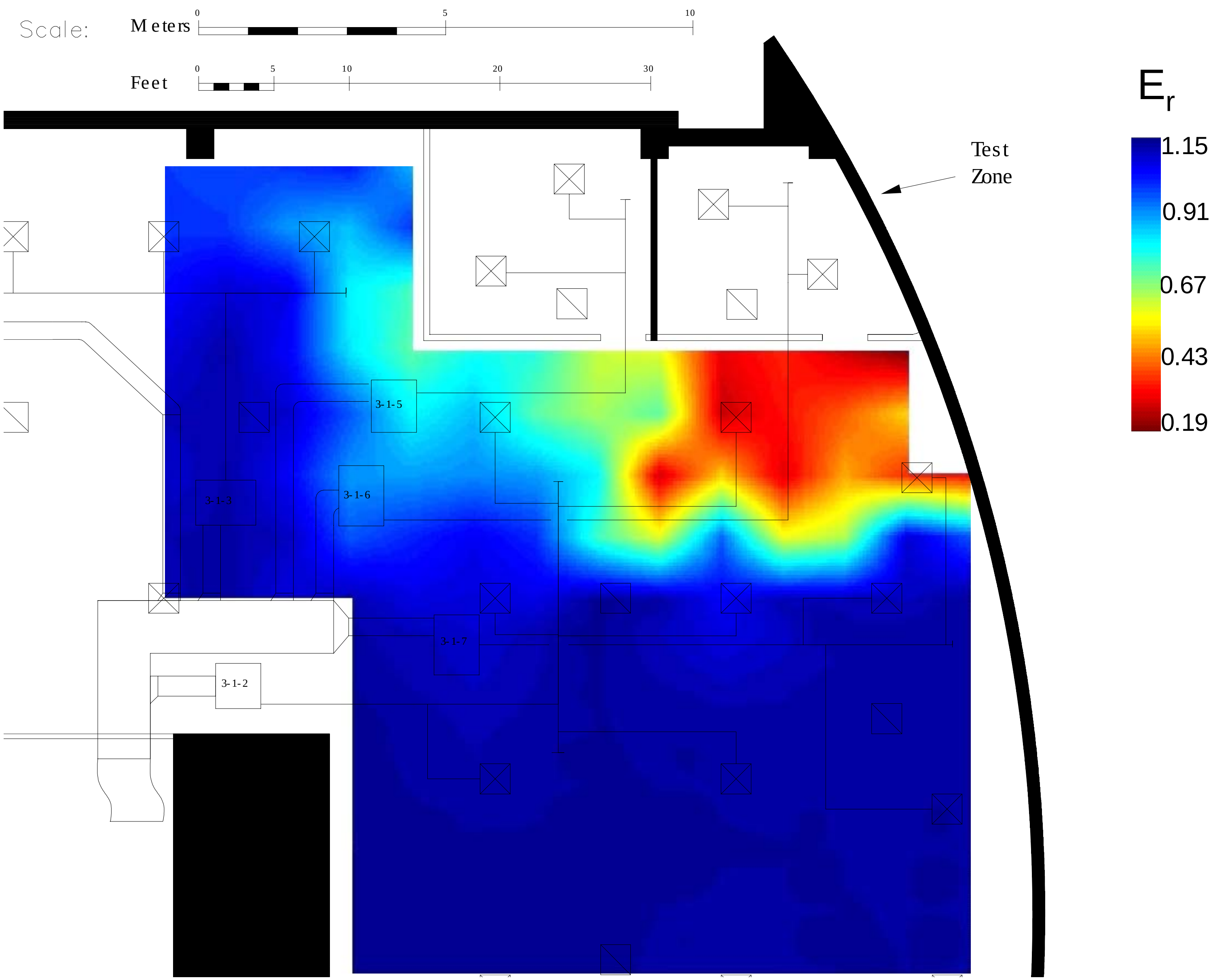


Appendix A Calculation using spreadsheet

Building:	**Typical Office Building**
System Tag/Name:	**AHU-1**
Operating Condition Description:	**Design cooling**
Units (select from pull-down list)	**IP**

Inputs for System	**Name**	**Units**	**System**		
Floor area served by system	As	sf	15080		
Population of area served by system (including diversity)	Ps	P	73		
Design primary supply fan airflow rate	Vpsd	cfm	14000		
OA req'd per unit area for system (Weighted average)	Ras	cfm/sf	0.06		
OA req'd per person for system area (Weighted average)	Rps	cfm/p	5.0		
Does system have Outdoor Air Economizer		Select from pull-down list	No		
Inputs for Potentially Critical zones				**Potentially Critical Zones**	
Zone Name	*Zone title turns purple italic for critical zone(s)*			**North Conference Room**	***Interior Conference room***
Zone Tag				**VAV-3**	***VAV-20***
Space type		Select from pull-down list		**Conference/ meeting**	**Conference/ meeting**
Floor Area of zone	Az	sf		267	443
Design population of zone	Pz	P (default value listed; may be overridden)		10	10
Design total supply to zone (primary plus local recirculated)	Vdzd	cfm		265	325
Induction Terminal Unit, Dual Fan Dual Duct or Transfer Fan?		Select from pull-down list or leave blank if N/A		FT	FT
Local recirc. air % representative of ave system return air	Er			0.5	0.5
Inputs for Operating Condition Analyzed					
Percent of total design airflow rate at conditioned analyzed	Ds	%	100%	100%	100%
Zone air distribution effectiveness at conditioned analyzed	Ez			1.00	1.00
Primary air fraction of supply air at conditioned analyzed	Ep			0.90	0.69
Results					
Ventilation System Efficiency	Ev		**0.80**		
Outdoor air intake required for system	Vot	cfm	**1596**		
Outdoor air per unit floor area	Vot/As	cfm/sf	**0.11**		
Outdoor air per person served by system (including diversity)	Vot/Ps	cfm/p	**21.9**		
Outdoor air as a % of design primary supply air	Ypd	cfm	**11%**		

E_r Research (RP 1276)



Appendix A Method

- **Allows credit for systems with multiple recirculation paths**
  - Fan-powered VAV
  - Dual fan dual duct
  - Transfer or exhaust fans
- **Can justify low or even zero primary airflow minimum volume setpoints on these systems**
- **Can be used to backwards calculate zone V_{pz} for systems where V_{ot} is fixed**
  - Tenant improvements and remodels
- **Considerable judgment required to estimate variables**
  - Do we trust designers to do “the right thing?”
  - At least E_v cannot be larger than 1.0!

USGBC LEED Rating System & Going Beyond Code Minimum

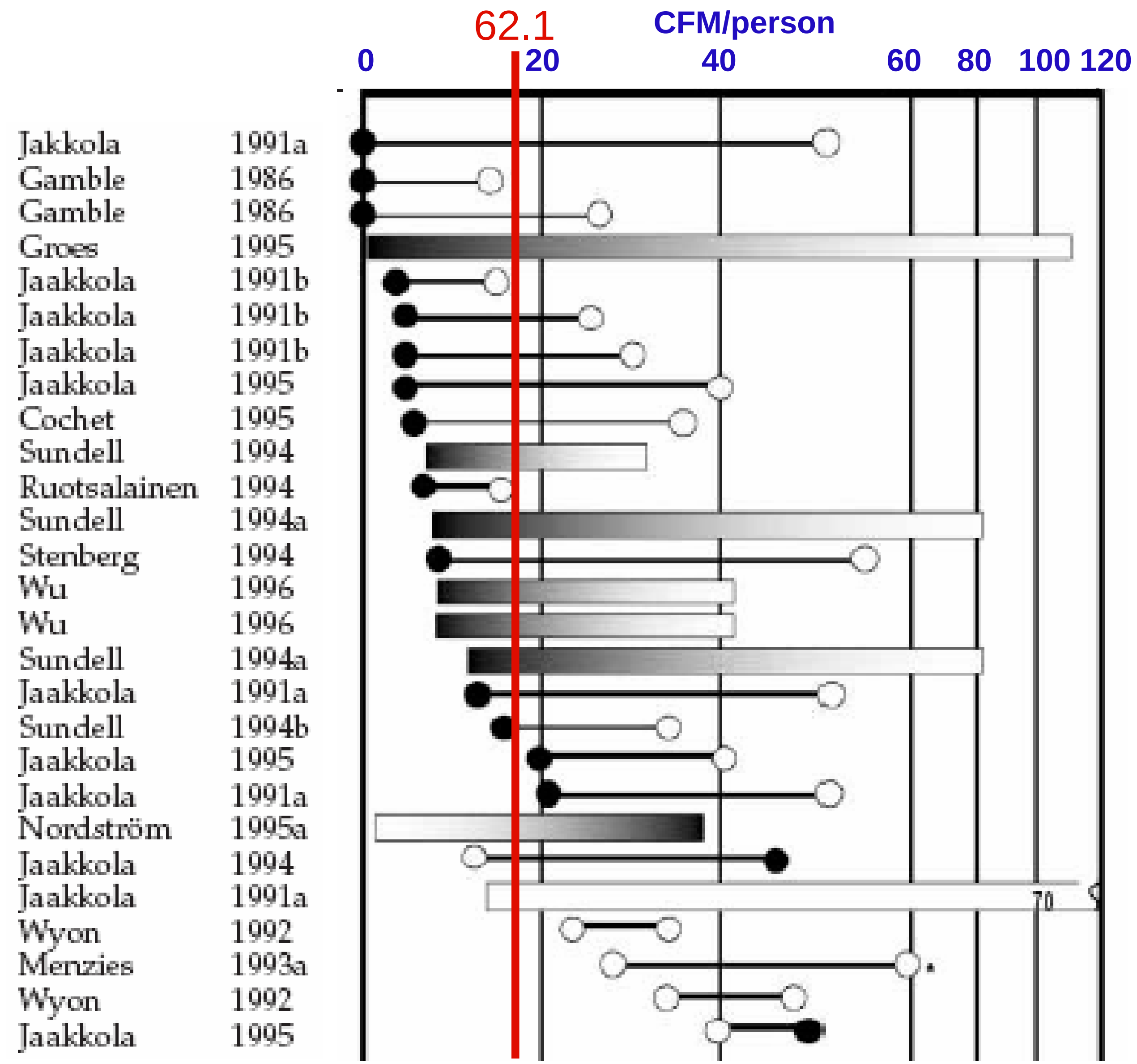
LEED NC IEQ Credit 2

- **LEED NC 2.1 Credit**
  - Air change effectiveness >0.9
  - Problem:
    - Achieved inherently in all cooling systems
    - Adjustment in rates required by Standard 62 so no IAQ impact
    - Current LEED documentation is onerous (ADPI and ACE calculation required for each space type)

LEED NC 2.2 IEQ Credit 2

- **Revised LEED 2.2 Credit**
  - Outdoor air rate > 30% above Standard 62.1-2004
- **Rationale**
  - 62.1-2004 rates are lower for most occupancies than 62-2001 due to code-minimum perspective
  - Recent research suggests higher rates offer reduced SBS symptoms and absenteeism, increased productivity
  - LEED should encourage beyond-code minimum designs

Research shows higher rates may be cost effective in offices

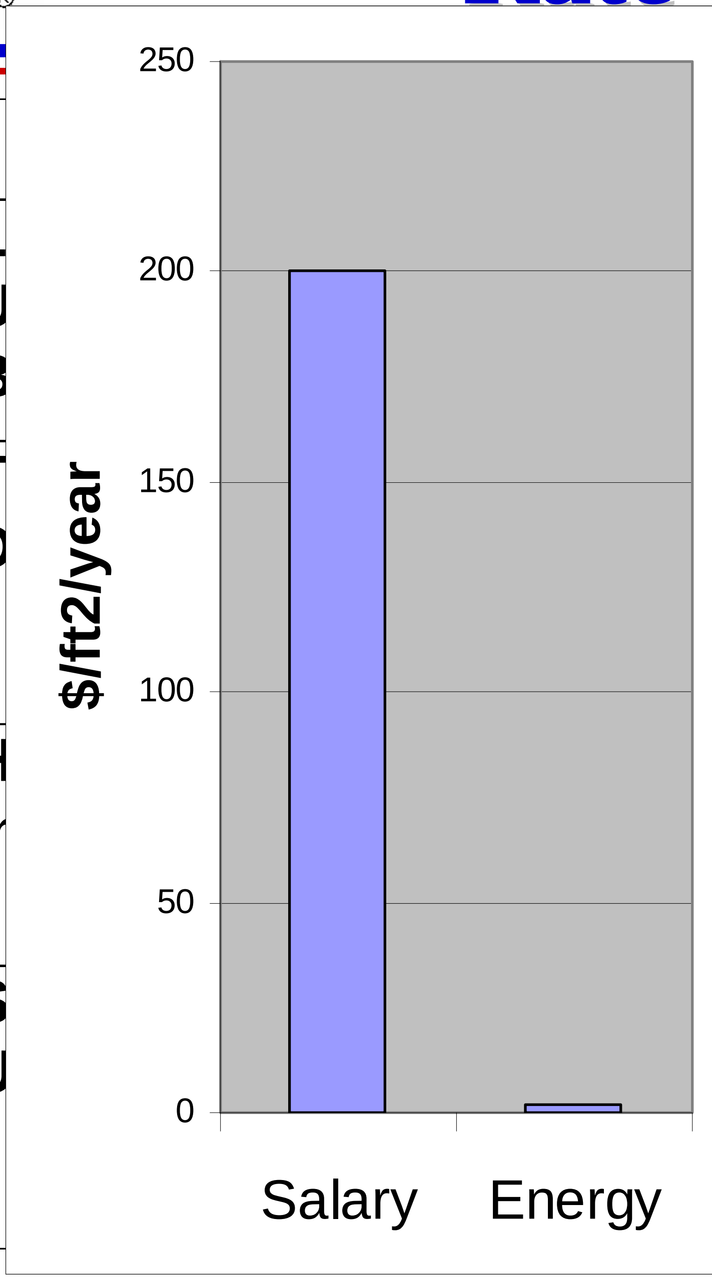


Source: Seppanen et al 1999

Other Recommendations

- EUROVEN, 2002: Outdoor air rates below 25 l/s (50 cfm) per person in offices increase the risk of SBS symptoms, increase short-term sick leave, and decrease productivity.
- Seppanen, 1999: Increases in ventilation rates above 10 L/s (20 cfm) per person up to approximately 20 L/s (40 cfm) per person, are associated with a statistically significant decrease in the prevalence of SBS symptoms.
- Wargocki, 2000: Over an outdoor airflow of 3, 10, and 30 L/s (6, 20, and 60 cfm) per person, for each twofold increase in ventilation rate, performance improved on average by 1.7%.

Effects of Outdoor Air Ventilation Rate on Productivity

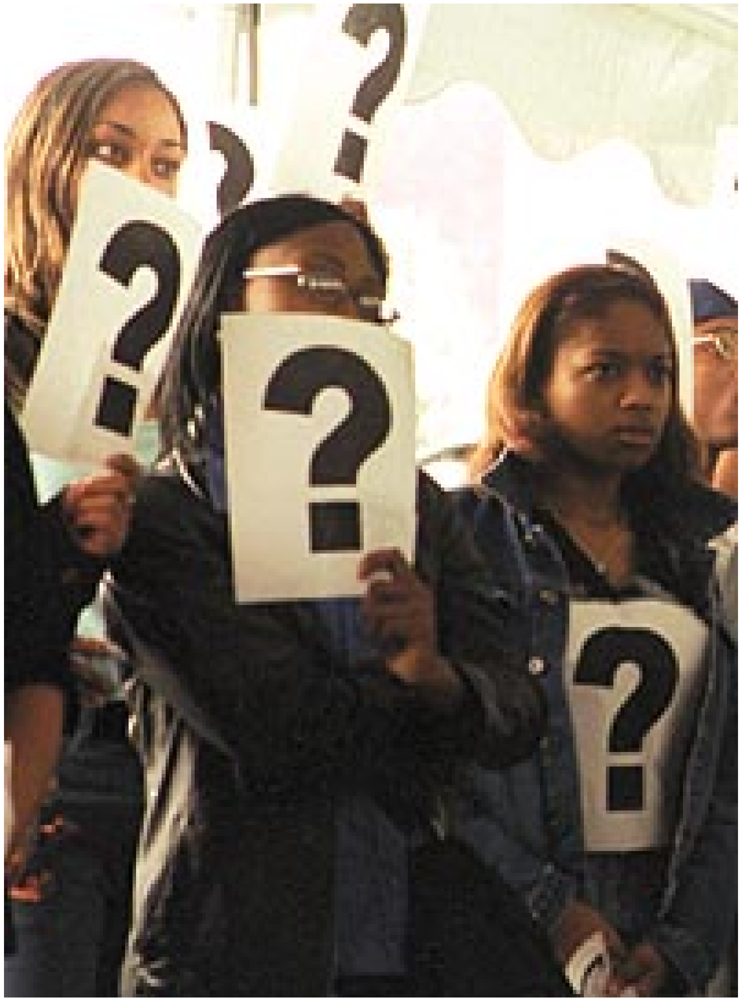


	Finding
L U B	**2% faster work with very high ventilation rate, but result may be coincidental**
T D	**6% faster work with 50 cfm/p. vs. 5 -10 cfm/p. when new air filter was in place, opposite finding with old filter**
H ir	**1% increase in work speed per 10 cfm/p. increase in ventilation rate**
S U	**9% increase in work speed with increase from 20 to 46 cfm/p, but only with higher indoor temp. (76 ^{o}F)**

Summary

- **Ventilation**
  - Fundamentals
  - Standard 62.1 Outdoor Air Requirements
- **LEED NC 2.2 Credit 2**
  - Requires 30% more outdoor air than 62.1

Questions?



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