Indoor Air Quality and Energy Efficiency: Can You Have Both?

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Seminar Objectives

- Learn the essential principles of Indoor Air Quality
- Review the *Indoor Air Quality Guide* (free from ASHRAE)
- Discuss practical applications of the Guide
- Evaluate effects of various energy savings practices on IAQ
- Learn the effects of ventilation and IAQ on performance in schools and offices

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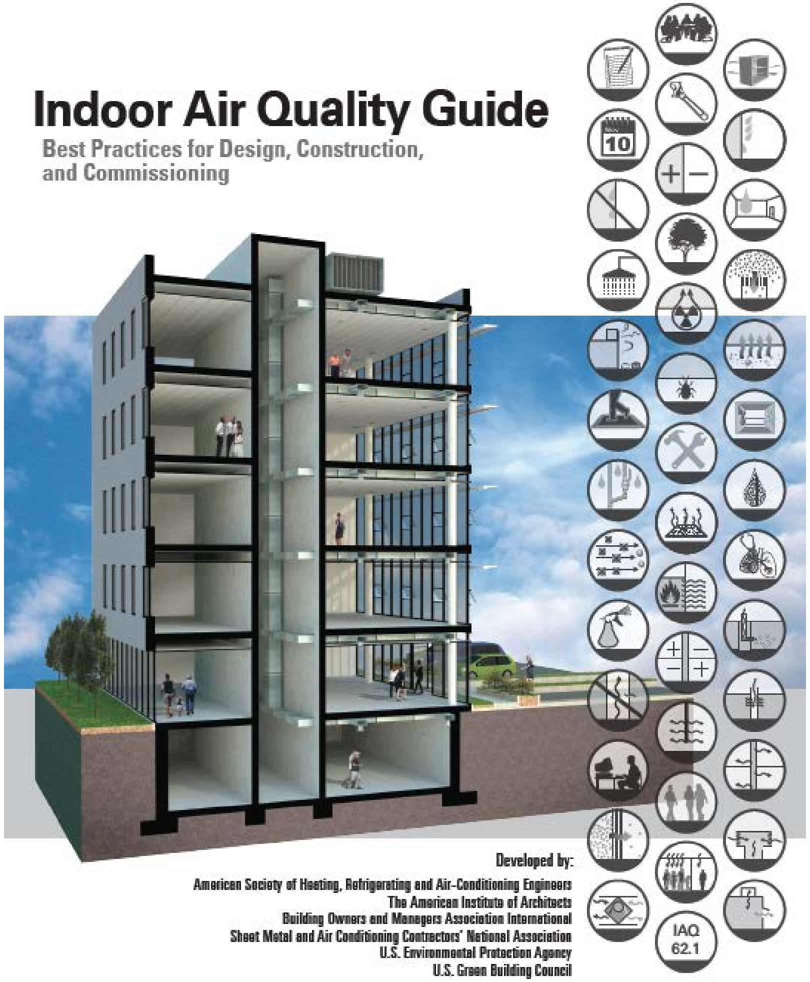
Agenda

8:30am	Logistics and Introductions
8:45am	Indoor Air Quality Guide
10:00am	Break – 15min
10:15am	Indoor Air Quality Guide
12noon	Lunch
12:45pm	Afternoon Exercise: Applying the IAQ Guide in Your Facility
2:00pm	Break
2:15pm	Energy Savings Ideas that Affect IAQ. Effects of IAQ on Performance in Offices and Schools
3:30pm	Learning Assessment and Feedback Forms



ASHRAE's IAQ Guide

- Hoy Bohanon

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Why an IAQ Guide?

- Describe design and construction strategies to improve IAQ relative to current practice and minimum codes & standards.
- Provide a comprehensive, practical resource for building professionals on achieving good IAQ.
- Provide a rational framework for evaluation of "trendy" measures to enhance IAQ.

IAQ Guide: Collaborating Organizations

AIA

ASHRAE ®

BOMA International

EPA

SMACNA

U.S. GREEN BUILDING COUNCIL USGBC ®

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IAQ Guide: Steering Committee & Authors

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Why Worry About IAQ?

Poor IAQ:

- Increases absenteeism
- Increases health costs
- Decreases productivity
- Ties up O&M resources on complaints
- Increases vacancies & turnover
- Lowers rent levels
- Can cause building closures
- Can require costly repairs
- Can lead to litigation

common causes of IAQ problems

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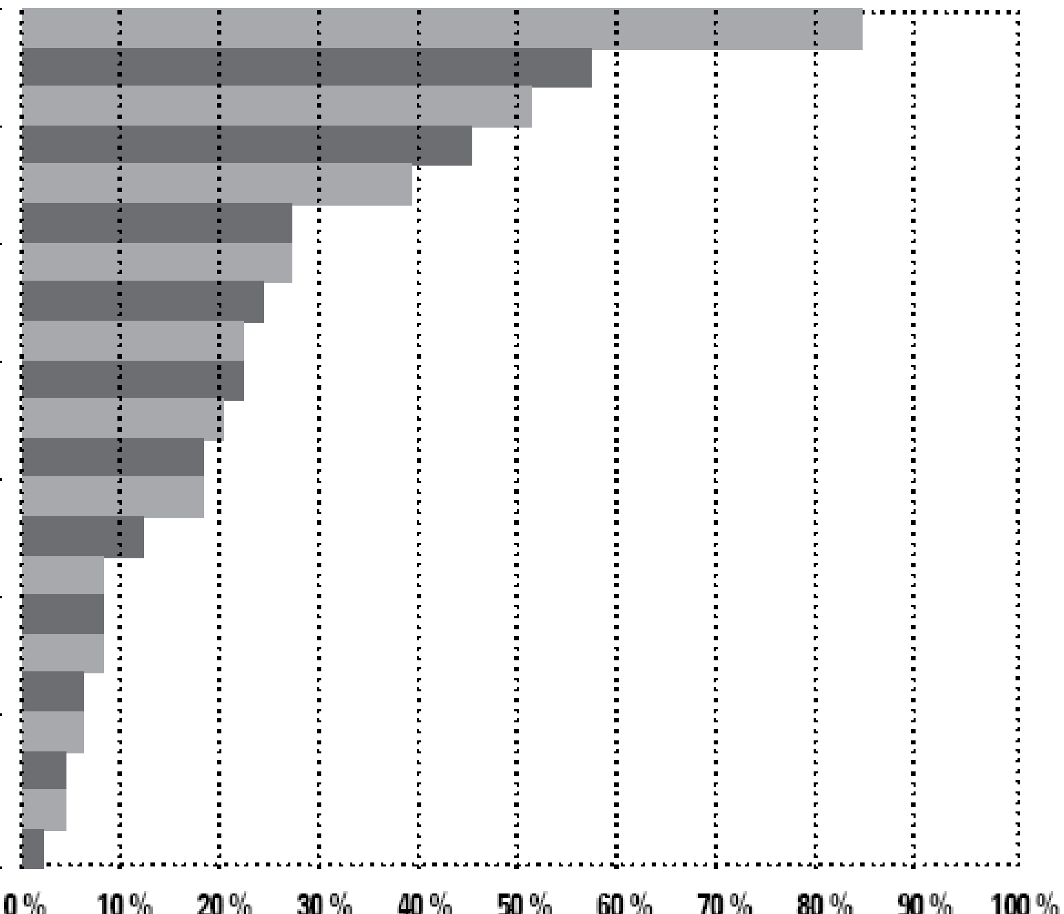
Building Factors Associated with IAQ Problems from 49 NIOSH School Reports

Building Factor Cited	%
Insufficient Outdoor Air	84
Water Leaks in Building Shell	57
Inadequate Source Exhaust	51
Poor Distribution or Balance	45
Poor HVAC Maintenance	39
Controls Dirty or Malfunctioning	27
Maintenance+ w/o Controls	27
Need IEQ Management Plan	24
Re-Entrainment or Exhaust	22
Low Filter Efficiency	22
Poor Outdoor Air Intake Location	20
HVAC Modification-Energy	18
Dirty Supply Ducts, Air Handlers	18
Poor HVAC Condensate Drain	12
Poor Access to Filters, etc.	8
Filter Bypasses	8
Filters Very Loaded	8
No Relief Vents	6
Fan Running Backwards or Off	6
Undersized Fan or Duct	4
Storage in HVAC Return	4
HVAC Modification-Fire Code	2



Adapted from Angell and Daisey 1997

Key Problems Causing Building-Related Symptom Complaints*

- In decreasing order of importance:
  - Excessive building moisture
  - Inadequate amount or quality of outdoor air
  - Surface dust
  - Gases and odors
  - Inadequate thermal control
  - Inadequate attention by management to preventing adverse effects of IEQ on occupants vs. minimizing immediate costs

*Mendell, *et al*. 2006

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Organization of the Guide

Objective 1	Manage the Process to Achieve Good IAQ
Objective 2	Control Moisture in Building Assemblies
Objective 3	Limit Entry of Outdoor Contaminants
Objective 5	Control Moisture and Contaminants Related to Mechanical Systems
Objective 5	Limit Contaminants from Indoor Sources
Objective 6	Contain and Exhaust Contaminants from Building Equipment and Activities
Objective 7	Reduce Contaminant Concentrations through Ventilation and Air Cleaning
Objective 8	Apply More Advanced Ventilation Approaches

Objective 1. Manage the Design & Construction Process To ACHIEVE GOOD IAQ

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Manage the Design & Construction Process

- Integrate design approach and solutions (1.1)
- Commission to ensure that the owner's IAQ requirements are met (1.2)
- Select HVAC systems to improve IAQ and reduce the energy impacts of ventilation (1.3)
- Schedule and manage construction to preserve IAQ (1.4)
- Design and build to facilitate O&M for IAQ (1.5)

Integration starting at conceptual design is critical:

Integrate design approach and solutions

- Many early decisions affect IAQ: e.g., siting, massing, orientation, openings, access
- Avoids foreclosing options, as sometimes happens when conceptual design focuses on aesthetics and presentation without considering implications for ventilation, IAQ, thermal control, illumination, acoustics and energy
- Early interaction allows synergies to be captured
- Lays groundwork for an interactive process

1.1

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1.1

Integrate design approach and solutions

Traditional approach:

Design➔ retrofit ➔ build?

Traditional Design Approach

- Hierarchical
- Compartmentalized
- Linear/sequential
- Transactional

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Integrated Design

1.1

Integrate design approach and solutions

Integrated approach: Potentially more optimized and cost-effective

- Team-based (& larger team)
- Holistic
- Organic
- Collaborative

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1.1

Integrate design approach and solutions

Example

Interactions among ceiling height & type, air quality, thermal control and daylighting:

- Higher ceilings and taller windows allow daylight to penetrate deeper into the space, reduce illumination energy and associated loads.
- Proper shading admits light but controls unwanted solar gain, glare, material emissions.
- Higher ceilings allow thermal and air pollutant stratification. Displacement ventilation capitalizes on this.
- Exposed ductwork and elimination of suspended ceilings offset some costs of greater height.
- Longer lag time associated with thermal stratification may permit further reductions in equipment sizing.

1.1

Select HVAC systems to improve IAQ and reduce energy impacts of ventilation

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1.3

Select HVAC systems to improve IAQ

Regional/local and project-specific IAQ issues

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Select HVAC systems to improve IAQ

Regional/local, project-specific IAQ issues

1.3

Example: Need for positive building pressurization and HVAC system type

Table 1.3

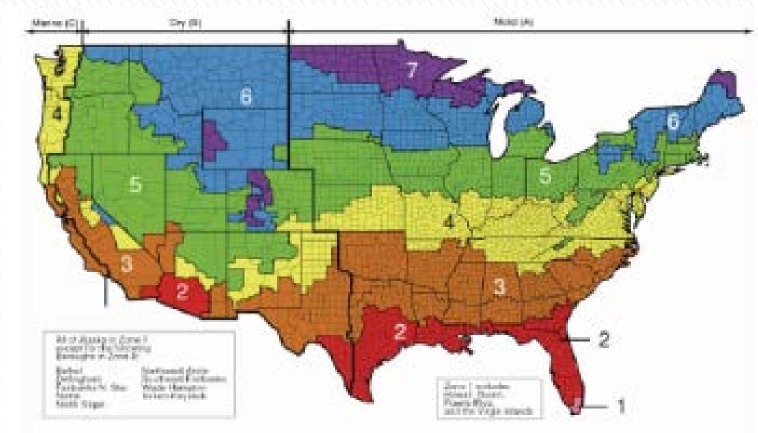

Figure 1.3-F U.S. Map Showing the DOE Climate Zones
Source: Briggs et al. (2003).

Figure 1.3-I U.S. Counties with PM2.5 Nonattainment Areas
Graph courtesy of EPA.

1.3

Select HVAC systems to improve IAQ

Consider IAQ implications of HVAC system options

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1.3

Select HVAC systems to improve IAQ

Consider IAQ implications of HVAC system options

Example: VAV with reheat

VAV System With Reheat – IAQ Considerations:

- Maintaining minimum OA flow when supply air flow decreases
- Different zones need different amounts of OA but AHU provides OA fraction – need to satisfy zone with highest OA requirement
- Heating/cooling costs of high pct OA
- Water piping in ceiling space to serve the reheat coils
- Requires service access for reheat coils and valves, VAV damper actuators and flow sensors
- Relatively simple to understand and maintain

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KEY POINTS

1.2

Commission to ensure that IAQ requirements are met

Build quality in from the start

- Cx is NOT just inspection at the end!!
- Pre-design
  - Owner's IAQ requirements – risk-based approach to scope and budget
  - Needed specialists
  - Schedule considerations
- Design
  - IAQ Basis of Design
  - Design review
  - Prep Cx specifications
- Construction & occupancy
  - Coordination
  - Submittal review
  - Mock-ups
  - Construction observation
  - TAB verification
  - Functional testing
  - Systems manual, O&M training

1.2

Commission to ensure that IAQ requirements are met

No quality control… no quality

Why Commission?

- No QC, no quality
- Every building is a prototype
- Every project has a new team
- Budget pressures
- Time pressures

1.2

Why Commission?

Commission to ensure that IAQ requirements are met

No quality control… no quality

- Architectural
  - Performance specs without construction details
  - Diffusion of responsibility among envelope contractors
- Mechanical
  - Performance specs for the control system
  - Controls contractor may not understand HVAC systems
- Innovative systems may cause innovative problems

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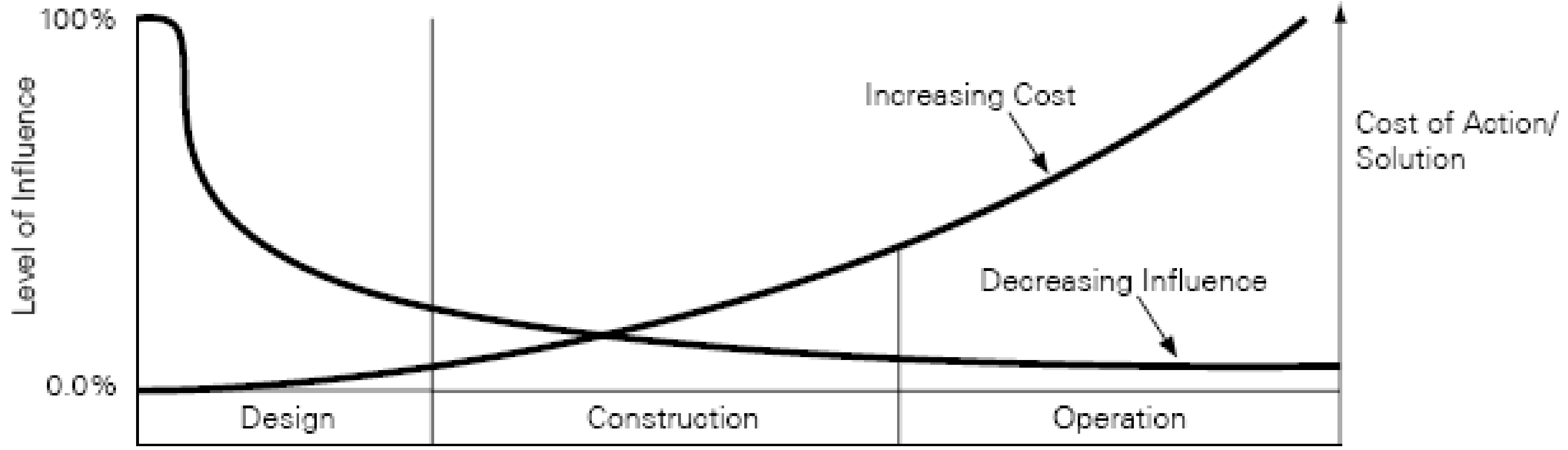
Commission to ensure that IAQ requirements are met

Start in pre-design to maximize impact and minimize cost



Adapted from CH2M HILL

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1.2

Commission to ensure that IAQ requirements are met

Pre-design

Identify owner's project requirements for IAQ

- Risk-based approach, e.g.
  - Moisture
  - *Legionella*
  - OA quantity
  - OA quality
  - Exhaust of contaminants
  - Air distribution
  - HVAC maintenance
  - Innovative systems, e.g. ERV, UFAD
- Define performance and acceptance criteria
- Resources:
  - IAQ Guide
  - ASHRAE Guideline 0 Annex J
  - NIBS Guideline 3 Annex J
  - ASHRAE Guideline 1.1 Annex J

1.2

Commission to ensure that IAQ requirements are met

Pre-design

- Include needed specialists
  - e.g., bldg envelope specialist
- Integrate Cx for IAQ into schedule
  - Design phase workshop
  - Design review
  - Submittal review
  - Pre-construction meeting
  - Construction and testing of mock-ups
  - Construction observations while assemblies are open
  - TAB verification
  - Functional testing

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1.2

Commission to ensure that IAQ requirements are met

Design Phase: IAQ Basis of Design

- Developed by designer
- "Concepts, calculations, decisions, and product selections used to meet the [OPR] and to satisfy the applicable regulatory requirements, standards, and guidelines"
- Resources
  - ASHRAE Standard 62.1
  - ASHRAE Guideline 1.1 Annex K
  - NIBS Guideline 3 Annex K
  - IAQ Guide

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Commission to ensure that IAQ requirements are met

Design Phase: IAQ Basis of Design

Regional & local outdoor air quality (Std 62.1)

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1.2

Commission to ensure that IAQ requirements are met

Design Phase: IAQ Basis of Design – Ventilation design criteria and VRP Assumptions (Std 62.1)

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Commission to ensure that IAQ requirements are met

Design Phase: IAQ Basis of Design
VRP Assumptions (Std 62.1): Example

VUV - Typical Classroom (28 VUV's Total)											
zone name	zone ceiling height	zone area A (z)	zone people P (z)	oa rate/ person R (p)	oa rate/ area R (a)	zone cfm V (pz)	cfm per sq ft	a/ch per hour	breathing zone oa V (bz)	air dist. zone eff. E (z)	design zone oa V (oz)
classroom	9	1,000	30	10	0.12	1,250	1.25	8.3	420	0.8	525
totals		1,000	30								525
design results											
system total supply cfm		1,250									
system total OA cfm V (ot)		525	42%								

VUV basis of design courtesy Hallberg Engineering, Inc.
Photo courtesy Center for Energy & Environment

1.2

Commission to ensure that IAQ requirements are met

Design Phase: IAQ Basis of Design – Building enclosure (NIBS Gdl 3)

- Air leakage criteria for walls, windows, curtain walls, storefronts, skylights, doors
- Water leakage criteria for same plus below-grade systems, slabs on grade
- Water vapor and condensation requirements for same
- Thermal performance criteria
- Site circulation/access (vehicle exhaust issues)
- Exhausts that may damage roofs
- Roof drain sizing

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1.2

Commission to ensure that IAQ requirements are met

Design Phase: Design review

- General quality
- Coordination: constructability, interfaces
- Discipline-specific review for achieving the OPR
- Spec applicability to project, inclusion of Cx requirements, submittal requirements, consistency with OPR and BOD, coordination

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1.2

Commission to ensure that IAQ requirements are met

Design Phase: Design review

Example

- Two buildings, 900,000 ft^2
- Humid climate
- Peer review of structural systems showed drift under wind loads would exceed movement tolerances of building enclosure, allowing rainwater intrusion
- ID during design review avoided significant IAQ problems and repair costs

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1.2

Commission to ensure that IAQ requirements are met

Design Phase: Cx-specific construction process requirements

- Contractor participation in Cx
- Submittal requirements for Cx
- Laboratory testing
- Mock-ups of exterior assemblies
- Periodic inspections during construction
- Documentation of equipment and component performance (checklists)
- Schedule for witnessing testing
- Field testing of enclosures
- TAB verification
- Functional testing of HVAC&R systems
- Development and implementation of training that meets user needs
- Systems manual

1.2

Commission to ensure that IAQ requirements are met

Construction and Occupancy

- Coordination
- Submittal review
- Mock-ups
- Construction observation
- Verification of checklists
- TAB verification
- Functional testing
- Systems manual, O&M training meeting user needs

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1.2

- Drain pan drains?
  - No, even though double-sloped, because AHU is not level; "Too late now…"
  - Should be caught during checklisting

Commission to ensure that IAQ requirements are met

Checklists

Photo courtesy Center for Energy & Environment

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1.2 Commission to ensure that IAQ requirements are met: *TAB verification*

Classroom unit ventilator air flows before (blue) and after (yellow) commissioning

1.2

Commission to ensure that IAQ requirements are met

Enclosure functional tests

Example

- 229-room expansion of hotel in Florida
- OPR: moisture-free
- Sliding glass door unit failed initial water spray testing and second round after modifications by Cx, design and construction team
- After modifications by manufacturer and implementation of a checklist procedure, all doors tested passed

Photo courtesy Dave MacPhaul, copyright CH2M HILL

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1.2

Commission to ensure that IAQ requirements are met

Enclosure functional tests

Example

Photos courtesy Dave MacPhaul, copyright CH2M HILL

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1.2

Was it worth all that testing?

Commission to ensure that IAQ requirements are met

Enclosure functional tests

Example

- Six months after the hotel expansion opened, Hurricanes Charley, Frances and Jeanne struck. Top wind speeds over 90 mph (~40 m/s) and rain totaling over 14 in. (~356 mm).
- Older portions of this hotel and other properties in the area suffered severe water and wind damage.
- This new hotel expansion did not experience any identified water intrusion.
- The expansion had hundreds of sliding glass doors, so failure of this component could have been catastrophic.

1.2

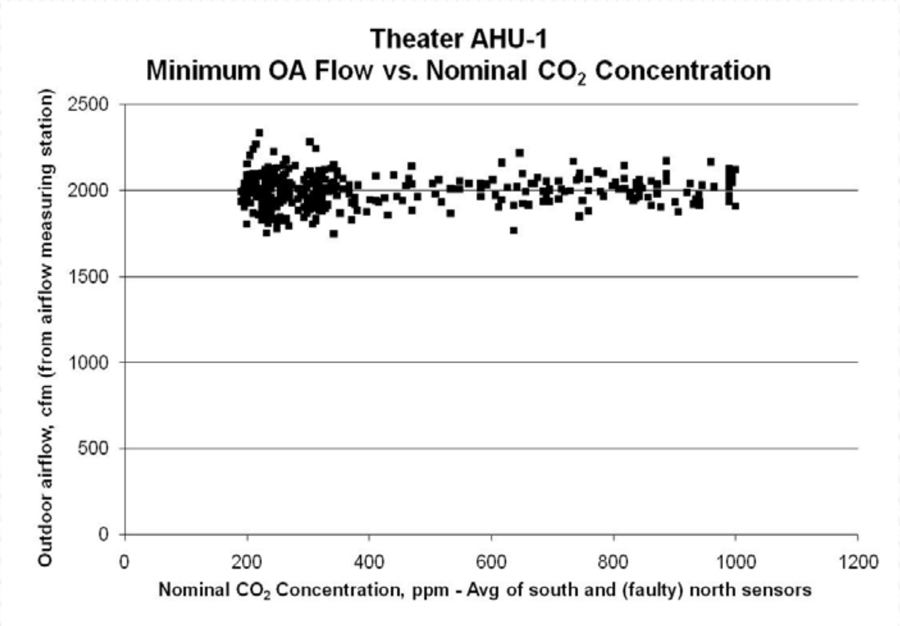
Demand-controlled ventilation of a theater

Commission to ensure that IAQ requirements are met

Ventilation functional tests

Example

- Design ventilation rate 7200 cfm, reset 2000 – 7200 to keep CO_2 below 900 ppm
- Actual flow never went above 2000 cfm (BAS trending)



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1.2

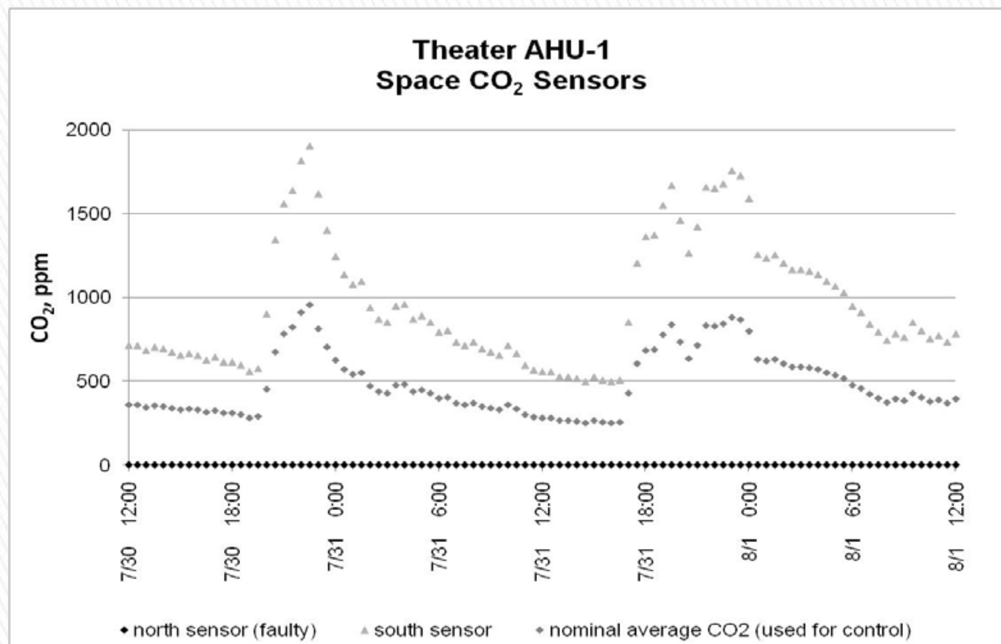
Stuffy, anyone?

Commission to ensure that IAQ requirements are met

Ventilation functional tests

Example: sensor calibration, programming problems

- Programmed reset 2000 cfm at 1000 ppm CO_2 to 3000 cfm at 1500 ppm
- One of two CO_2 sensors read 4 ppm all the time so "average" CO_2 50% low
- AFMS read 1100 cfm with fan off



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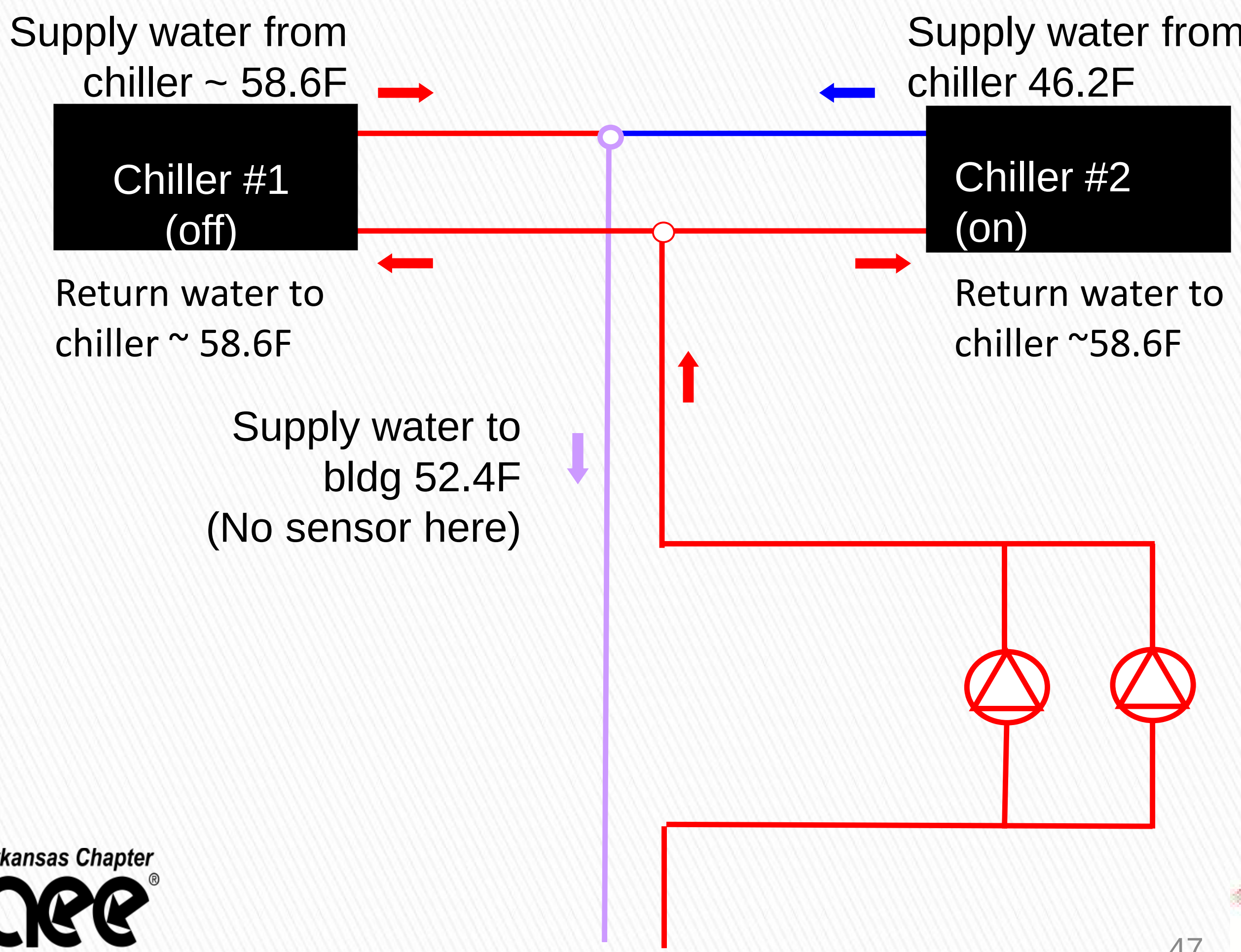
1.2

Commission to ensure that IAQ requirements are met: *HVAC functional tests for IAQ – not just ventilation*



- No isolation of inactive chiller
- High CHW supply temp
- Higher air flow and energy use
- High AHU DAT, high space humidity

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OBJECTIVE 2. Control Moisture in Building Assemblies

Control Moisture in Building Assemblies

- Limit penetration of liquid water (2.1)
- Limit condensation of water vapor within the building enclosure (2.2)
- Maintain proper building pressurization (2.3)
- Control indoor humidity (2.4)
- Select suitable materials/equipment/assemblies for areas that are unavoidably wet (2.5)
- Consider impacts of landscaping and indoor plants (2.6)

2.1

KEY POINTS

Limit penetration of liquid water

- Design
  - Continuous drainage plane
  - Capillary breaks
  - Site drainage
  - Contract documents
- Quality control
  - Pen test
  - Submittals/shop drawings
  - Water penetration testing
  - Construction observation

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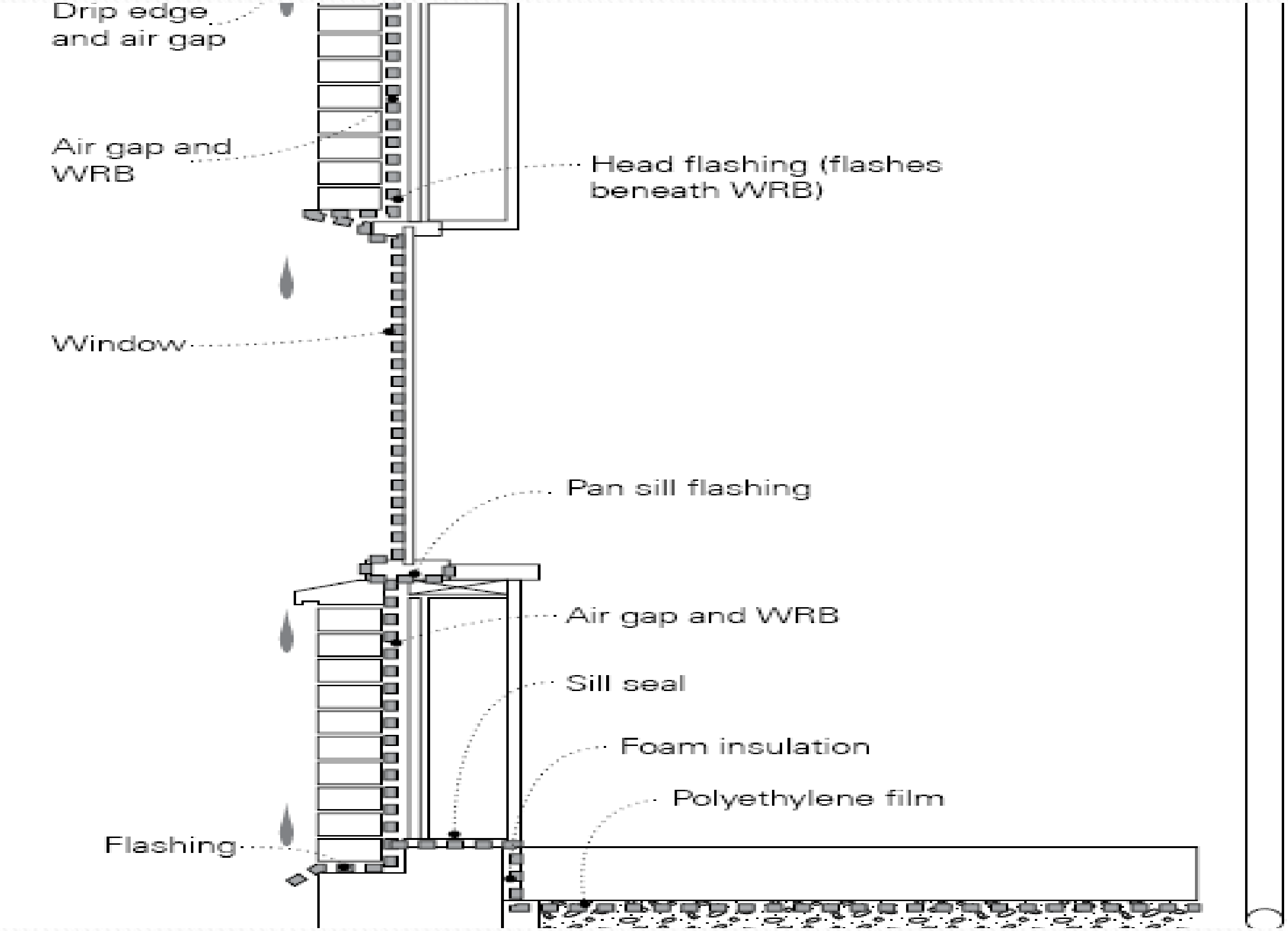
2.1

Limit penetration of liquid water

Continuous drainage plane



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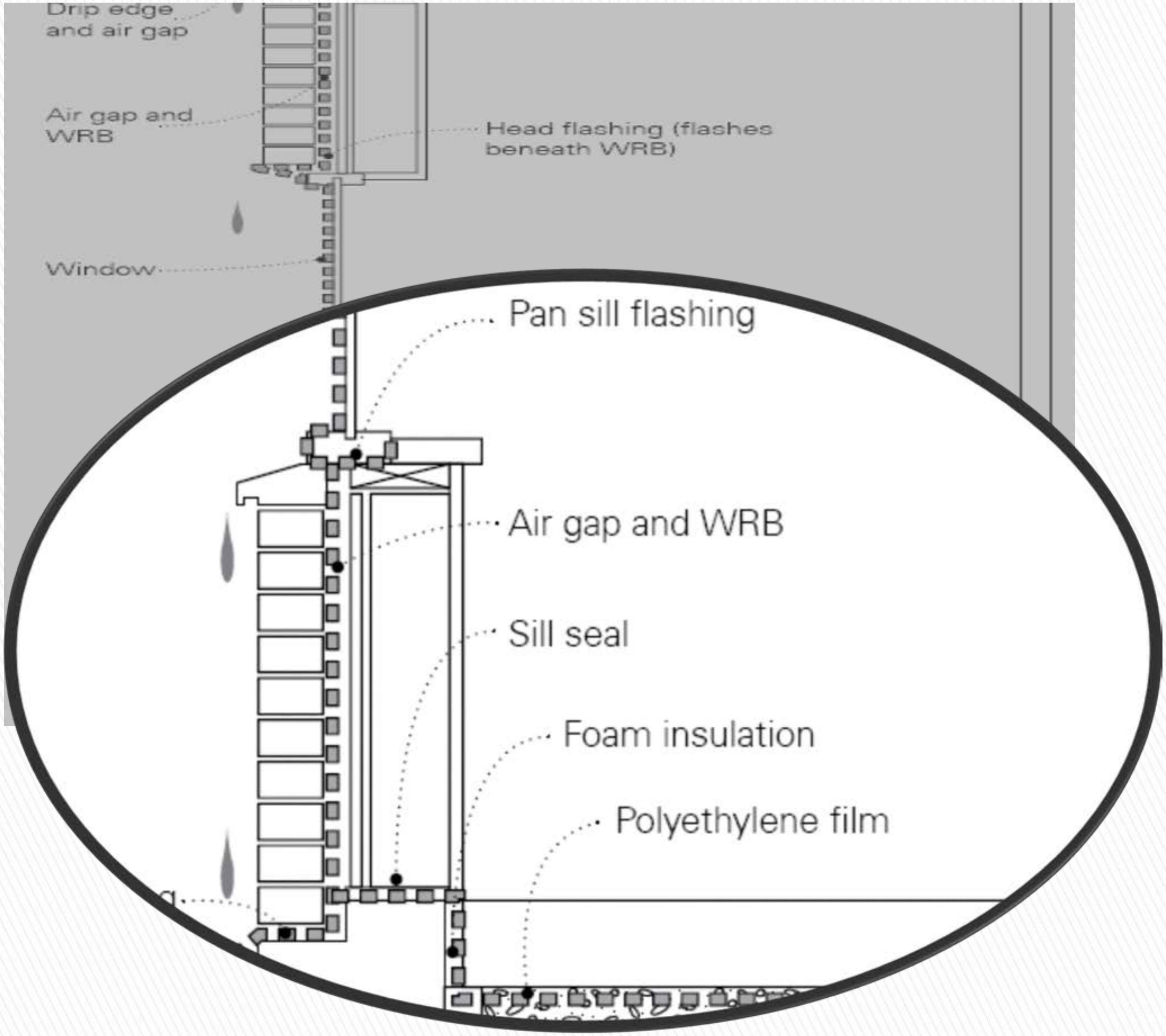
2.1

Limit penetration of liquid water

Capillary breaks



Limit penetration of liquid water

Site drainage

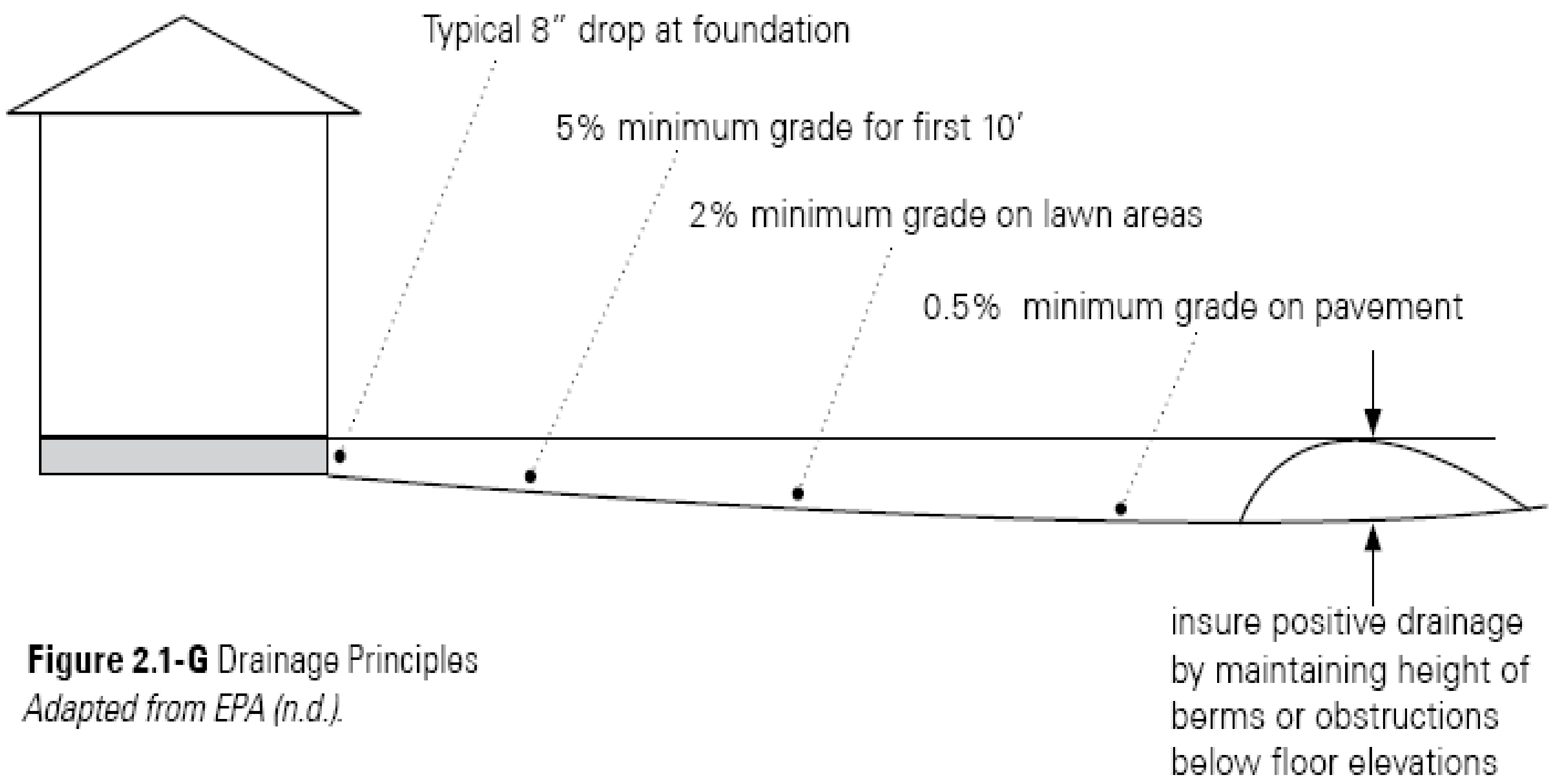


Figure 2.1-G Drainage Principles
Adapted from EPA (n.d.).

2.1

Limit penetration of liquid water

Contract documents

- Provide all necessary sectional and detail drawings, including 3D
- Use pen test to verify continuous drainage plane

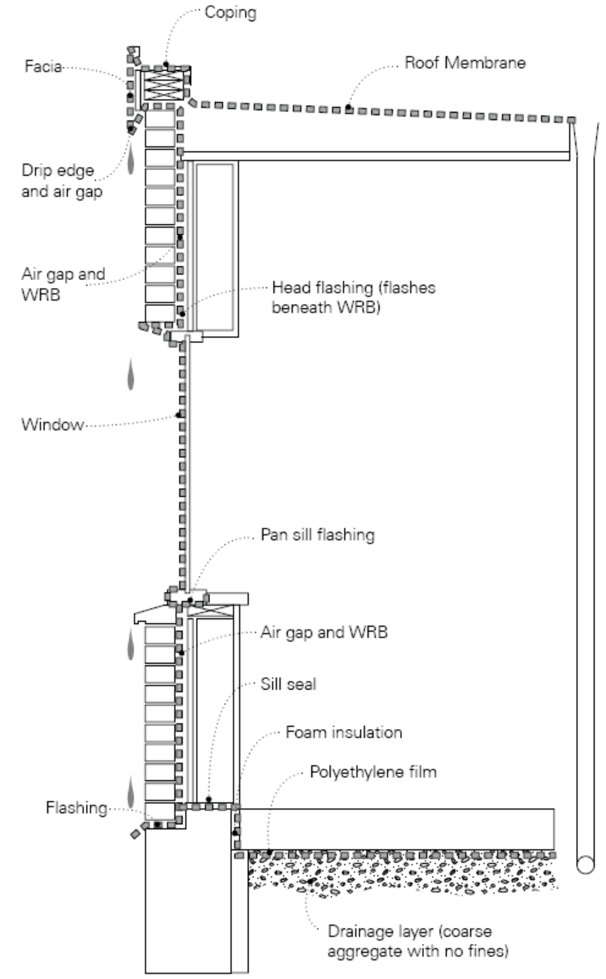


Figure 2.1-Z Typical Pen Test for Proving that Rainwater Barrier is Continuous
Adapted from EPA (n.d.).

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2.1

Limit penetration of liquid water

Case study: Multifamily complex

Remediation cost: $2M

Water Intrusion in a Multi-Family Complex

Figure 2.1-A Points of Water Entry into the Building Envelope

Limit penetration of liquid water *Case study: Multifamily complex Improper roof flashing detail*

How do you avoid this?

- 3D details
- Pen test
- Construction observation

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Limit penetration of liquid water
Case study: Multifamily complex
Improper window flashing

How do you avoid this?

- 3D details
- Pen test
- Construction observation

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2.1

Limit penetration of liquid water

Window flashing:
Detailed info in Guide

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Mold, moisture and IAQ problems:

2.1

Limit penetration of liquid water

Case Study:

Church, church offices, daycare

- Pastor symptoms: pastors' offices moved to a different building
- Parishioner symptoms: signage warning sensitive people of mold problems
- Daycare in building, concerns about effects on students

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2.1

Limit penetration of liquid water

Case Study:

Church, church offices, daycare

Incomplete drainage plane

Drainage space behind face brick filled with mortar in many areas

Missing flashing, missing weep holes in some areas

Photos courtesy Center for Energy & Environment

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2.1

Limit penetration of liquid water

Case Study: Church, church offices, daycare

Other problems

- Non-continuous air barrier allows mold in walls to move into building
- Offices and daycare served by residential furnaces and window AC – no ventilation
- Worship space ventilated only 7 hrs/wk (Sunday a.m.)

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2.2

Limit condensation within the building enclosure

KEY POINTS

- Design
  - Air barrier system
  - Control of convection
  - Vapor retarder
  - Fenestration condensation resistance factor (CFR)
  - Below-grade slabs/walls
  - Thermal bridging
  - Construction documents

2.2

Limit condensation within the building enclosure

KEY POINTS

- Quality Control
  - Air barrier pen test
  - Submittals/shop drawings
  - Pre-construction meetings
  - Mock-ups
  - Qualitative inspections
  - Testing and verification

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2.2

Types of leaks

Limit condensation

Air barrier system

__Air movement__ can transport hundreds of times more moisture than diffusion

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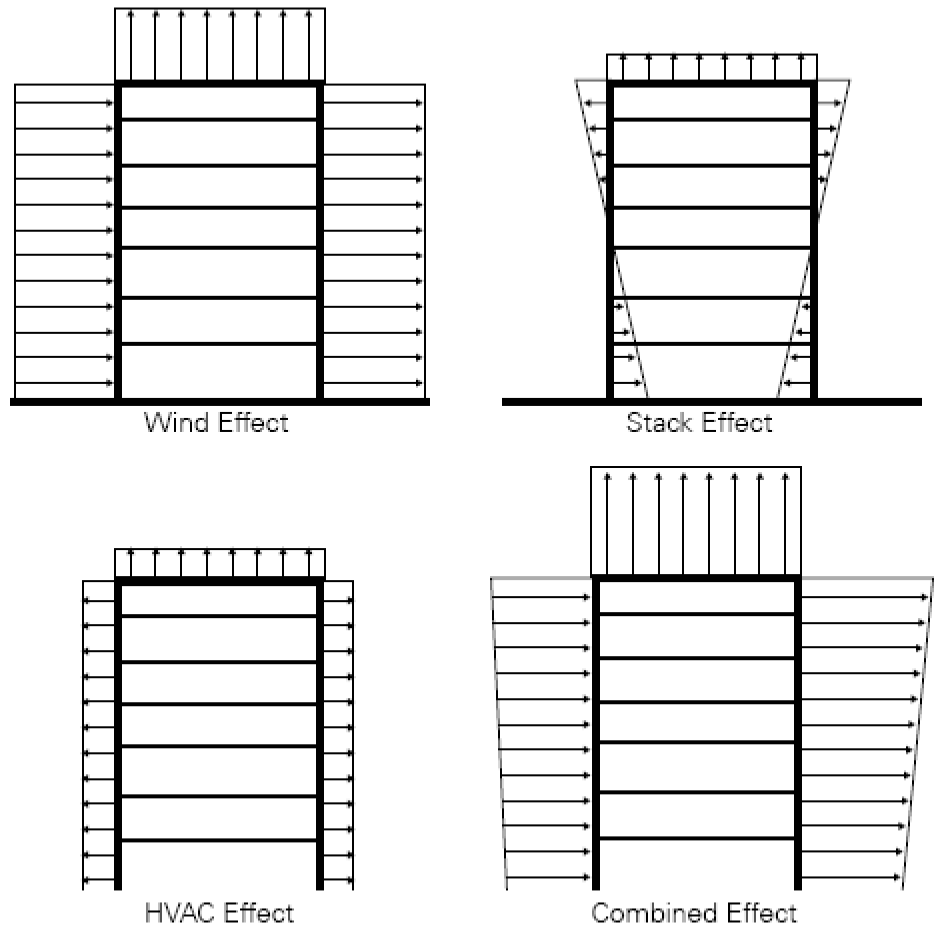
Limit condensation

Air barrier system:

Driving forces for air flow

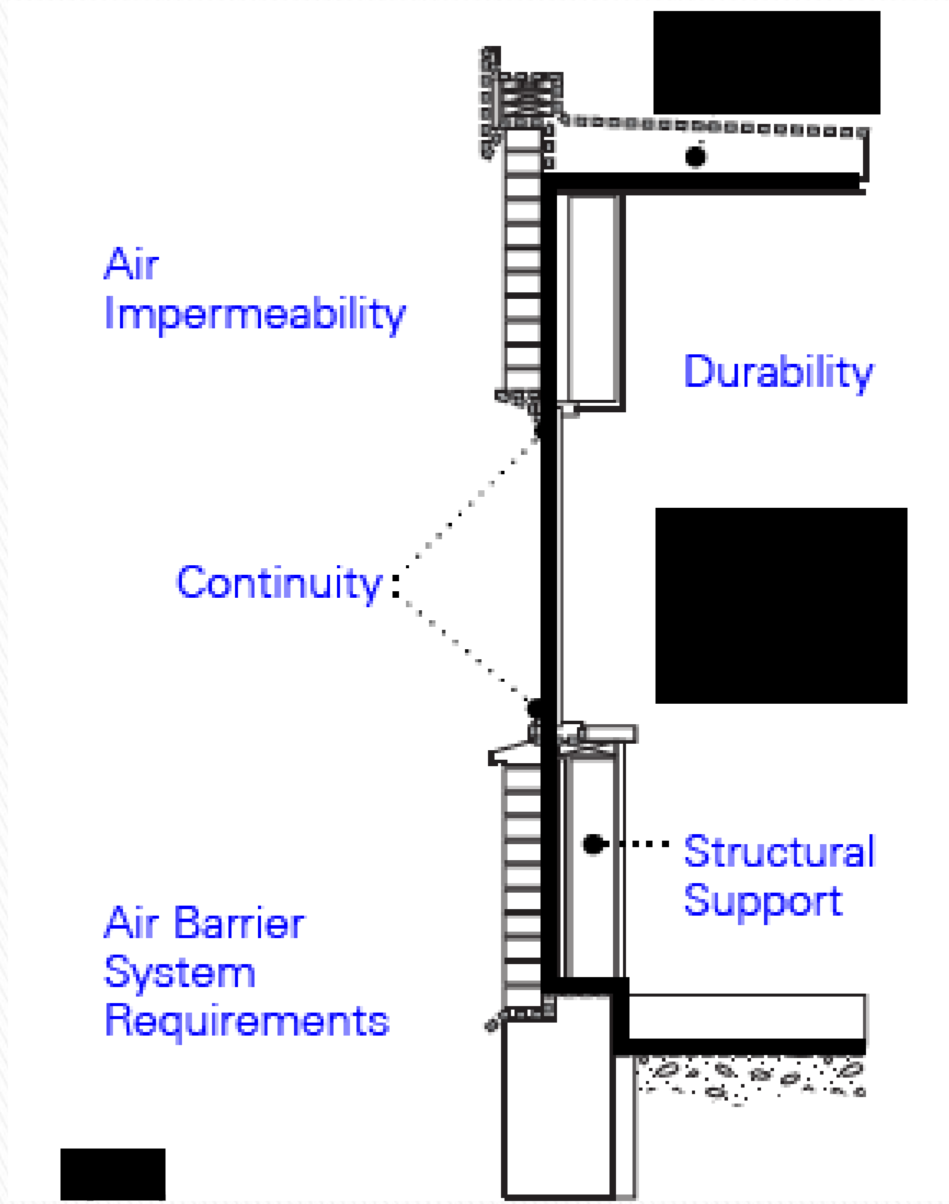


2.2

Limit condensation

Air barrier system:

Requirements



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2.2

Limit condensation

Air barrier system:

Continuity

Also seal all penetrations

Peel-and-stick trim work

Liquid-applied air barrier

Shepley Bulfinch Richardson and Abbott, Architect
Photos courtesy of Wagdy Anis

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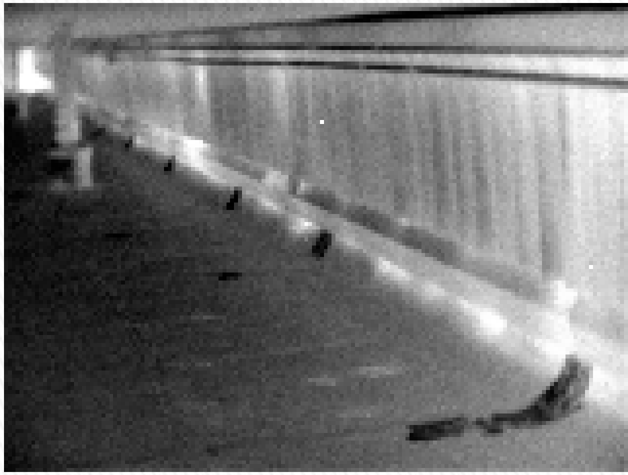
2.2

Limit condensation

Air barrier system:

Continuity

Airtight parapet? Not so much…



Photos courtesy Center for Energy & Environment

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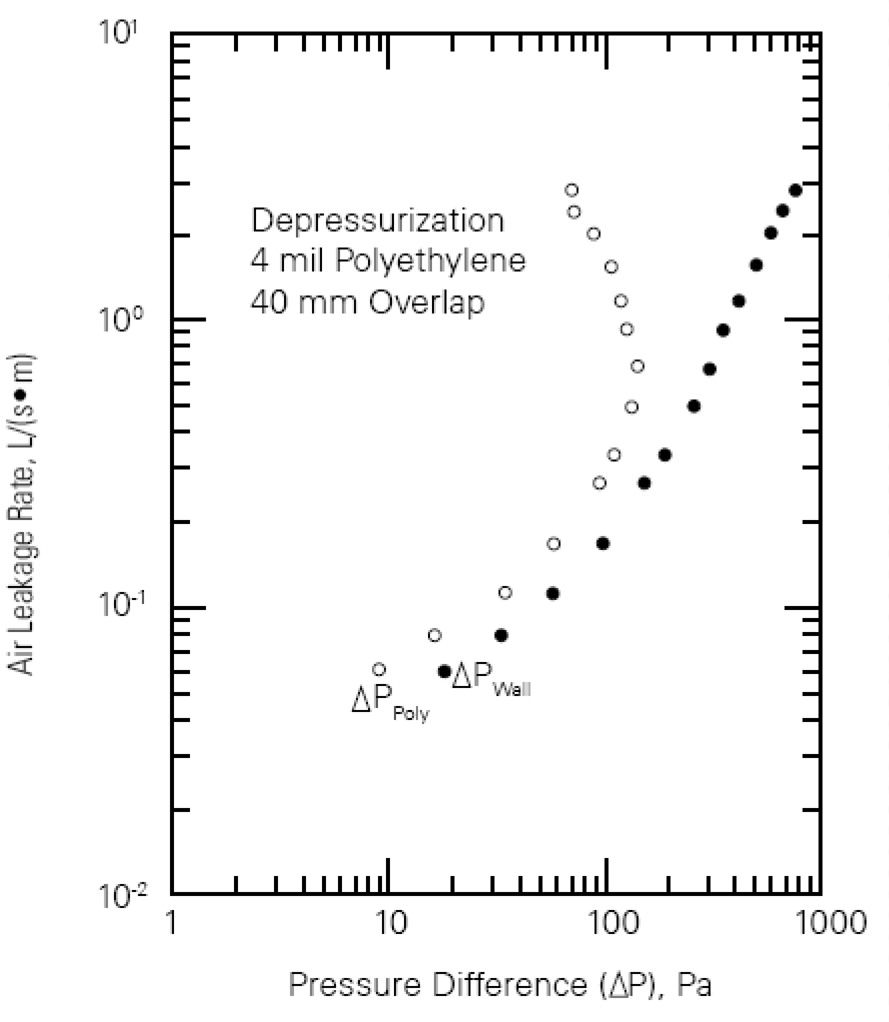
2.2

Limit condensation

Air barrier system:

Structural support

Unsupported materials can "pump" moisture or rupture



Adapted from Shaw 1985

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Limit condensation

Air barrier system

Flexibility

Foam sealant between insulation sheathing boards

Peel-and-stick tape on primed insulation sheathing boards

Photos courtesy of Wagdy Anis.

2.2

Limit condensation

Air barrier system:

Durability

For the life of the structure, or accessible for maintenance

No duct tape on curtain wall insulation!

Photo courtesy Center for Energy & Environment

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2.2

Limit condensation

Air barrier system:

Placement

- The air barrier can be placed anywhere:
  - If placed on the warm-humid side, it can control diffusion; too if it is a low perm vapor barrier material: *air and vapor barrier*
  - If placed on the cool drier side, it should be vapor permeable (>=5 to 10 perms)
- See IAQ Guide for link to numerous free details

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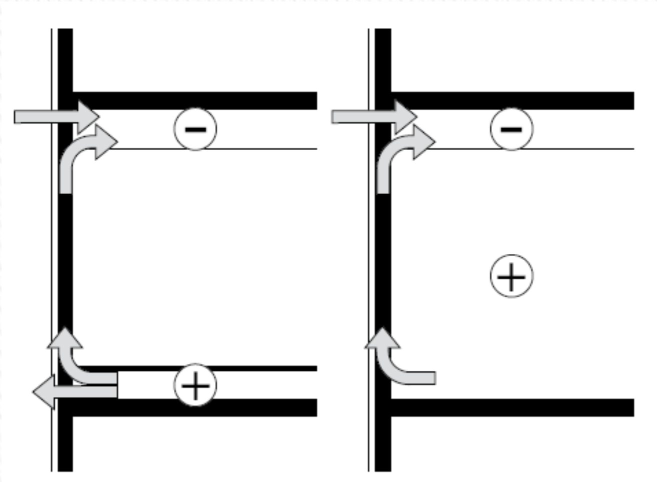
2.2

Limit condensation

Air barrier system:

More

- A mechanically fastened and ballasted roof is not an air barrier
- Disconnect HVAC plenums from the enclosure



- Air sealing foundation walls and slab reduces radon and vapor intrusion

2.2

Limit condensation

Air barrier system:

Quality control

- Air barrier pen test
- Submittals/shop drawings
- Pre-construction meetings
- Build and test mock-ups esp. for complex/unusual details
- Qualitative observations
  - Site and substrate
  - Air barrier application
  - Tests with smoke, IR, etc.
- Construction verification
  - Assemblies
  - Whole building

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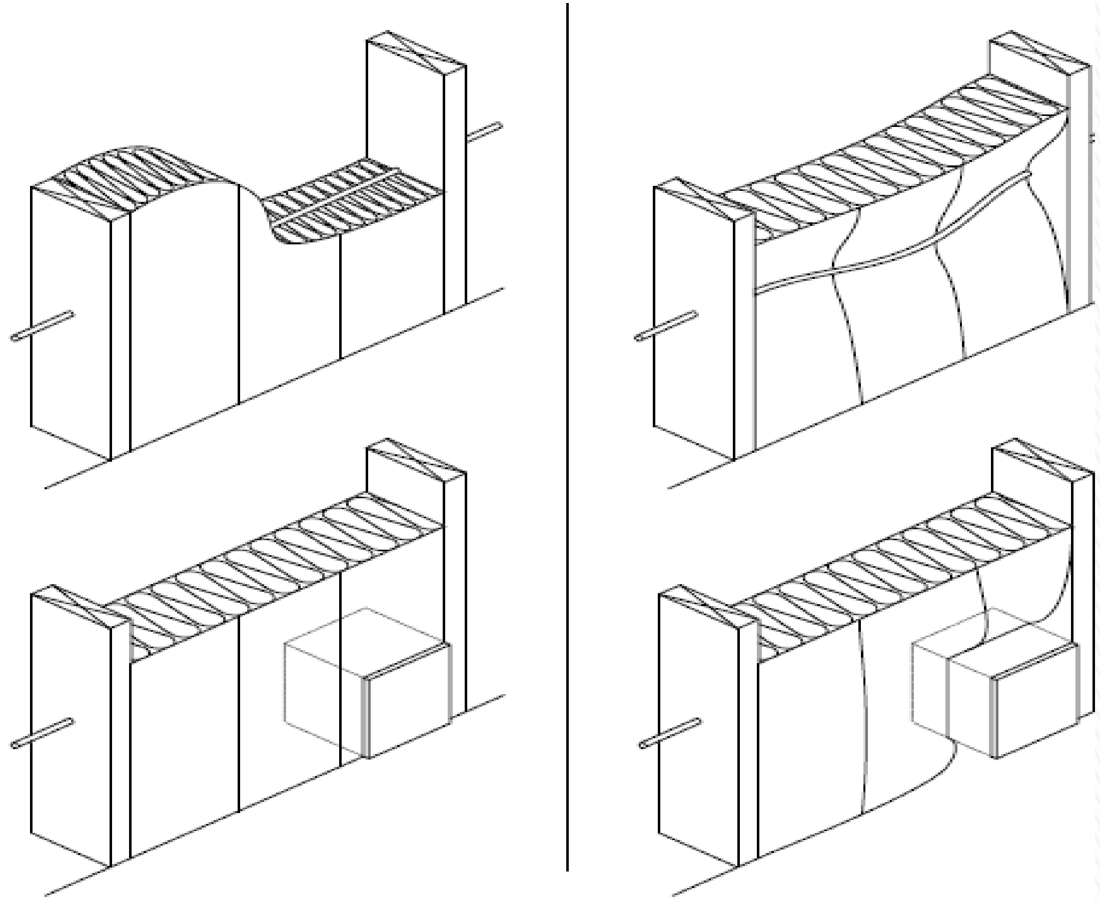
2.2

Limit condensation

Control of convection



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2.2

Limit condensation

Control of convection

Bad: Gaps between and behind

Good: Embedded in mastic with sealed joints

Photos courtesy of Wagdy Anis

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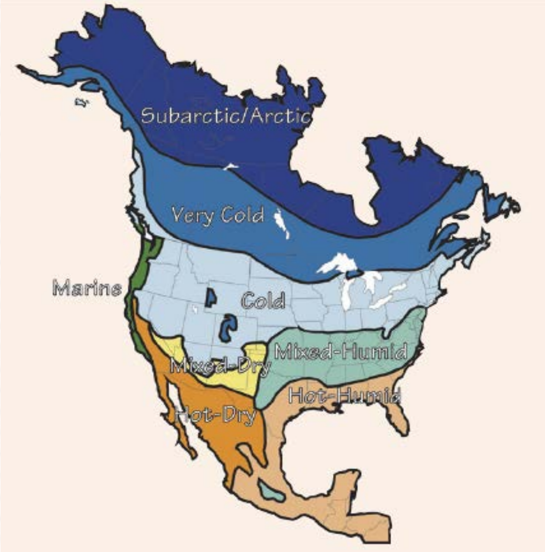
2.2

Limit condensation

Vapor retarders



- Use vapor control measures appropriate to the climate
- Avoid v-barriers where v-retarders are satisfactory
- Avoid v-retarders where v-permeable materials are satisfactory
- Don't put v-barriers on both sides of assemblies
- Don't use v-barriers and vinyl wall coverings on the interior of air-conditioned assemblies

2.2

Limit condensation

Below-grade slabs and walls

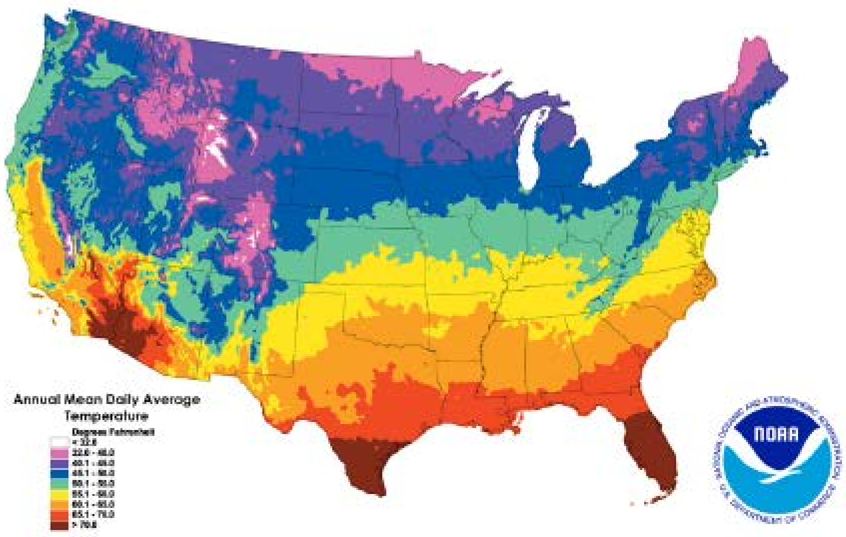


Figure 2.2-A Average Mean Daily Temperatures
Image courtesy of National Climatic Data Center.

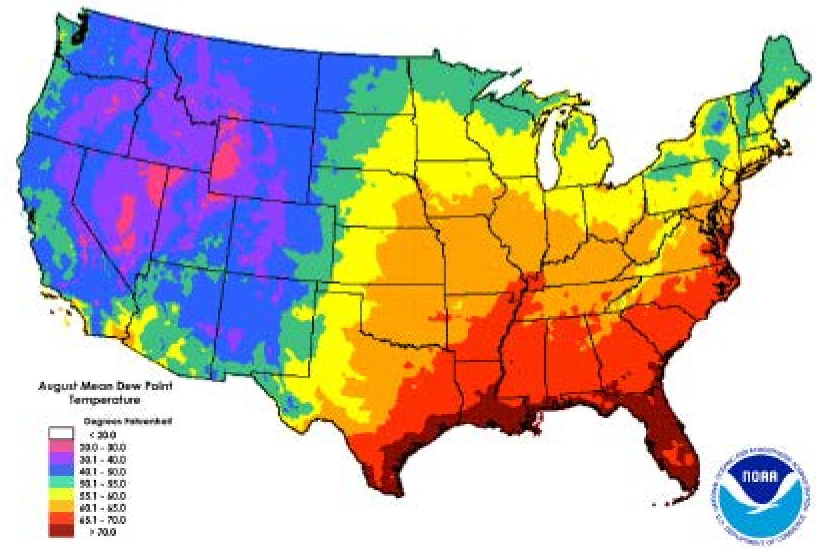


Figure 2.2-B Mean Dew-Point Temperatures for August
Image courtesy of National Climatic Data Center.

- If August dewpoint T > Annual average T, condensation on below-grade walls is likely

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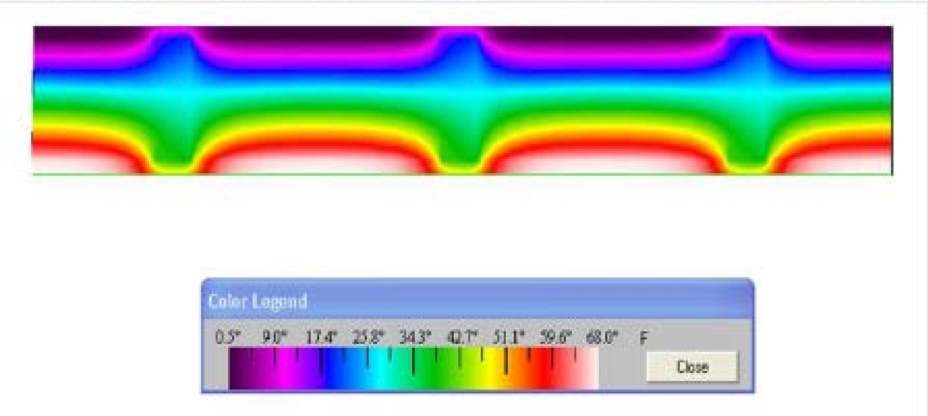
2.2

Limit condensation

Thermal bridging



Photocopyright Wiss, Janney, Elstner and Associates, Inc.

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2.3

Maintain proper building pressurization

KEY POINTS

- Pressure differences move moisture and contaminants through building envelope
- Driving forces: stack effect, wind, mechanical
- Pressure differences are not the same over the entire envelope
- Envelope leakage is significant and affects the excess of supply over exhaust needed for positive pressurization

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2.3

Maintain proper building pressurization

Applications needing positive pressurization

- Mechanically cooled buildings in hot humid climates
- Low-temperature buildings or spaces; e.g., refrigerated warehouses, ice arenas
- Buildings in areas with poor outdoor air quality

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2.3

Maintain proper building pressurization

Applications needing negative or neutral pressure

- Humidified buildings or spaces in cold climates; e.g. natatoriums, indoor gardens, kitchens, hospitals, museums, musical instrument storage
- Other buildings in cold climates

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2.3

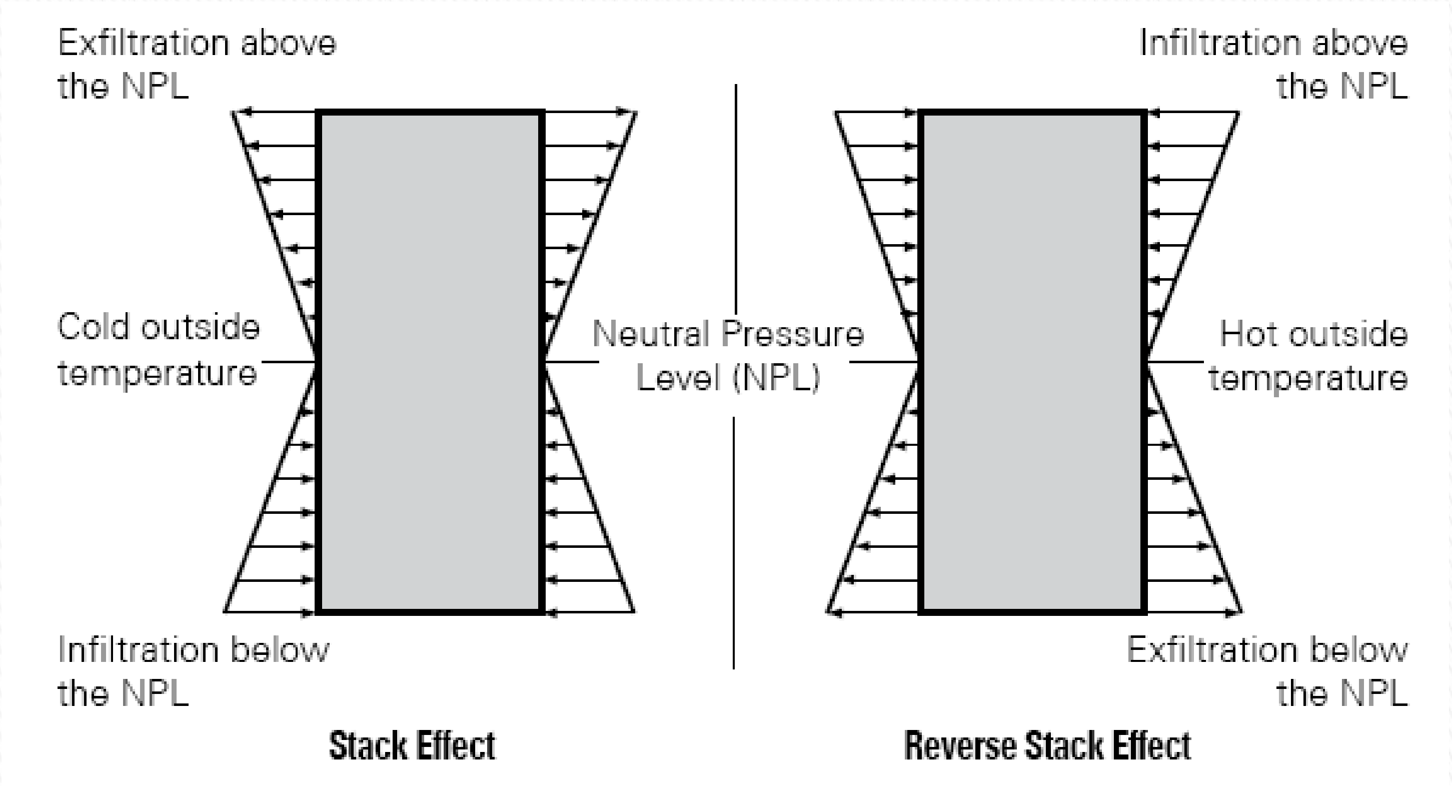
Maintain proper building pressurization

Driving forces for infiltration, exfiltration

- Stack effect
- Wind effect
  - In on the windward side, out on the leeward side
- Mechanical effect
  - Exhaust-only ventilation
  - Return plenums
  - Supply plenums (UFAD)
  - Intentionally depressurized (labs) or pressurized (OR's) areas
  - Balancing problems

2.3

Maintain proper building pressurization
Stack effect



Adapted from Ross, 2004

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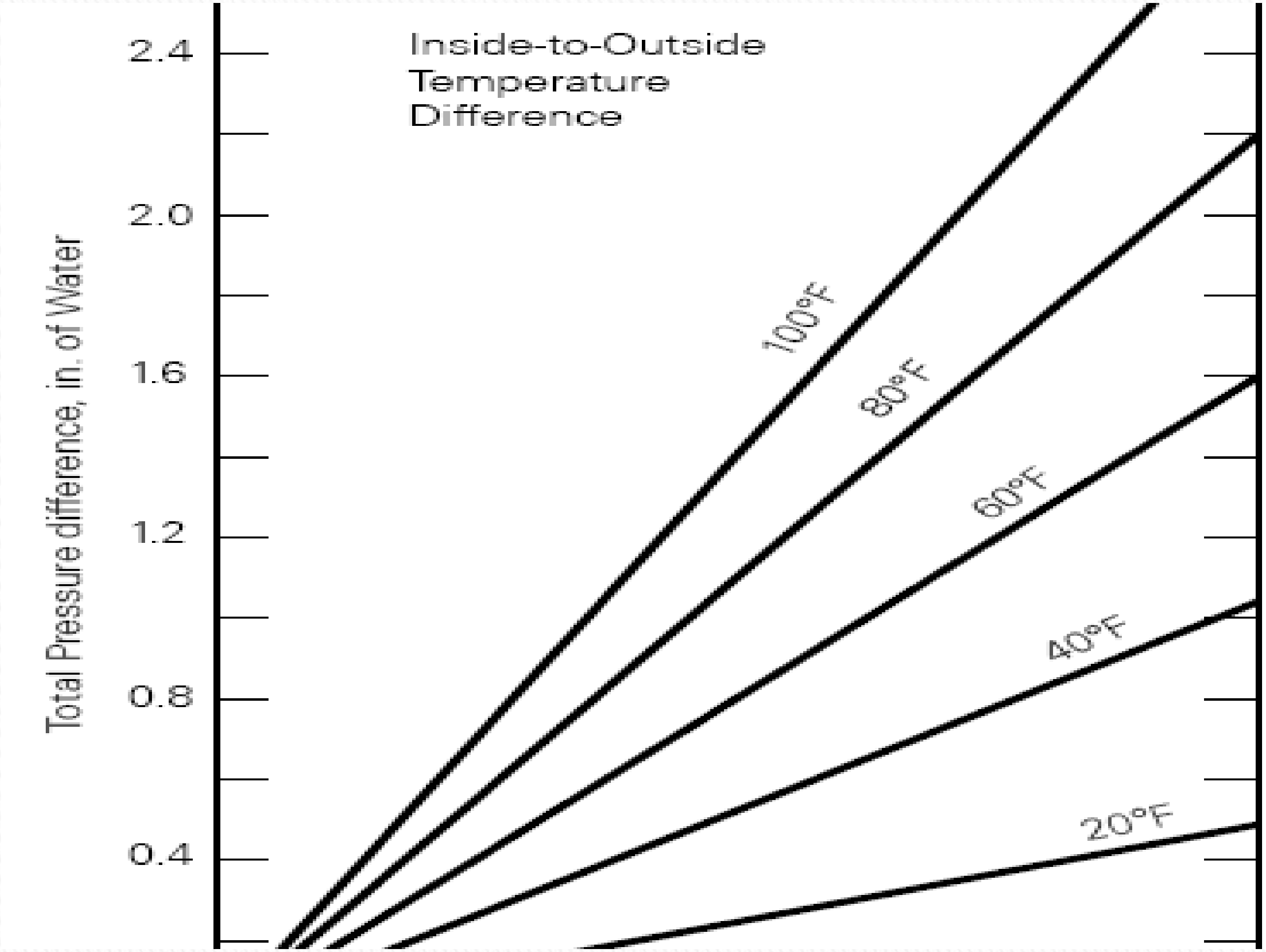
2.3

Maintain proper building pressurization

Stack effect – total pressure difference



Adapted from Wilson & Tamura 1968)

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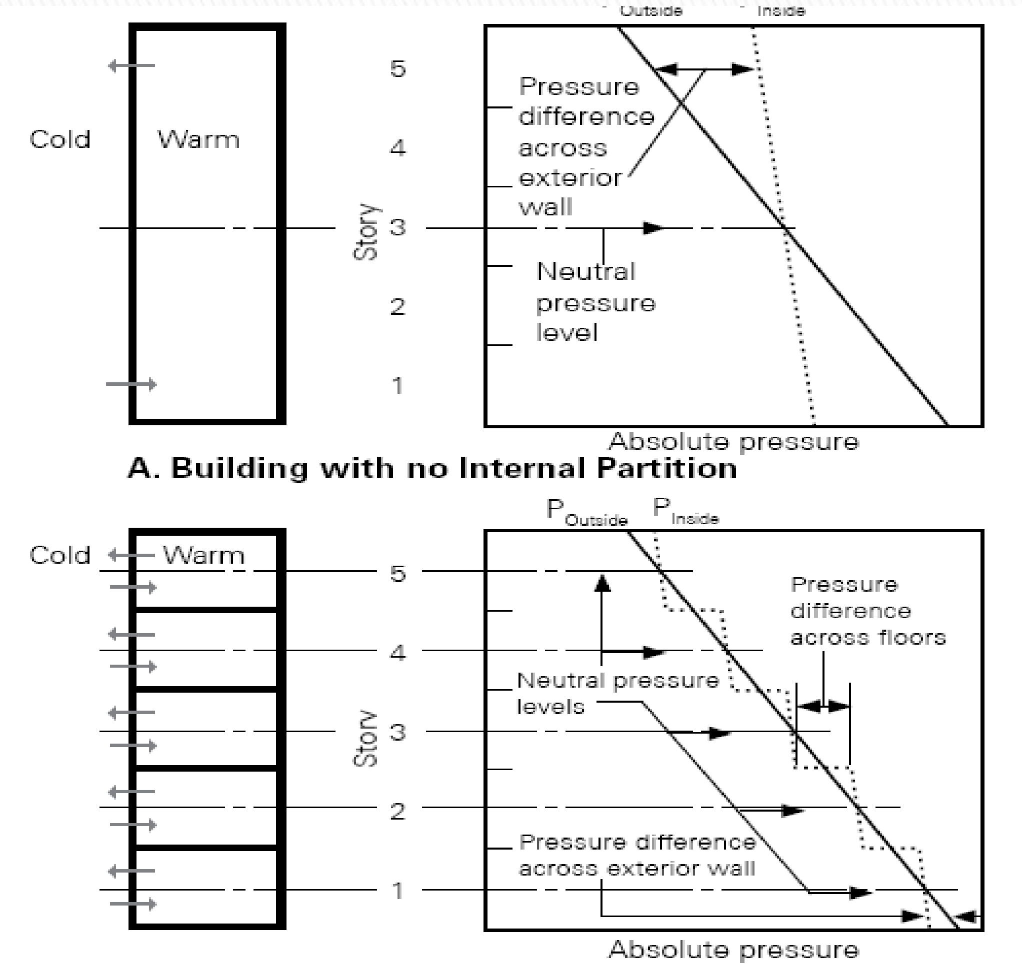
2.3

Maintain proper building pressurization

Compartmentalization (or lack thereof)



Adapted from ASHRAE 2009

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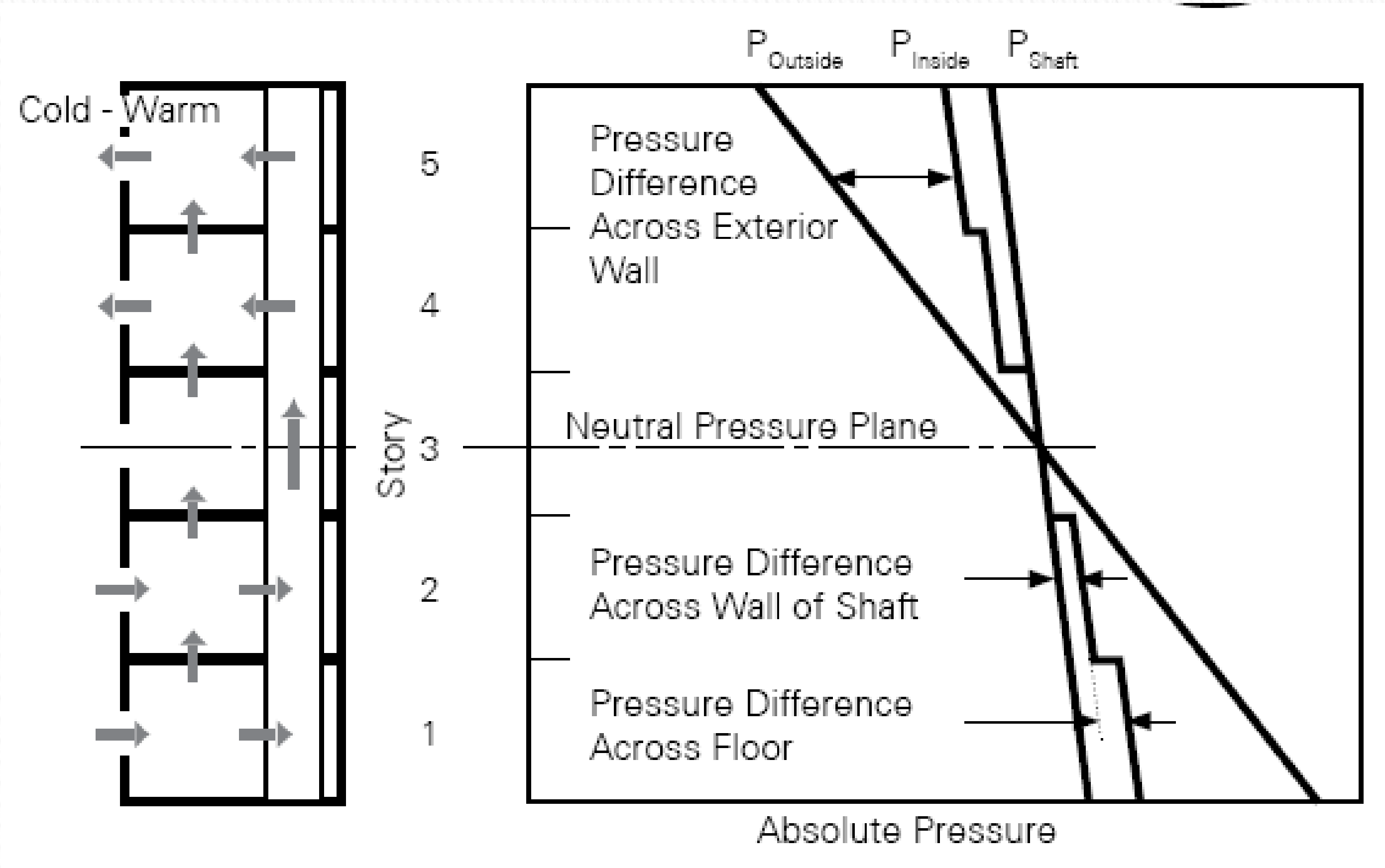
2.3 Maintain proper building pressurization *Typical real building*



Adapted from Wilson & Tamura 1968

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2.3

- Return plenum negatively pressurized with respect to outdoors

Photo courtesy Wagdy Anis

2.3

Maintain proper building pressurization

Exhaust only ventilation of a hotel in hot humid climate

- Vinyl wall covering
- 6 air changes/hr via toilet exhaust
- $5.5M damage before opening

Photo copyright CH2M HILL

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2.3

Maintain proper building pressurization

Solutions

- Building height & orientation
- Building layout
  - Keep negatively pressurized spaces in the interior in humid climates
- Envelope air sealing
- Compartmentalization
  - Multi-story atria (not)
  - Vestibules, revolving doors
  - Air barriers between floors

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2.3

Maintain proper building pressurization

Solutions

- Mechanical system selection, sizing and control
  - Separate AHUs for atria, floors
  - Judicious plenum use/design
  - Avoiding exhaust-only ventilation
  - Direct delivery of OA to exterior zones
  - Sufficient OA capacity for pressurization
  - Building static pressure control

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Objective 3. Limit Entry of Outdoor Contaminants

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Limit Entry of Outdoor Contaminants

- Evaluate regional and local outdoor air quality (3.1)
- Locate OA intakes to minimize introduction of contaminants (3.2)
- Control entry and radon (3.3) and intrusion of vapors from subsurface contaminants (3.4)
- Provide effective track-off systems (3.5)
- Design and build to exclude pests (3.6)

3.1

Investigate regional and local outdoor air quality

KEY POINTS

- Regional pollutants
  - National Ambient Air Quality Standards
- Local pollutants
- Documentation
  - Required by ANSI/ASHRAE Standard 62.1-2007
- Training

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3.1

Investigate regional and local outdoor air quality

ANSI/ASHRAE Standard 62.1-2007 requirements (partial)

4. OUTDOOR AIR QUALITY

Outdoor air quality shall be investigated in accordance with Sections 4.1 and 4.2 prior to completion of ventilation system design. The results of this investigation shall be documented in accordance with Section 4.3.

4.1 Regional Air Quality. The status of compliance with national ambient air quality standards shall be determined for the geographic area of the building site. In the United States, compliance status shall be either in "attainment" or "non-attainment" with the National Ambient Air Quality Standards (NAAQS)[1] for each pollutant shown in Table 4-1. In the United States, areas with no EPA compliance status designation shall be considered "attainment" areas.

4.2 Local Air Quality. An observational survey of the building site and its immediate surroundings shall be conducted during hours the building is expected to be normally occupied to identify local contaminants from surrounding facilities that may be of concern if allowed to enter the building.

4.3 Documentation. Documentation of the outdoor air quality investigation shall be reviewed with building owners or their representative and shall include the following:

1. Regional air quality compliance status.

Note: Regional outdoor air quality compliance status for

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3.1

Investigate regional and local outdoor air quality

National Ambient Air Quality Standards (NAAQS)

- U.S. EPA Green Book
- http://www.epa.gov/air/oaqps/greenbk
- NAAQS particles
  - PM10
  - PM2.5
  - Lead
- NAAQS gases
  - Ozone (O_3)
  - Nitrogen dioxide (NO_2)
  - Sulfur dioxide (SO_2)
  - Carbon monoxide (CO)

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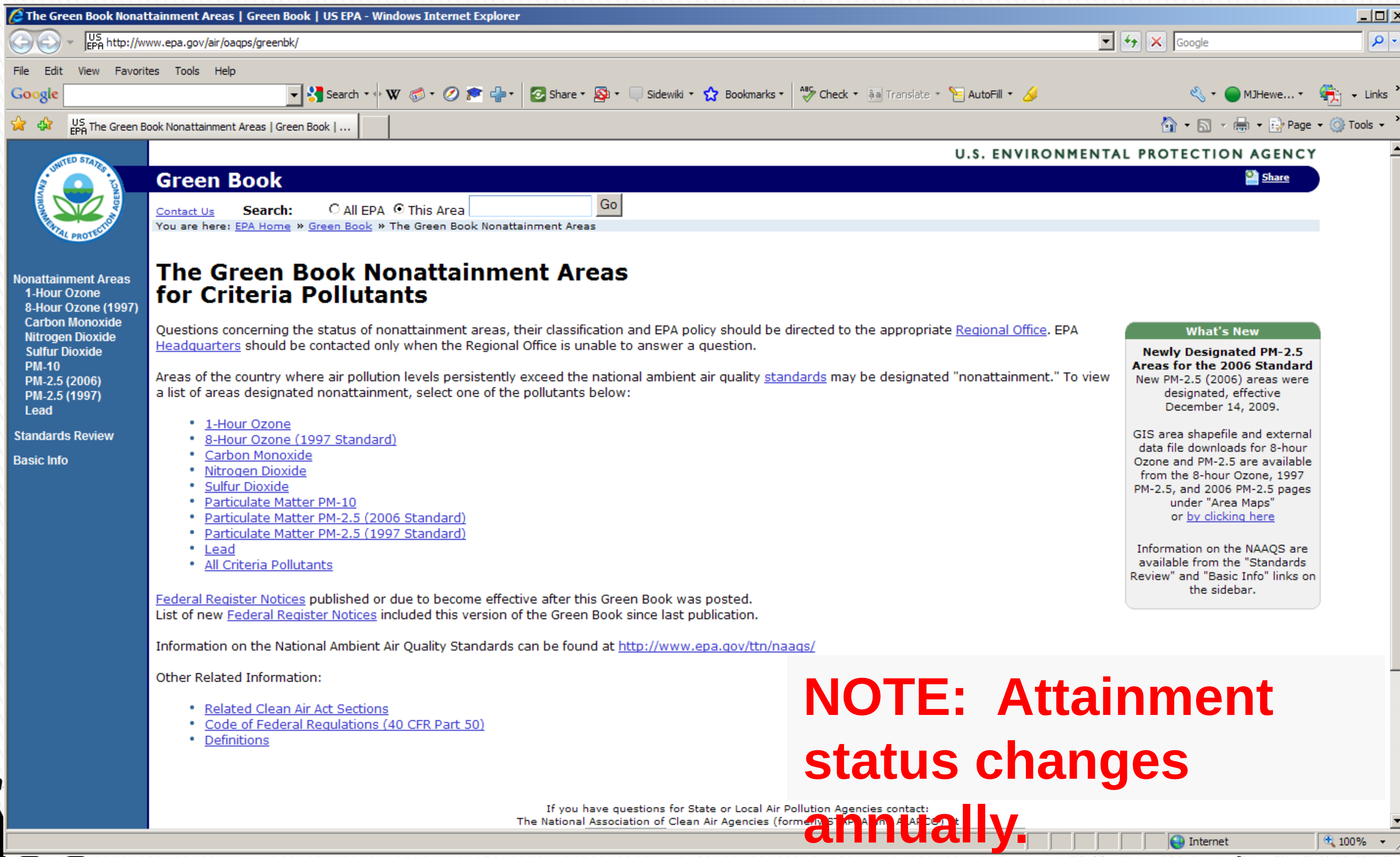
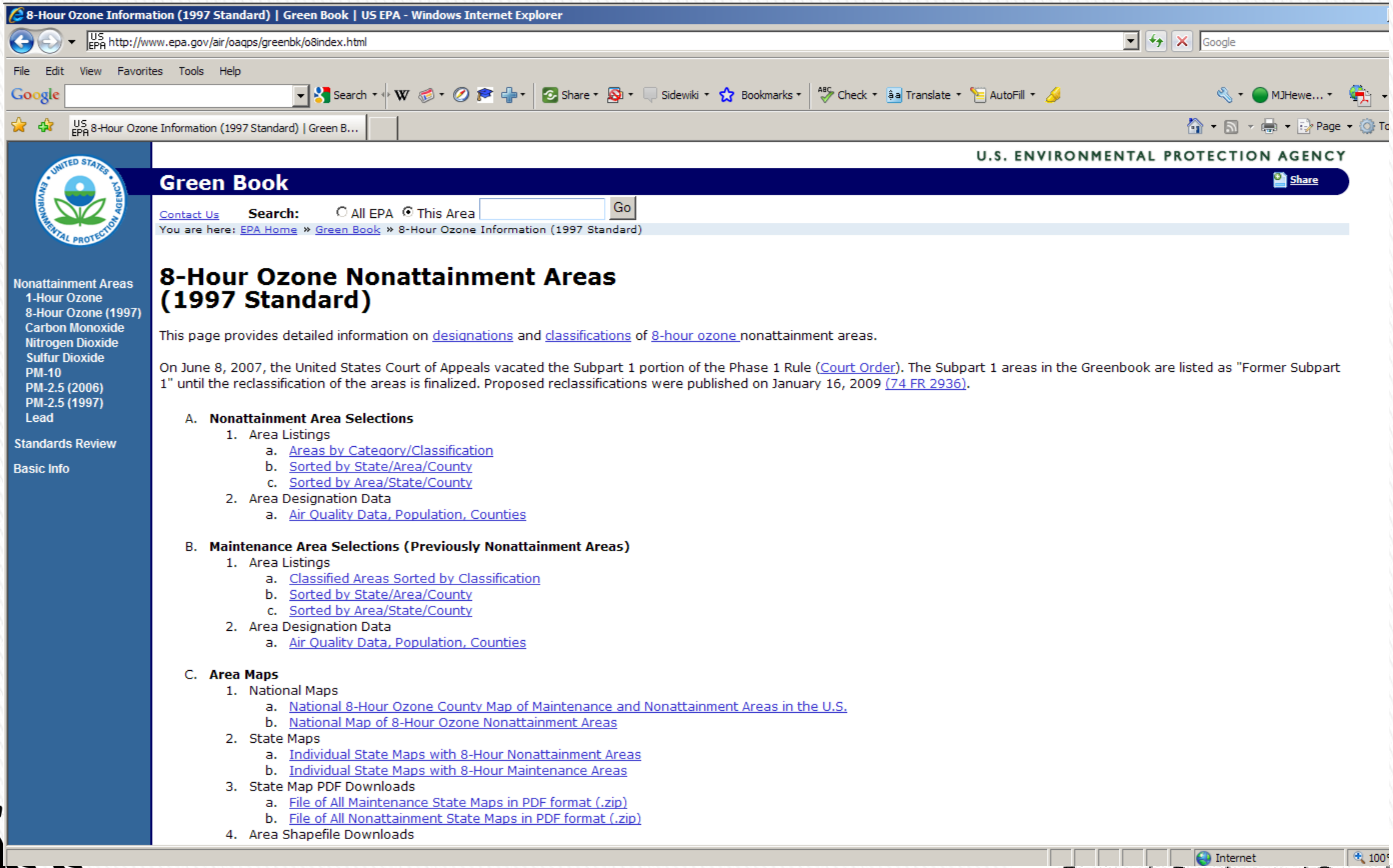
Investigate Regional and Local Outdoor Air Quality *NAAQS – EPA Green Book*



NOTE: Attainment status changes annually.

Investigate Regional and Local Outdoor Air Quality *NAAQS – EPA Green Book*



8-Hour Ozone Information (1997 Standard) | Green Book | US EPA - Windows Internet Explorer

http://www.epa.gov/air/oaqps/greenbk/o8index.html

U.S. ENVIRONMENTAL PROTECTION AGENCY

Green Book

Contact Us   Search: All EPA This Area Go

You are here: EPA Home » Green Book » 8-Hour Ozone Information (1997 Standard)

- Nonattainment Areas
  - 1-Hour Ozone
  - 8-Hour Ozone (1997)
  - Carbon Monoxide
  - Nitrogen Dioxide
  - Sulfur Dioxide
  - PM-10
  - PM-2.5 (2006)
  - PM-2.5 (1997)
  - Lead
- Standards Review
- Basic Info

8-Hour Ozone Nonattainment Areas (1997 Standard)

This page provides detailed information on designations and classifications of 8-hour ozone nonattainment areas.

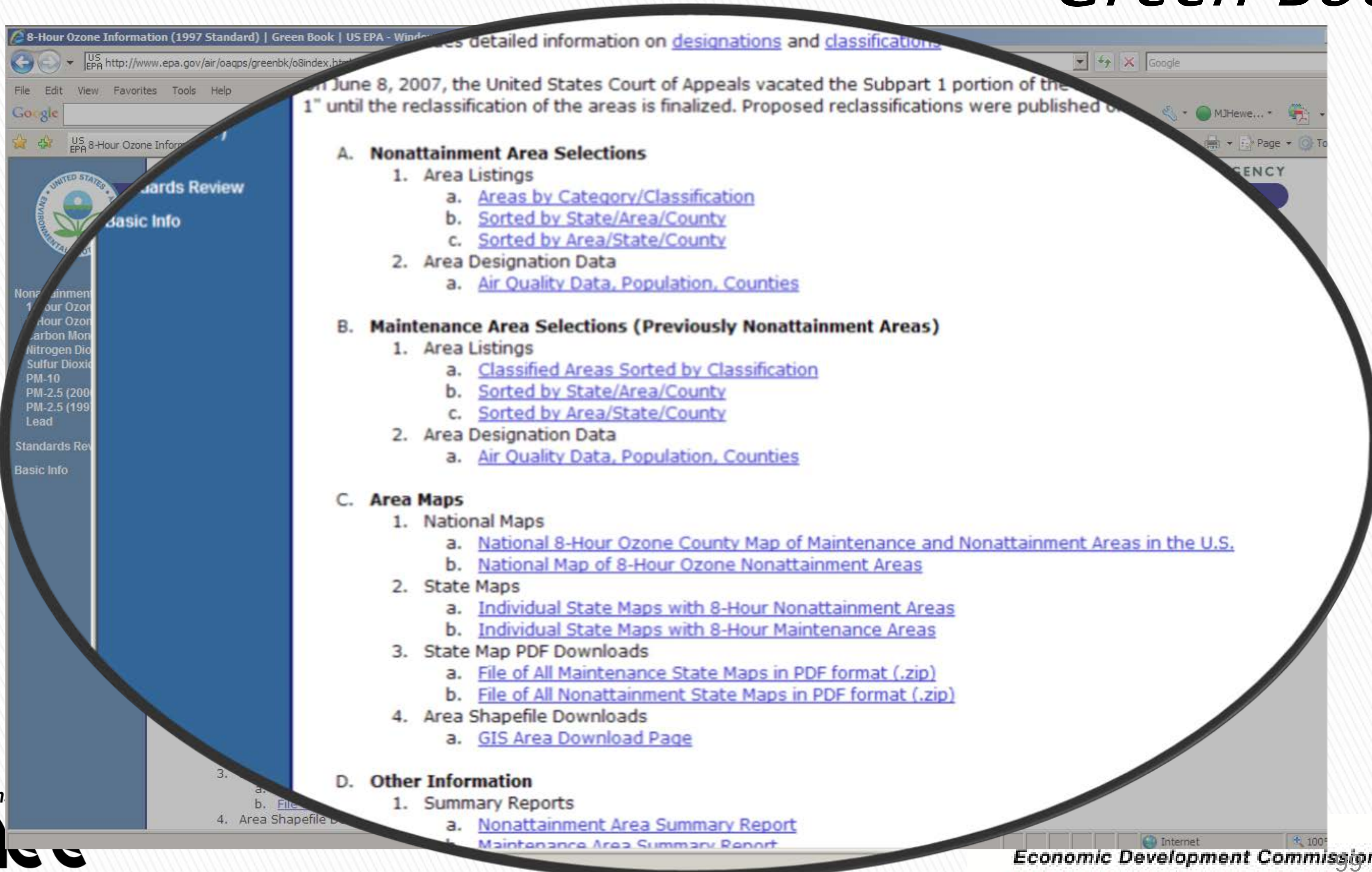
On June 8, 2007, the United States Court of Appeals vacated the Subpart 1 portion of the Phase 1 Rule (Court Order). The Subpart 1 areas in the Greenbook are listed as "Former Subpart 1" until the reclassification of the areas is finalized. Proposed reclassifications were published on January 16, 2009 (74 FR 2936).

A. **Nonattainment Area Selections**
   1. Area Listings
      a. Areas by Category/Classification
      b. Sorted by State/Area/County
      c. Sorted by Area/State/County
   2. Area Designation Data
      a. Air Quality Data, Population, Counties

B. **Maintenance Area Selections (Previously Nonattainment Areas)**
   1. Area Listings
      a. Classified Areas Sorted by Classification
      b. Sorted by State/Area/County
      c. Sorted by Area/State/County
   2. Area Designation Data
      a. Air Quality Data, Population, Counties

C. **Area Maps**
   1. National Maps
      a. National 8-Hour Ozone County Map of Maintenance and Nonattainment Areas in the U.S.
      b. National Map of 8-Hour Ozone Nonattainment Areas
   2. State Maps
      a. Individual State Maps with 8-Hour Nonattainment Areas
      b. Individual State Maps with 8-Hour Maintenance Areas
   3. State Map PDF Downloads
      a. File of All Maintenance State Maps in PDF format (.zip)
      b. File of All Nonattainment State Maps in PDF format (.zip)
   4. Area Shapefile Downloads

Investigate Regional and Local Outdoor Air Quality *NAAQS – EPA Green Book*



8-Hour Ozone Information (1997 Standard) | Green Book | US EPA

http://www.epa.gov/air/oaqps/greenbk/o8index.html

...es detailed information on designations and classifications

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      a. Individual State Maps with 8-Hour Nonattainment Areas
      b. Individual State Maps with 8-Hour Maintenance Areas
   3. State Map PDF Downloads
      a. File of All Maintenance State Maps in PDF format (.zip)
      b. File of All Nonattainment State Maps in PDF format (.zip)
   4. Area Shapefile Downloads
      a. GIS Area Download Page

D. **Other Information**
   1. Summary Reports
      a. Nonattainment Area Summary Report
      b. Maintenance Area Summary Report

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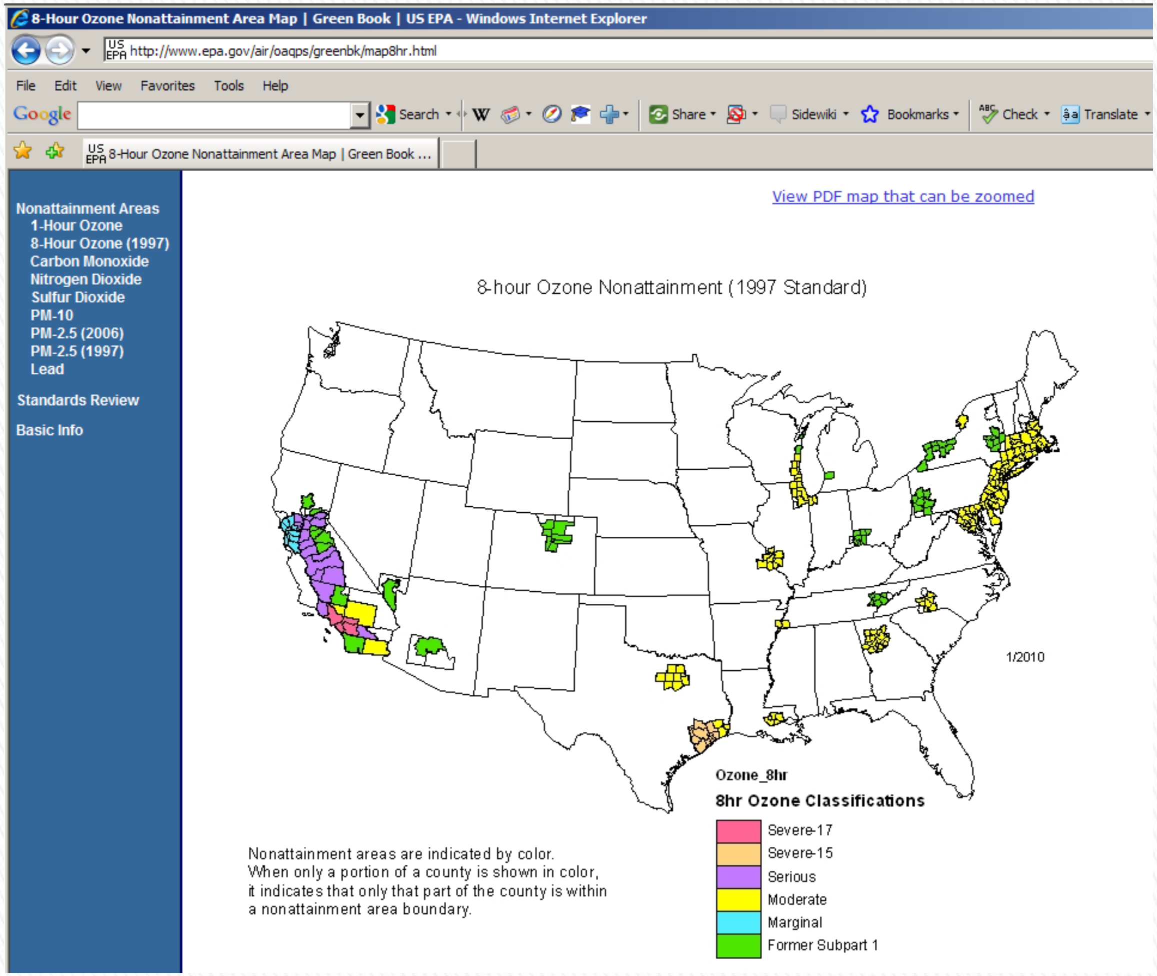
3.1

Investigate regional and local outdoor air quality

NAAQS – EPA Green Book national maps



http://www.epa.gov/air/oaqps/greenbk/map8hr.html

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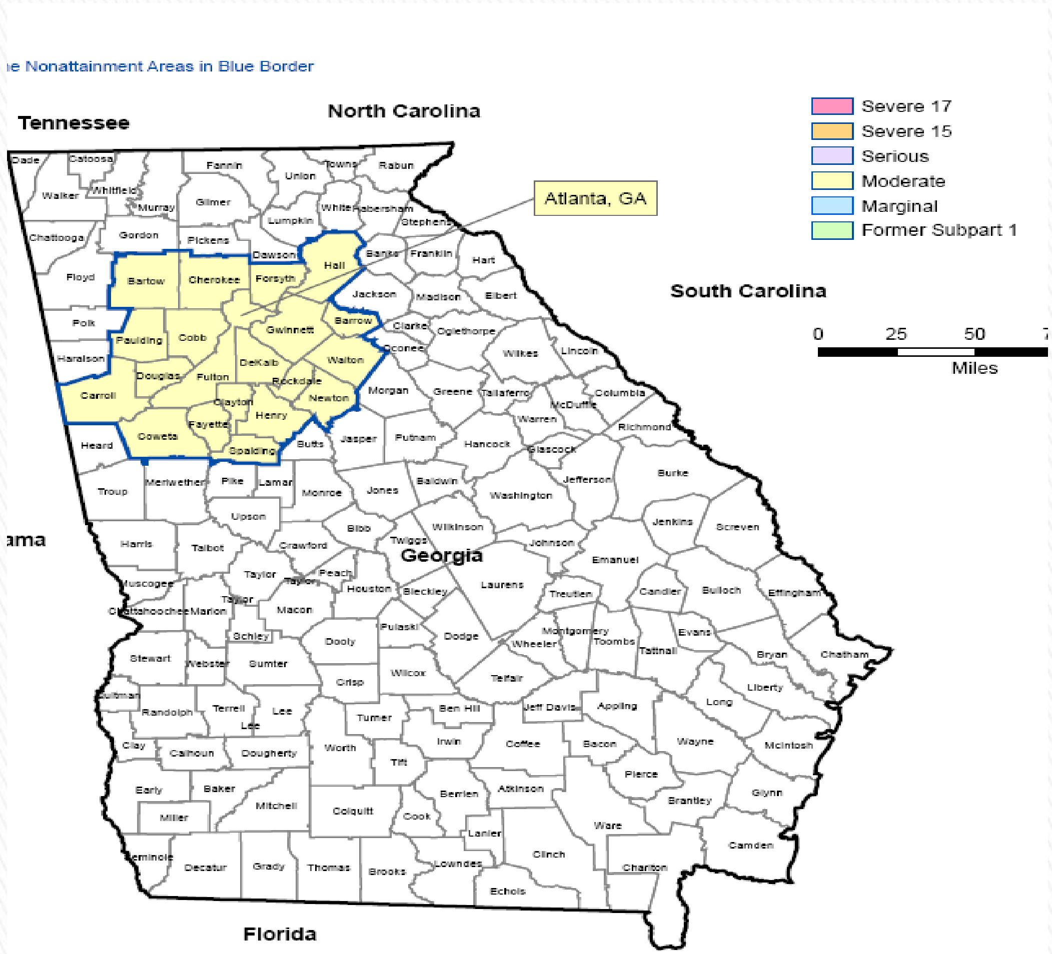
3.1

Investigate regional and local outdoor air quality

NAAQS – EPA Green Book state maps



http://www.epa.gov/air/oaqps/greenbk/ga8.html

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Health Effects

3.1

Investigate regional and local outdoor air quality

PM 2.5 and 10

- Increased respiratory symptoms; e.g., irritation of the airways, coughing, or difficulty breathing
- Decreased lung function
- Aggravated asthma
- Development of chronic bronchitis
- Irregular heartbeat
- Nonfatal heart attacks
- Premature death in people with heart or lung disease

(http://epa.gov/air/particlepollution/health.html)

3.1

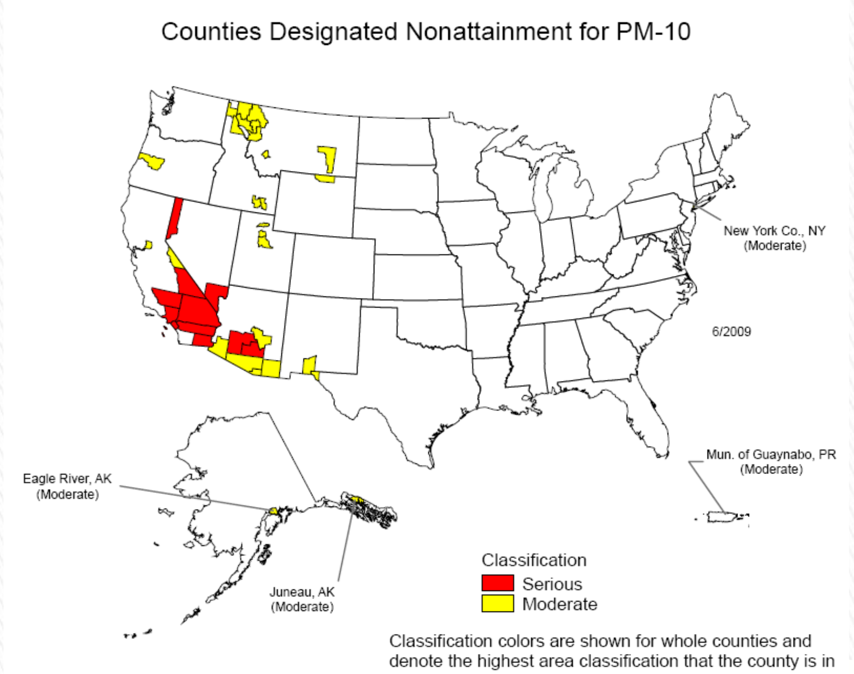
Investigate regional and local outdoor air quality

PM10

40 counties, 25.5M people: 8% of U.S. population

http://www.epa.gov/air/oaqps/greenbk/mappm10.pdf

- Standard 62.1-2007 requires MERV 6 filters in PM10 non-attainment areas [and upstream of all cooling coils or other wetted surfaces through which air is supplied to an occupiable space].
- Standard 189.1 requires MERV 8 upstream of coils/wetted surfaces.
- Higher MERVs will provide greater removal efficiency.



3.1

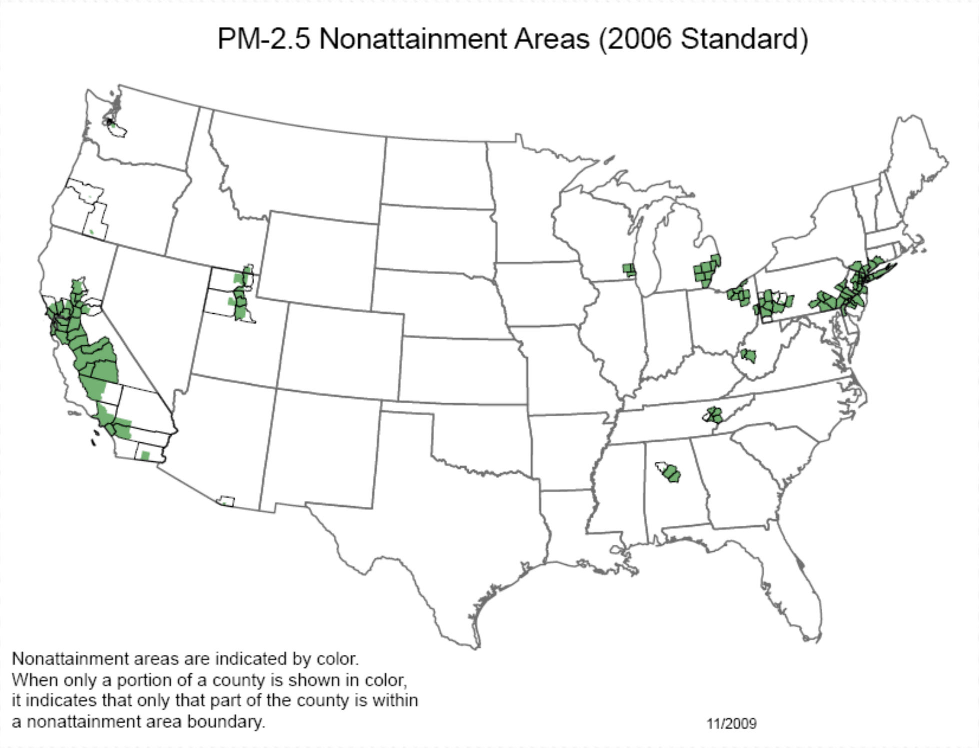
Investigate regional and local outdoor air quality

PM2.5

120 counties, 70.2M people: 23% of U.S. population

http://www.epa.gov/air/oaqps/greenbk/mappm25_2006.pdf

- Must have MERV 9 or higher filters to have any effective removal
- MERV 11 or more much more effective
- Standard 189.1 requires MERV 13 in PM2.5 non-attainment areas



3.1

Investigate regional and local outdoor air quality

Lead

2 counties, 4700 people

- Neurological & cardiovascular
- Solid: separate particle or attached to other particles
- Can be removed by filters that remove small particles

3.1

Investigate regional and local outdoor air quality

Ground-level ozone

What is it?

- Primary constituent of smog
- Formed by photochemical reaction; requires:
  - sunlight
  - warm temperatures
  - nitrogen oxides (NOx)
  - photochemically reactive VOCs
- Reacts with trace VOCs in the indoor environment to create reaction products that may be even more toxic

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3.1

Investigate regional and local outdoor air quality

Ground-level ozone

Health effects

http://epa.gov/air/ozonepollution/health.html

Health Effects of Ozone Itself

- Airway irritation, coughing, pain when taking a deep breath
- Wheezing and breathing difficulties during exercise or outdoor activities
- Inflammation, much like a sunburn on the skin
- Aggravation of asthma and increased susceptibility to respiratory illnesses like pneumonia and bronchitis
- Permanent lung damage with repeated exposures

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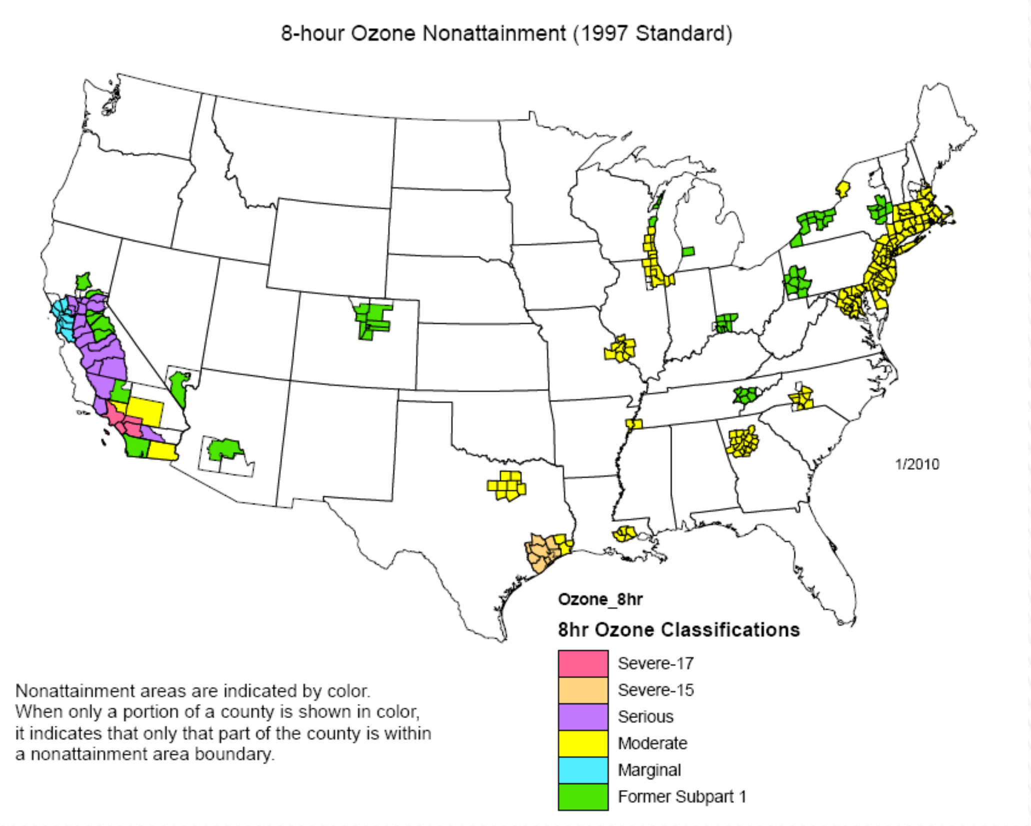
3.1

Investigate regional and local outdoor air quality

Ground-level ozone

266 counties, 122M people: 40% of U.S. population



http://www.epa.gov/air/oaqps/greenbk/map8hr.pdf

- Note: peaks in ozone “maintenance” areas also affect indoor environment

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3.1

Investigate regional and local outdoor air quality

Ground level ozone Removal

- Standard 62.1-2007 requires air-cleaning devices with 40% removal efficiency for ozone when the 2nd highest daily one-hour average concentration exceeds 0.16 ppm, with some exceptions
- Standard 189.1-2009 requires air cleaning devices for ozone when the building is in a non-attainment area

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3.1

Investigate regional and local outdoor air quality

Ground level ozone Removal

- Can be removed by carbon or other sorbent filters that cause ozone to react on their surface
- Good quality air cleaner can provide control for an entire ozone season in many areas
- Ozone filter should be protected by a high-quality particle filter; otherwise blinding of the sorbent by dirt can prevent the filter from working

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3.1

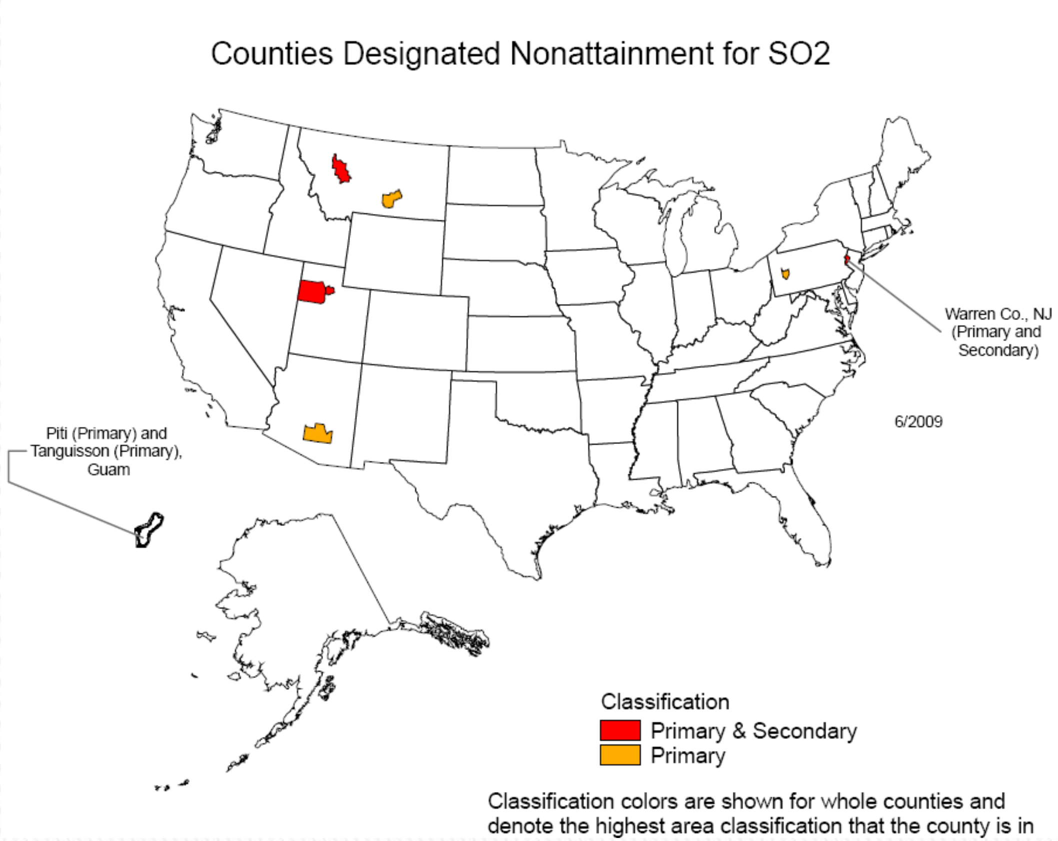
Investigate regional and local outdoor air quality

Sulfur dioxide

9 counties, 1.1M people

- Respiratory effects from short-term exposure, especially for children, elderly, asthmatics

http://epa.gov/air/sulfurdioxide/health.html



http://www.epa.gov/air/oaqps/greenbk/mapso2.pdf

3.1

Investigate regional and local outdoor air quality

Sulfur dioxide Removal

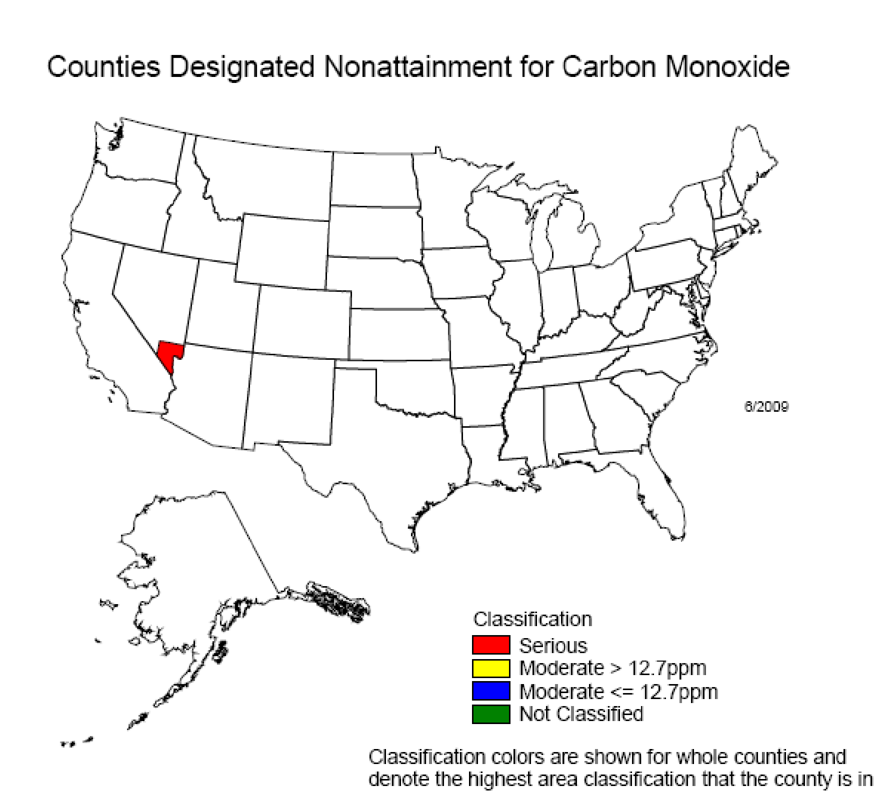
- Gas phase air cleaning (e.g., activated alumina/$KMnO_4$)
- Air cleaner should be protected by particle filter to prevent blinding of sorption sites
- Life of cleaner depends on concentration of SO_2 and other sorbed compounds

3.1

- Cardiovascular and nervous system effects
- No room temp removal technology
- Control by scheduling of activities and ventilation system operation, selection of outdoor air intake location

Investigate regional and local outdoor air quality

Carbon monoxide
1 county
480,000 people



http://www.epa.gov/air/oaqps/greenbk/mapco.pdf

3.1

Investigate regional and local outdoor air quality

Additional local pollutants

- Airborne dust
  - Agricultural, desert areas, some industrial areas, high pollen areas
  - Focus on dust-holding capability
- VOCs
  - Traffic, industrial, wastewater lagoons, etc.
  - Filtration and air cleaning
- Odors
  - Air cleaning

3.1

Required by ANSI/ASHRAE 62.1-2007

Investigate regional and local outdoor air quality

Documentation and training

Particulates (PM2.5)	(Yes/No)
Particulates (PM10)	(Yes/No)
Carbon monoxide—1 hour/8 hours	(Yes/No)
Ozone	(Yes/No)
Nitrogen dioxide	(Yes/No)
Lead	(Yes/No)
Sulfur dioxide	(Yes/No)

Local Outdoor Air Quality Survey	Date:	Time:
a) Area surveyed	(Brief description of site)	
b) Nearby facilities	(Brief description type of facilities—industrial, commercial, hospitality, etc.)	
c) Odors or irritants	(List and describe)	
d) Visible plumes	(List and describe)	
e) Nearby sources of vehicle exhaust	(List and describe)	
f) Prevailing winds	(Direction)	
g) Other observations		
Conclusions	(Remarks concerning the acceptability of outdoor air quality)	

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3.2

Locate OA intakes to minimize introduction of contaminants

KEY POINTS

- Codes and standards are minimums – more is better
- ANSI/ASHRAE 62.1-2007 generally requires greater distances and covers more sources than codes
- Consider implications for OA intake locations when selecting HVAC system types

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3.2 Locate OA intakes to minimize introduction of contaminants

ANSI/ASHRAE 62.1-2007 requirements

Object	Minimum Distance, ft (m)
Significantly contaminated exhaust (Note 1)	15 (5)
Noxious or dangerous exhaust (Notes 2 and 3)	30 (10)
Vents, chimneys, and flues from combustion appliances and equipment (Note 4)	15 (5)
Garage entry, automobile loading area, or drive-in queue (Note 5)	15 (5)
Truck loading area or dock, bus parking/idling area (Note 5)	25 (7.5)
Driveway, street, or parking place (Note 5)	5 (1.5)
Thoroughfare with high traffic volume	25 (7.5)
Roof, landscaped grade, or other surface directly below intake (Notes 6 and 7)	1 (0.3)
Garbage storage/pick-up area, dumpsters	15 (5)
Cooling tower intake or basin	15 (5)
Cooling tower exhaust	25 (7.5)

Stretched string distance between closest points

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3.2

Example – Cooling Tower Exhaust

Locate OA intakes to minimize introduction of contaminants

Codes and standards are minimums

- IMC: 5 ft above or 20 ft away
- ANSI/ASHRAE 62.1-2007: 25 ft stretched string distance
- 18,000 cases of Legionnaire's disease in the U.S. annually; 4000-5000 fatalities
- *Legionella* also causes Pontiac fever
- Documented cases of *Legionella* traveling hundreds of feet

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3.2

Locate OA intakes

Example:

Drift from cooling tower with clean-looking, treated basin causes Legionnaires' Disease in 3 workers from neighboring building (~330 ft)

3.2

Locate OA intakes

Example:

Cooling tower exhaust within 20 ft of OA intake. Shroud added to protect intake.

Photos courtesy Leon Alevantis

3.2

Locate OA intakes to minimize introduction of contaminants

Example:

OA intake downwind of and close to toilet exhaust

Photo courtesy Hal Levin

3.2

Locate OA intakes to minimize introduction of contaminants

Consider OA intake locations in system selection

Systems with OA intakes close to the ground may get clogged (!) and encourage introduction of dirt (food for microbes), mold, pesticides, herbicides, fertilizers, vehicle exhaust, etc.

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Objective 4. control moisture and contaminants related to mechanical systems

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Control Moisture and Contaminants Related to Mechanical Systems

- Control moisture and dirt in air handling systems (4.1)
- Control moisture associated with piping, plumbing fixtures and ductwork (4.2)
- Facilitate access for inspection, cleaning and maintenance (4.3)
- Control *Legionella* in water systems (4.4)

4.1

Control moisture and dirt in air handling systems

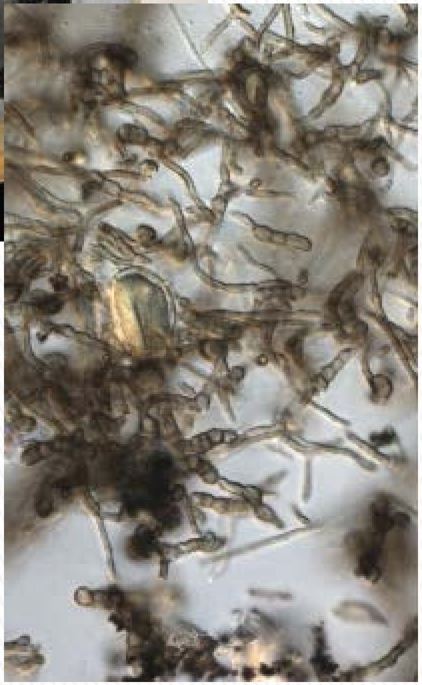
KEY POINTS

- Moisture + dirt (food) = critters
- Minimize entry of moisture and dirt at air intakes and areaways
- Use higher efficiency filtration to keep systems clean; keep filters dry
- Make sure drain pans drain
- Minimize condensate carryover
- Provide smooth, cleanable surfaces
- Select humidifiers to avoid carryover of microbes in water droplets

4.1

Control moisture and dirt in air handling systems

Moisture + dirt = critters



~400x

Photos courtesy Phil Morey

4.1

Control moisture and dirt in air handling systems

OA intakes and intake areaways

- Minimize rain and snow intrusion
- Recognize that below-grade and grade level OA intakes are most susceptible to entry of leaves, pesticides, fertilizers, etc.
- If below-grade or grade level intakes are used, provide easy access for cleaning
- Provide smooth, corrosion-resistant, cleanable OA intakes

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4.1

Control moisture and dirt in air handling systems

Filtration

- Dust = food for microbes
- Std. 62.1-2007 – MERV 6 upstream of coils;
  Std. 189.1-2009 – MERV 8
- High efficiency filtration helps keep food out of wet biological niches in HVAC systems (MERV 11 good, MERV 13 better)
- Locate filters where they will stay dry, and provide for periodic inspections (O&M) to ensure they stay dry

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4.1

Control moisture and dirt in air handling systems

Filtration

- Dirty coil – not protected by adequate filtration

Photo courtesy Center for Energy & Environment

4.1

Control moisture and dirt in air handling systems

Drain pans

- Make sure drain pans drain
  - Slope 0.125 in./ft; make sure AHUs with integral pan are level so pan slopes as intended
  - Drain hole at lowest point flush with bottom
  - P-trap deep enough to maintain seal and allow water to drain under maximum negative pressure created by fan
  - Verify proper drainage through commissioning
  - Train operators to locate, properly inspect (slimy?) and physically clean pans

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4.1 Control moisture and dirt in air handling systems *Drain pans*

Trap depth

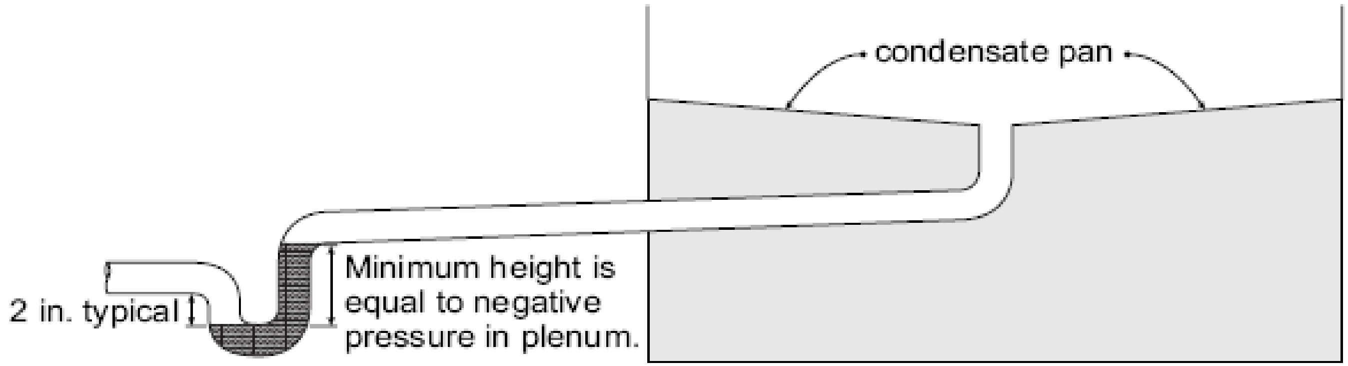

Figure 5-T—

ANSI/ASHRAE Standard 62.1-2007 Users Manual

4.1

Control moisture and dirt in air handling systems

Drain pans: Example

- Drain pan inspected due to building- related symptoms and illnesses in area served
- Poor access (10 fasteners)
- Outlet not flush w/bottom
- Biofilm – gelatinous mass of fungi, bacteria and protozoa

Photo courtesy Phil Morey

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4.1

Control moisture and dirt in air handling systems

Drain pan: Condensate carryover

- Wide enough to collect water droplets across entire width
- Extend downstream at least half the height of the coil
- Extend as far as necessary to limit carryover to 1.5 ml/m^2 (!) per hour under peak conditions (0.0044 oz/ft^2)
- High face velocity causes carryover: with non-uniform airflow, local face velocity far exceeds average

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4.1

Control moisture and dirt in air handling systems *Drain pan: Condensate carryover*

Photos courtesy Center for Energy & Environment

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4.1

- Critters can grow on smooth but dirty surfaces, but growth is usually greatest on porous or irregular surfaces

Control moisture and dirt in air handling systems

Smooth, cleanable surfaces

Photo courtesy Phil Morey

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4.1

Control moisture and dirt in air handling systems

Smooth, cleanable surfaces

- Consider acoustic solutions that don't require porous liners
  - Equipment selection, sizing and location
  - Proper air distribution design: sizing, velocity, fabrication integrity, diffuser selection
  - Double-wall ductwork

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4.1

Control moisture and dirt in air handling systems

Humidifiers

- Water droplets aerosolized from sumps are heavily colonized
- Aerosolize molecules, not droplets
- Use potable water; (Note: boiler water contains corrosion inhibiters)
- Use smooth, cleanable surfaces within the moisture-absorbing distance

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Objective 5. Limit Contaminants from Indoor Sources

Limit Contaminants from Indoor Sources

- Select appropriate materials (5.1)
- Limit the impact of emissions (5.2)
- Minimize IAQ impacts associated with cleaning and maintenance (5.3)

6. Capture and Exhaust Contaminants from building equipment and activities

Capture and Exhaust Contaminants

- Properly vented combustion equipment (6.1)
- Provide local capture and exhaust for point sources (6.2)
- Design exhaust systems to prevent leakage of exhaust into occupied spaces or air distribution systems (6.3)
- Maintain proper pressure relationships between spaces (6.4)

7. Reduce Contaminant concentrations thru Ventilation, filtration and air cleaning

»

Reduce Contaminants Thru Ventilation, Filtration and Air Cleaning

- Provide appropriate OA for each room or zone (7.1)
- Continuously monitor and control OA (7.2)
- Effectively distribute OA to the breathing zone (7.3)
- Effectively distribute OA to multiple spaces (7.4)
- Provide particle filtration and gas phase air cleaning consistent with project IAQ objectives (7.5)
- Provide comfort conditions that enhance occupant satisfaction (7.6)

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7.2

Continuously monitor and control OA delivery

KEY POINTS

- Setting fixed minimum OA damper position and other indirect methods are inaccurate
- Direct methods can be accurate if applied properly
- Providing enough OA at the intake may not be sufficient
- Verify OA flow thru Cx
- Provide documentation and training

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7.2

Continuously monitor and control OA delivery

Use of fixed minimum damper position

- Still the most common method
- Not accurate
  - Pct damper position <> pct OA
  - Damper position not repeatable due to mechanical play & wear
  - DP across opening varies with wind, etc.
- Careful balancing, Cx and periodic RCx warranted if used

7.2

Continuously monitor and control OA delivery

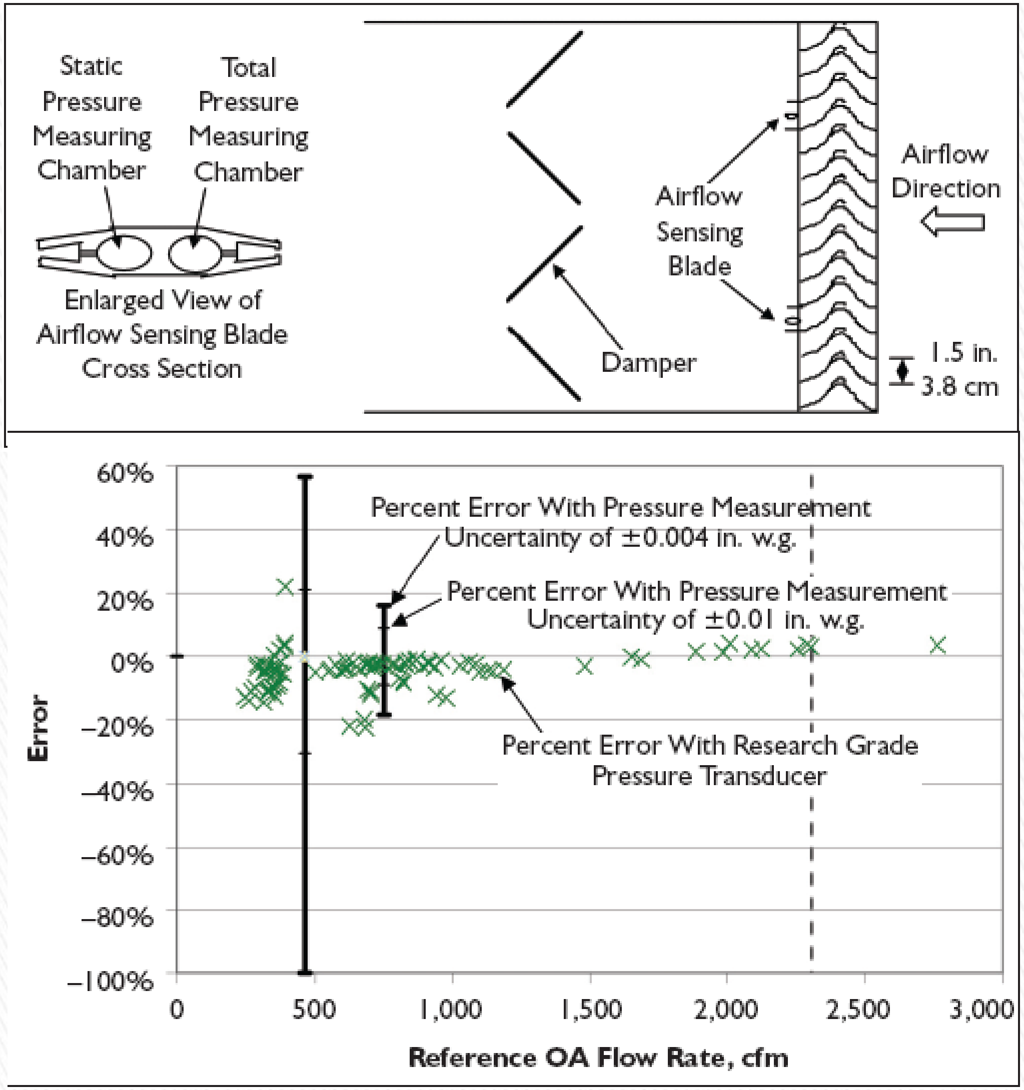
Direct measurement

- Long, straight duct runs optimal but rarely possible
  - 7-½ hydraulic diameters upstream of AFMS, 3 hydraulic diameters downstream
- Louver velocities are kept low to minimize entrainment of rain & snow (400-1000 fpm)
- Louvers often sized for max flow with economizer operation
- Velocity pressure low at max flow and very low at minimum OA
- Use separate minimum OA duct or non-pressure based air flow measurement technology

7.2

Continuously monitor and control OA delivery

Direct measurement accuracy example 1: Airflow sensing blades downstream of louver blades

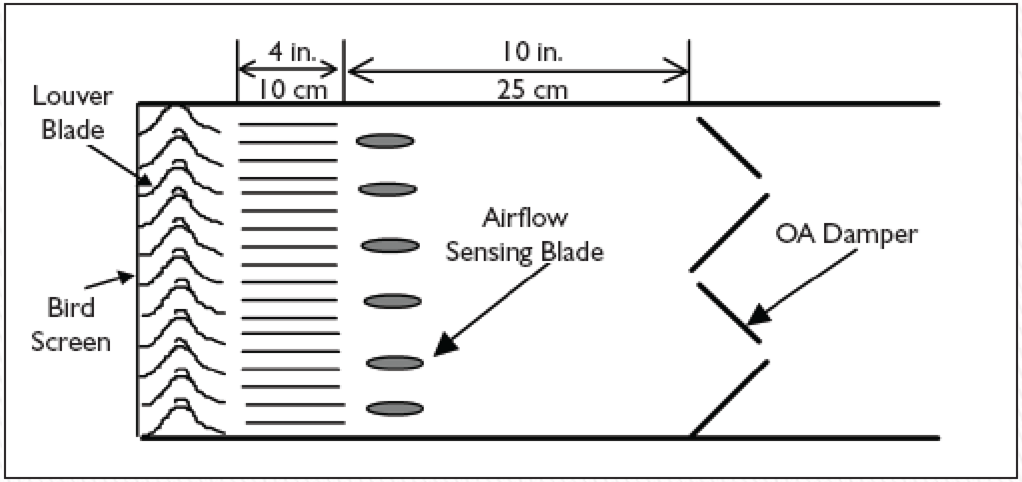


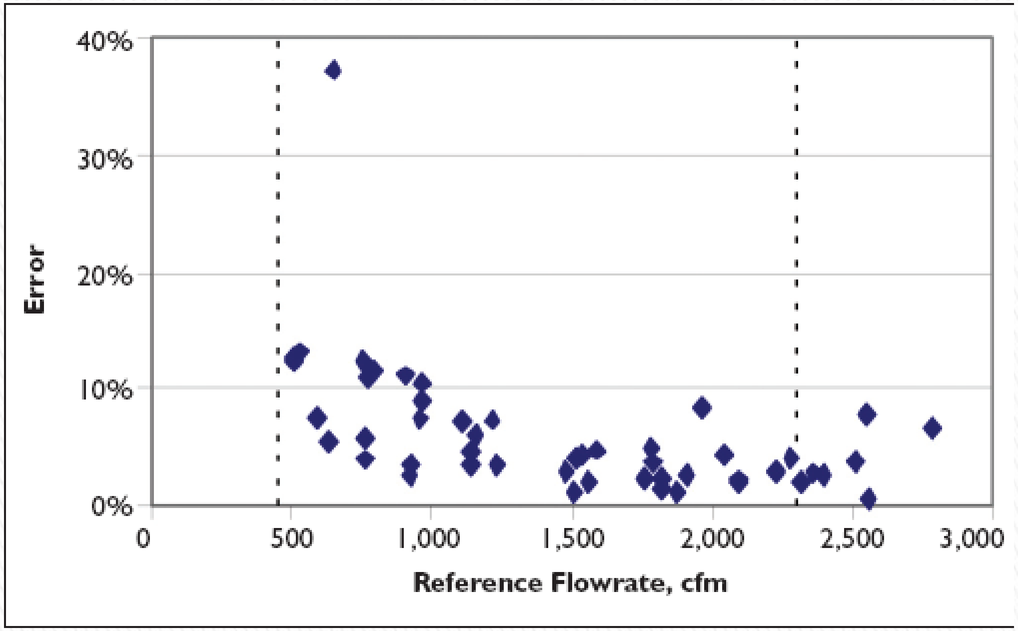
Fisk et al. ASHRAE Journal August 2006

7.2

Continuously monitor and control OA delivery

Direct measurement accuracy example 2: Honeycomb airflow straightener upstream of airflow sensing blades & straight duct section





Fisk, *et al. ASHRAE Journal,* August 2006

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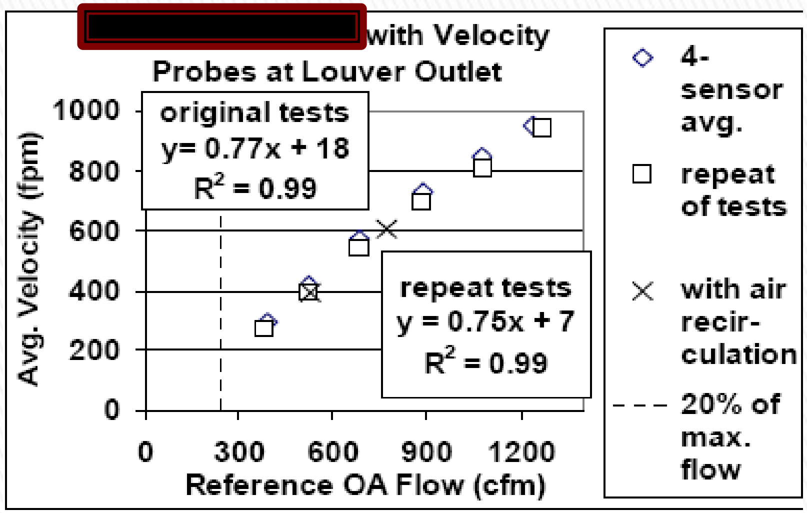
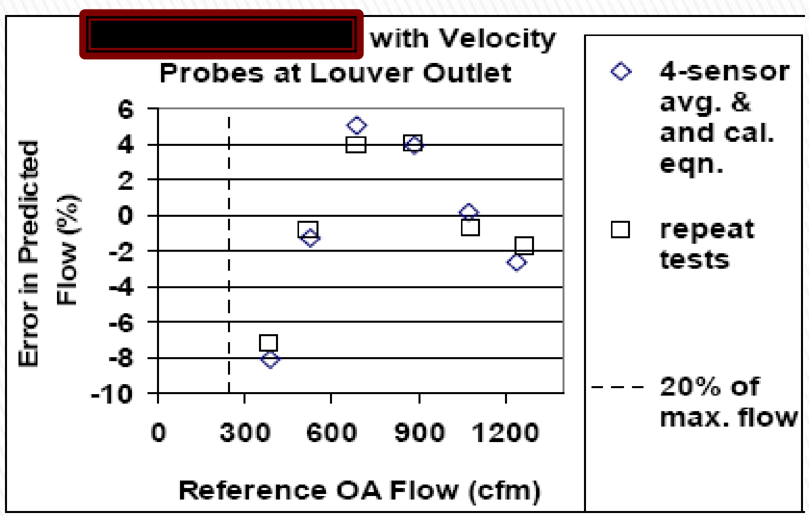
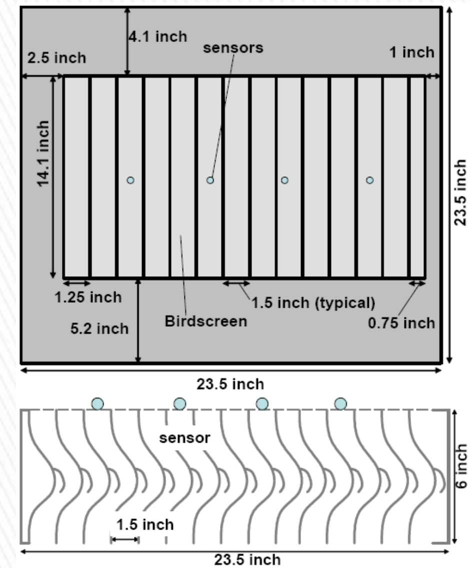
7.2

Continuously monitor and control OA delivery

Direct measurement accuracy example 3: Electronic air velocity probes between blades or on outlet face







From Fisk and Sullivan 2008

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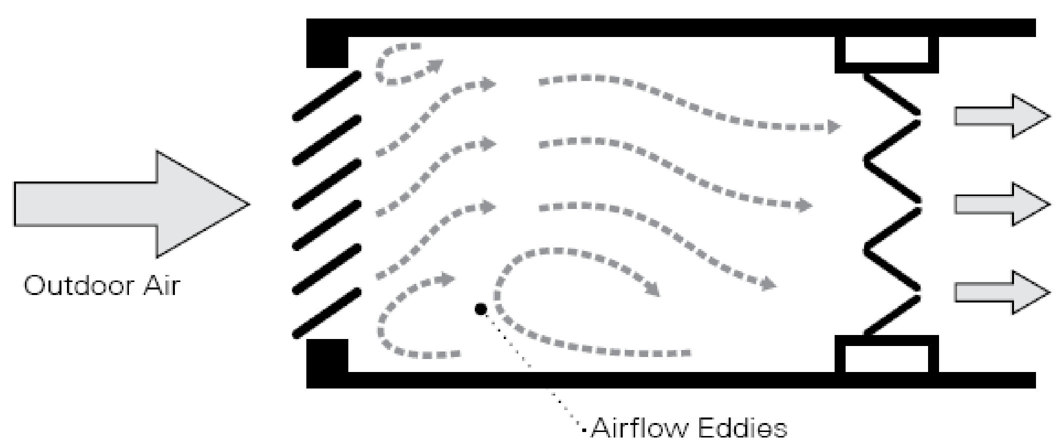
7.2

Continuously monitor and control OA delivery

Sensor location

Sensors installed between fixed louvers or on their outlet face may see higher, more uniform velocities and fewer eddies than sensors placed between louvers and dampers even with flow straightening device



Fisk, *et al.* 2005

7.2

Continuously monitor and control OA delivery

Indirect methods – generally inaccurate

- Plenum pressure control,
- Supply air flow plus CO_2 concentration balance
- Supply air flow plus temp–based energy balance
- Supply flow minus return flow
- Return fan tracking supply fan (VFDs)
- Fixed minimum damper position

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7.2

Continuously monitor and control OA delivery

System considerations

- Continuous monitoring at OA intake alone does not ensure proper OA delivery to breathing zone in each space
  - Poor mixing in mixed air chamber
  - Poor mixing in space

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7.2

Continuously monitor and control OA delivery

Verification, documentation, training

- Verify minimum OA flows during Cx and occupancy
- Provide easy access to sensors
- Provide hardware and software that can sense sensor and equipment malfunctions
- Document design criteria and occupancy assumptions
- Train staff re: O&M needs

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7.5

Provide particle and gas-phase air cleaning consistent with project IAQ objectives

KEY POINTS

- Consider FAC early
- Select FAC appropriate to IAQ objectives, e.g.
  - Keep ducts, coils cleaner
  - Reduce ozone
- Put the air through the filter
- Consider life-cycle costs
- Don't forget process issues
  - Construction storage and filtration
  - Documentation of rationale for owner
  - Operator training

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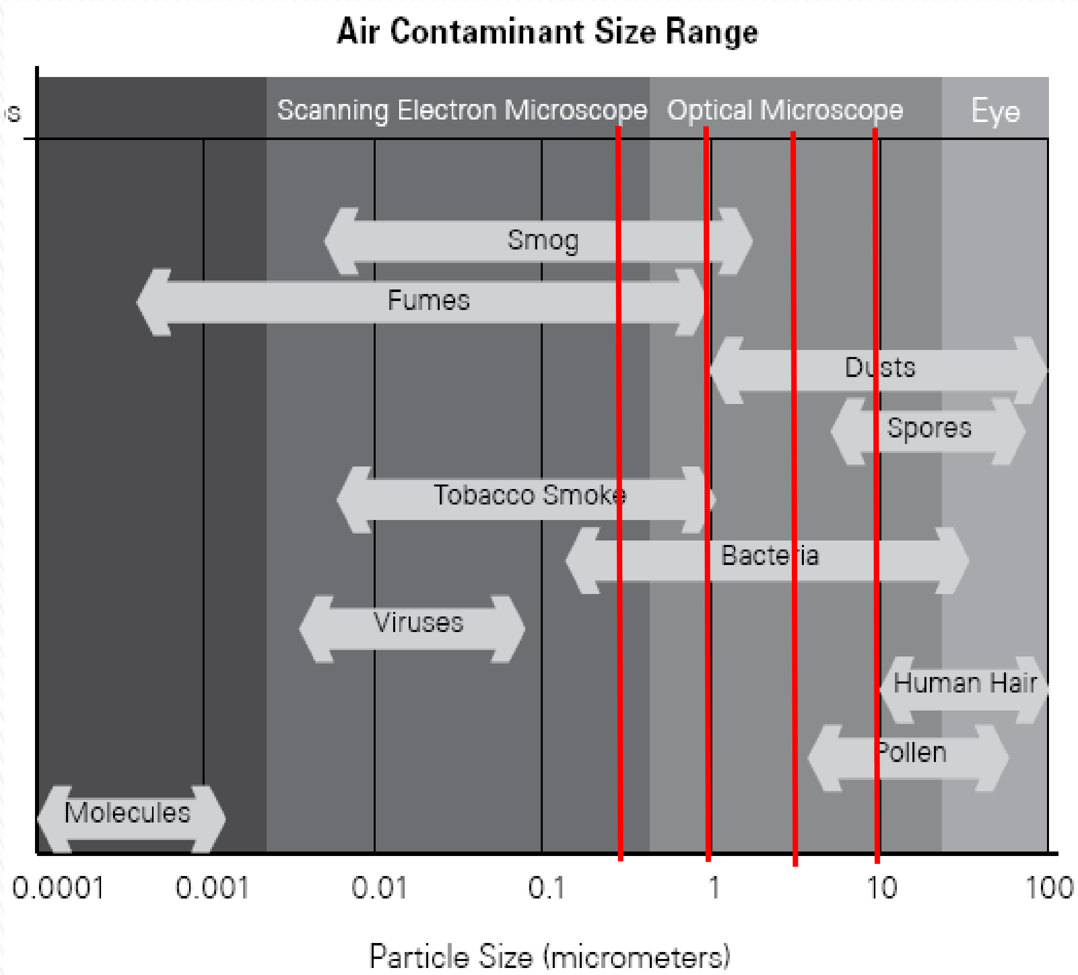
7.5

Provide particle and gas-phase air cleaning consistent with project IAQ objectives

Sizes of contaminant particles



Adapted from NIOSH 2003

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7.5

MERV: ASHRAE Std 52.2

"Minimum efficiency reporting value"

Provide particle and gas-phase air cleaning consistent with project IAQ objectives

MERV Level	Dust Spot %	Typical Particulate Filter Type	% 0.3–1 µm	% 1–3 µm	% 3–10 µm
1	N/A	Low-efficiency fiberglass and synthetic media disposable panels, cleanable filters, and electrostatic charged media panels	Too low efficiency to be applicable to ASHRAE Standard 52.2 (ASHRAE 2007) determination		
2	N/A				
3	N/A				
4	N/A				
5	N/A	Pleated filters, cartridge/cube filters, and disposable multi-density synthetic link panels			20–35
6*	N/A				36–50
7	25%–30%				50–70
8	30%–35%				>70
9	35%–40%	Enhanced media pleated filters, bag filters of either fiberglass or synthetic media, rigid box filters using lofted or paper media		>50	>85
10	50%–55%			50–65	>85
11	60%–65%			65–85	>85
12	70%–75%			>80	>90
13	80%–85%	Bag filters, rigid box filters, minipleat cartridge filters	>75	>90	>90
14	90%–95%		75–85	>90	>90
15	>95%		85–95	>90	>90
16	98%		>95	>95	>95
The following classes are determined by a different methodology than that of ASHRAE Standard 52.2 (ASHRAE 2007).					
NA	N/A	HEPA/ULPA filters evaluated using IEST Recommended Practice CC001.3 (IEST 1993). Types A through D yield efficiencies at 0.3 mm and Type F at 0.1 mm	99.97% IEST Type A		
NA	N/A		99.99% IEST Type C		
NA	N/A		99.999% IEST Type D		
NA	N/A		>99.999% IEST Type F		

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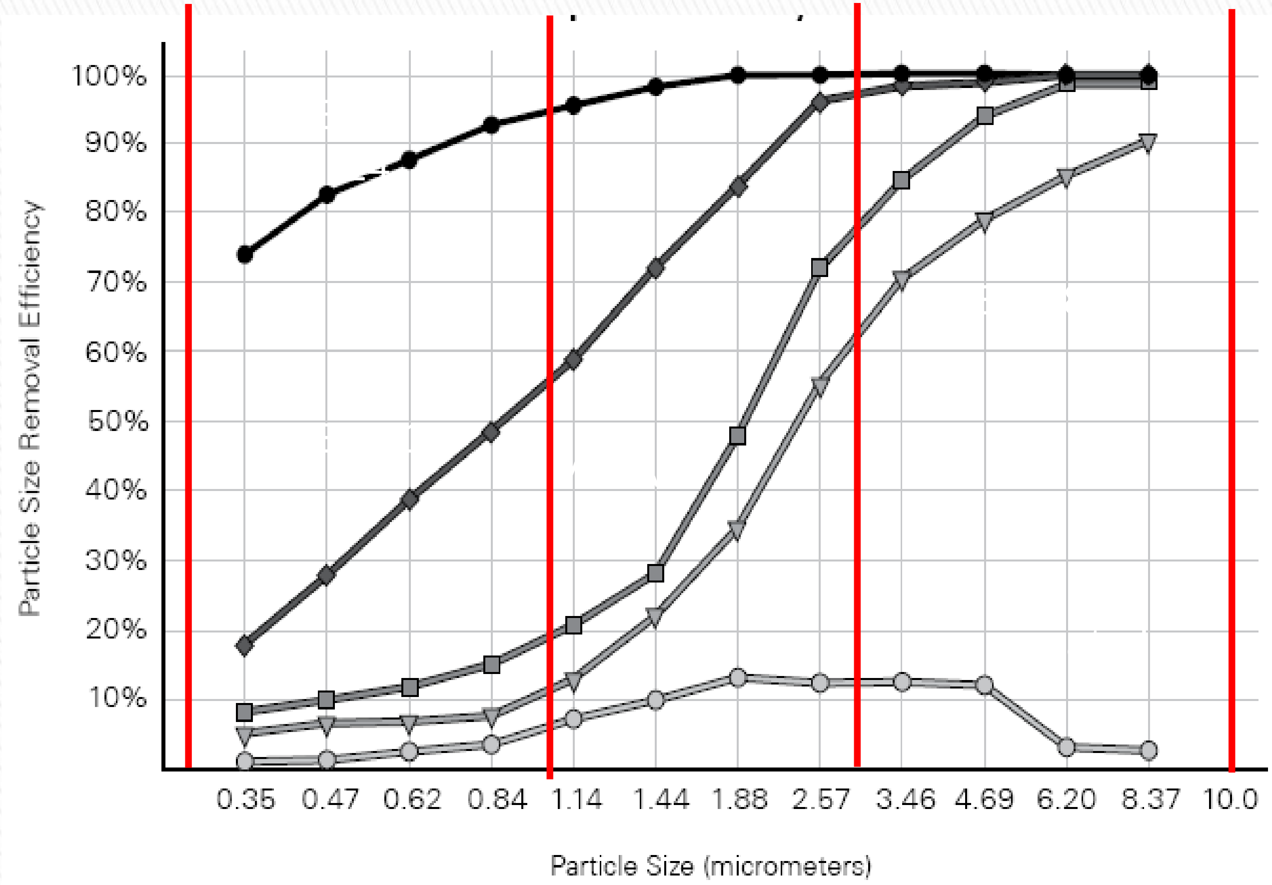
7.5 Provide particle and gas-phase air cleaning consistent with project IAQ objectives

MERV: ASHRAE Std 52.2

Sample composite minimum efficiency curves



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7.5

Provide particle and gas-phase air cleaning… *FAC Selection Guidance*

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7.5

Provide particle and gas-phase air cleaning consistent with project IAQ objectives

7.5.1, 7.5.2 keep coils, ducts, space cleaner:

MERV 8-13

- Extended media MERV 13 filter balances efficiency, capacity, pressure drop, first-cost, operating cost
- MERV 13 also available in 2 in. and 4 in. pleated but higher pressure drop

Photo courtesy The Filtration Group and Filtrair

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7.5

Provide particle and gas-phase air cleaning consistent with project IAQ objectives

7.5.3 control viable and pathogenic particles:

MERV 14-16

- Minimum MERV 14 because most viable particles < 1 μm
- Seals, gasketing, retainer systems critical
- Higher first-cost, higher PD, higher life cycle cost
- Substantial differences in PD among filters of a given MERV

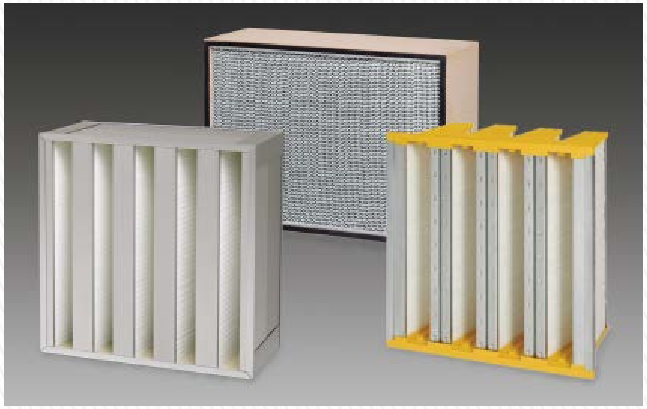

Photo courtesy The Filtration Group and Filtrair

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7.5

Provide particle and gas-phase air cleaning consistent with project IAQ objectives

7.5.4: Excessively polluted outside air:

MERV 11-14

Medium efficiency (ME) gas phase (50%-80%)

- Typically pleated chemical media filters 1-4 in.; solid bed flat panels, V-cells < 1 in.
- Same unit may remove both particles and gases
- Typically changed on a schedule
- Can be used to remove *ozone*: Change cycle based on experience or manufacturer's recommendation

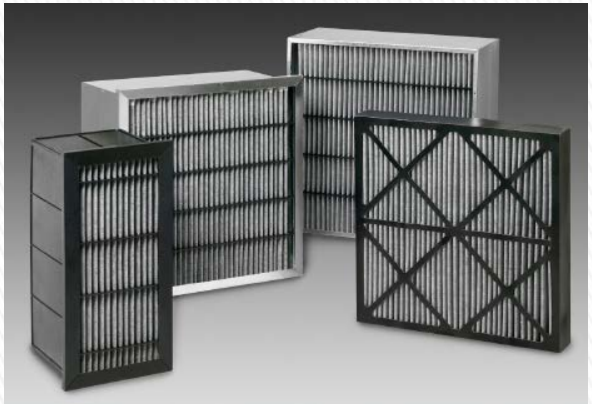

Photo courtesy The Filtration Group and Filtrair

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7.5

Provide particle and gas-phase air cleaning consistent with project IAQ objectives

Gas phase filters

- ANSI/ASHRAE Standard 145.1-2008 Method of Testing Gaseous Contaminant Air Cleaning Media for Removal Efficiency – bench-scale test of sorbent media
- 145.2 – testing of full-size cartridges in a test duct; expected publication 2010

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7.5

Provide particle and gas-phase air cleaning consistent with project IAQ objectives

Air capture and seals

- Air bypass:
  - Building infiltration
  - AHU doors, access panels, fabrication seams, openings
  - Flawed seals within or between retainers or tracking system
  - Gaps between filters, between filter and retainer, between filter and access door, between filter and access tracking

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7.5 Provide particle and gas-phase air cleaning consistent with project IAQ objectives

Air capture and seals

Effect of applying 1/8 in. neoprene gasket tape on vertical mating surfaces of MERV 13 frames (Burroughs 2006)

Particle Count Comparison	Particle Size Band 0.3 µm	0.5 µm	1 µm
Count prior to intervention	1177633	26862	2347
Count subsequent to gasketing	1000824	21637	1941
Average increase in efficiency	15.0%	19.5%	17.3%

Small bypasses can decrease filter performance by 2 or 3 MERV levels!

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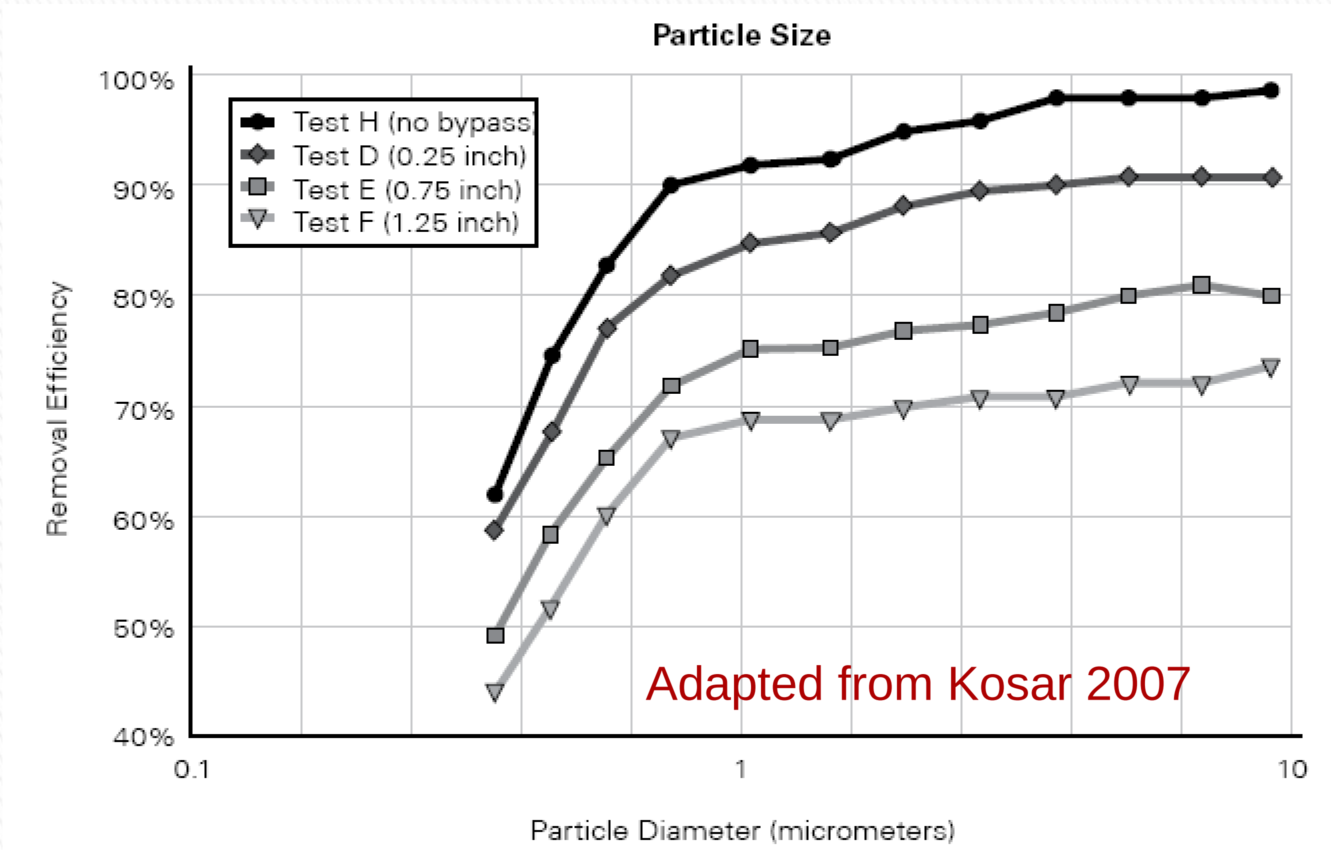
7.5 Provide particle and gas-phase air cleaning consistent with project IAQ objectives

Air capture and seals



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7.5

Provide particle and gas-phase air cleaning consistent with project IAQ objectives

Air capture and seals

- Balance building to limit infiltration
- Inspect by line-of-sight or light penetration to find and seal visible bypasses around FAC system, filter frames, retainer systems, access doors
- Seal mating metal surfaces with caulk or mastic: ductwork joints, adjoining frames, AHU seams
- Gasket seal planes of filter frames or headers
- Gasket filter frame mating surfaces

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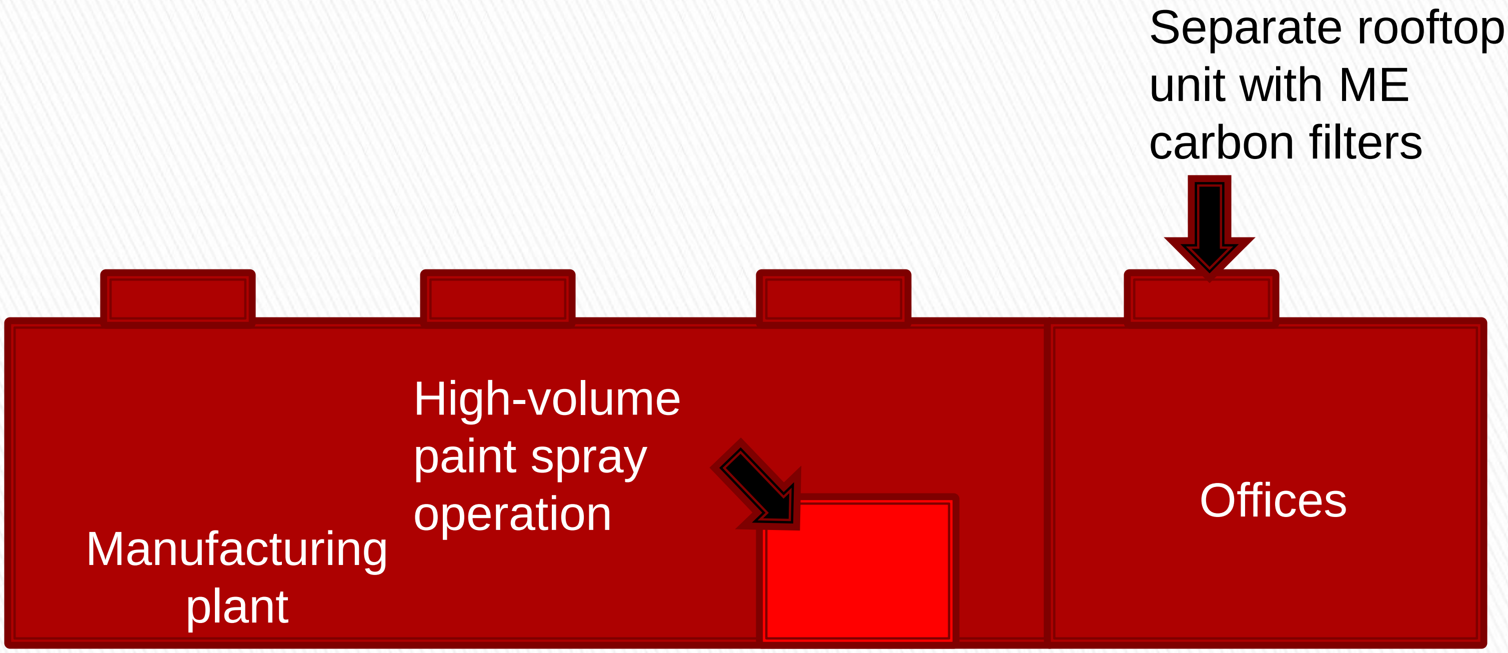
7.5

Provide particle and gas-phase air cleaning consistent with project IAQ objectives

Air capture and seals

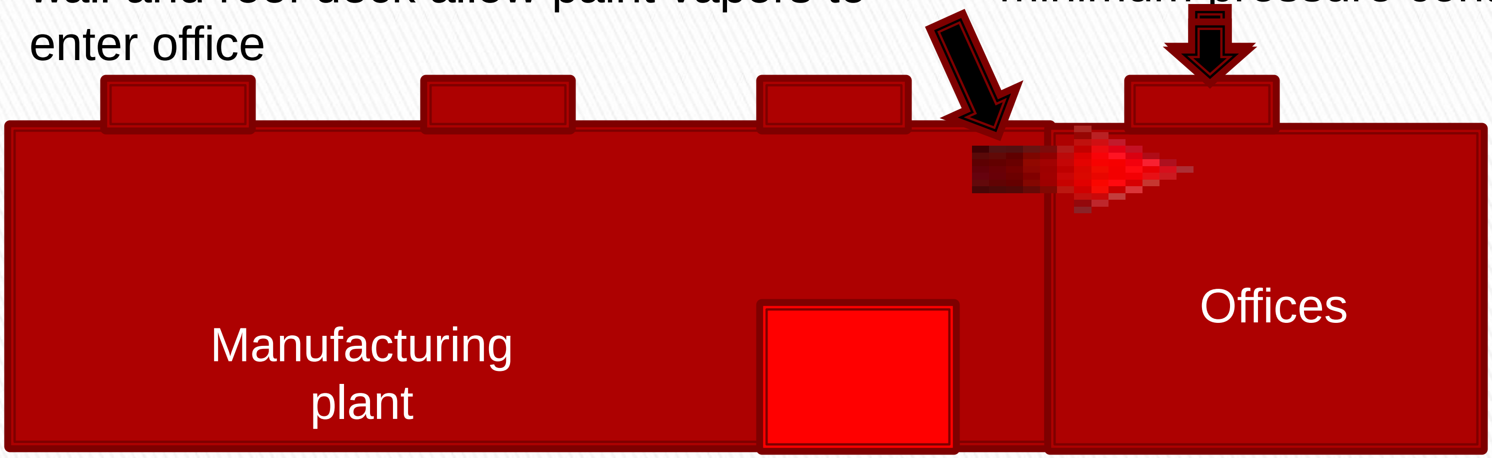


7.5 Provide particle and gas-phase air cleaning consistent with project IAQ objectives

Air capture and seals

Rooftop unit relieves high pressure when economizing but has no minimum pressure control

Large unsealed openings between top of wall and roof deck allow paint vapors to enter office



FAC can't do everything!

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7.5

Provide particle and gas-phase air cleaning consistent with project IAQ objectives

Selected items from design process protocol

- Select cartridge & framing to maximize life cycle & durability
- Provide appropriate monitoring instruments
- Specify component storage and system filtration requirements during construction
- Carefully evaluate the need for pre-filtration
- Provide for additional changes of specified filters for post-construction
- Provide owner with filter selection rationale and specifications, train operators

7.5

Provide particle and gas-phase air cleaning consistent with project IAQ objectives

Specify component storage and system filtration requirements during construction

Installed ductwork that had been unprotected during on-site storage and after installation

Photo courtesy of Wayne Thomann

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7.5 Provide particle and gas-phase air cleaning consistent with project IAQ objectives

Life cycle cost

For a given MERV, life cycle costs are controlled primarily by:

- Filter life cycle expectation
- Pressure drop

Filter Description	First Cost	Life Cycle Expectation*	Pressure Drop, in. w.g. (Pa) **	Cost/Year Total Operation***
MERV 8 2 in. pleat	$6.00	3 months	0.25 (62.5)	$88.00
MERV 8 4 in. pleat	$11.00	8 months	0.15 (37.5)	$45.73
MERV 14 cartridge	$115.00	2 years	0.60 (150)	$211.10
MERV 14 minipleat	$145.00	3 years	0.35 (87.5)	$137.93

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8. Apply More Advanced Ventilation approaches

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Apply More Advanced Approaches

- Use dedicated OA systems (8.1)
- Use energy recovery (8.2)
- Use demand-controlled ventilation (8.3)
- Use natural or mixed-mode ventilation (8.4)
- Use the Standard 62.1 IAQ Procedure (8.5)

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FOR MORE FUN, READ THE GUIDE!

www.ashrae.org/iaq

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Discussion – Application of IAQ Guide

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Following slides are discussion triggers if needed

- DO NOT PRINT THESE

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HVAC Maintenance?

IAQ Improvement Devices?

Filter Quality?

Cleaning Products?

Leaks and Mold?

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Humidity Control?

Ultra Violet Air Cleaning?

Indoor Plants?

Kitchen Ventilation?

Energy Savings and IAQ

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Energy Savings and IAQ

- Demand control ventilation (DCV)
- Chilled water temperature reset
- Air Side Economizer
- Reset VAV boxes to zero
- Replace ventilation with air transforming devices

Demand Control Ventilation (DCV)

- Manufacturer's claim – Studies show that demand controlled HVAC systems using CO_2 can **save up to 50% of energy costs** as well as improving comfort for the occupants.

Varying Ventilation Rates – 62.1

- Requirements of Standard 62
  - Ventilation Rates
  - Variable Load Conditions
  - Dynamic Reset
- Dynamic Reset
- Using CO_2 for Dynamic Reset
  - Must estimate number of people
  - Errors in assumptions for many applications
  - How to address multiple spaces

Requirements – Ventilation Rate

- **6.2.2.1 Breathing Zone Outdoor Airflow.** The design outdoor airflow required in the *breathing zone* of the occupiable space or spaces in a *zone*, *i.e., the breathing zone outdoor airflow* (V_{bz}), shall be determined in accordance with Equation 6.2.2.1.
- $V_{bz} = R_p \cdot P_z + R_a \cdot A_z$ (6.2.2.1)

where:

- A_z = *zone floor area*: the net occupiable floor area of the *zone* (ft^2).
- P_z = *zone population*: the largest number of people expected to occupy the zone during typical usage.
- R_p = outdoor airflow rate required per person as determined from Table 6.2.2.1.
- R_a = outdoor airflow rate required per unit area as determined from Table 6.2.2.1.

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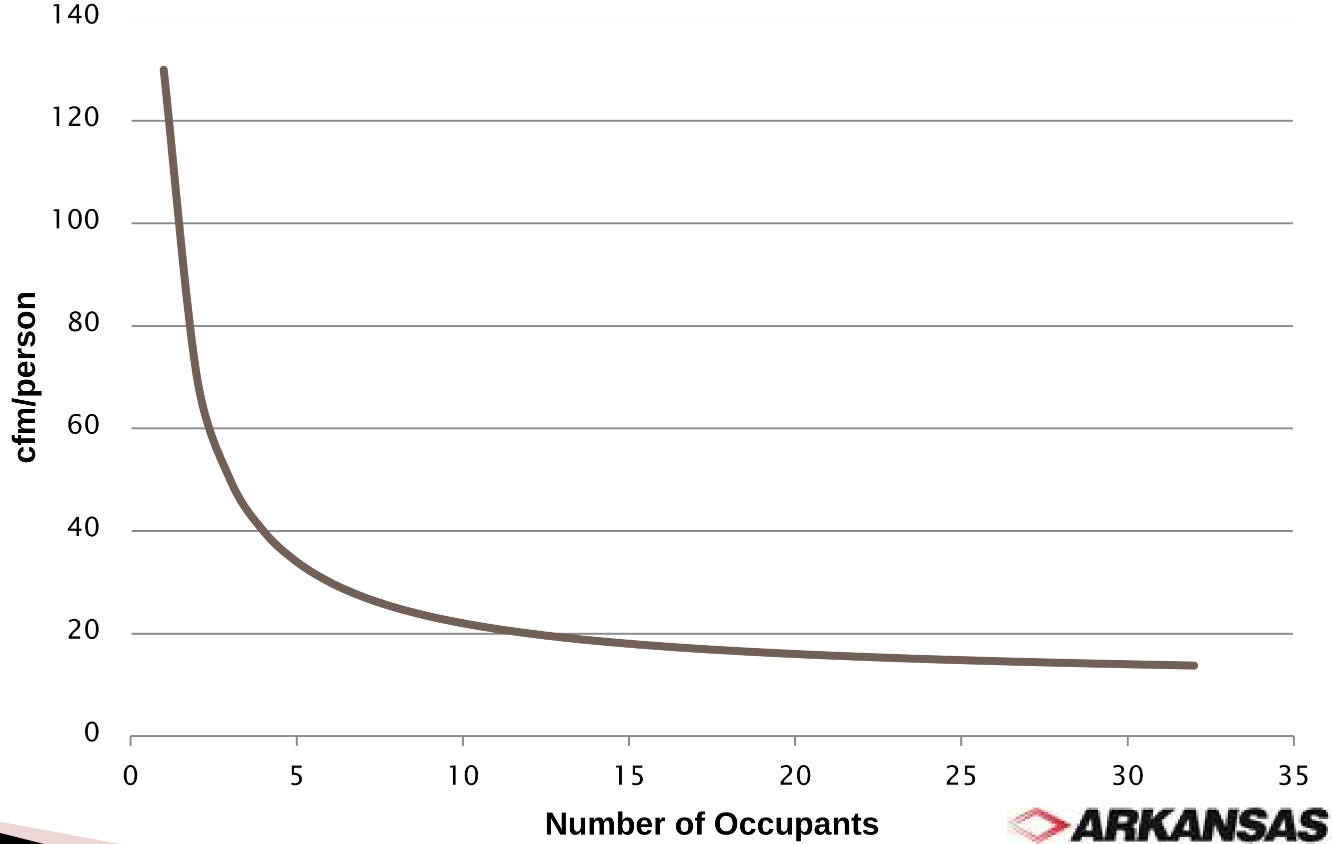
Elementary Classroom cfm/person vs Number of Occupants ventilated per ASHRAE 62.1-2016



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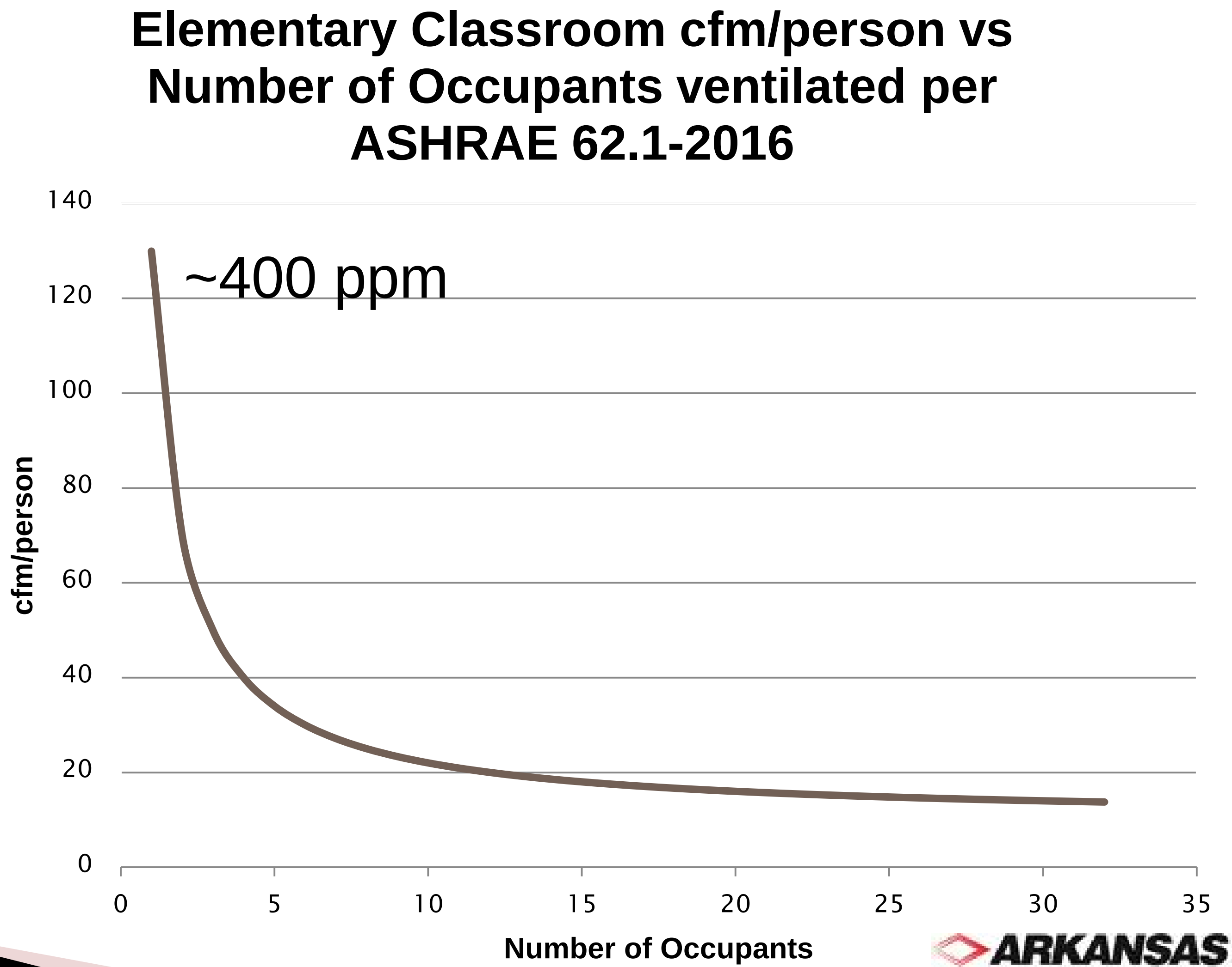
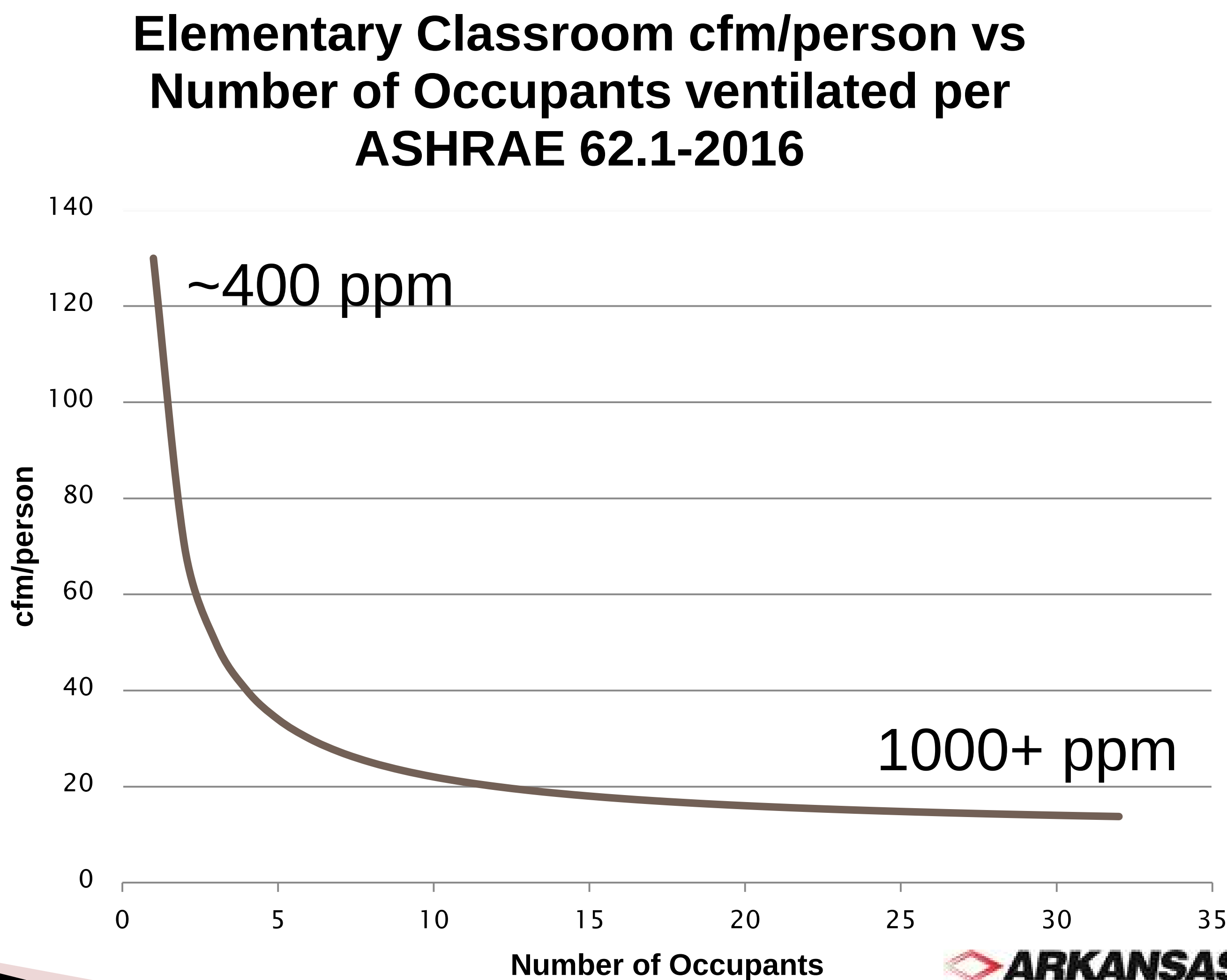

Elementary Classroom cfm/person vs Number of Occupants ventilated per ASHRAE 62.1-2016
~400 ppm
cfm/person
140
120
100
80
60
40
20
0
0
5
10
15
20
25
30
35
Number of Occupants



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Ventilation Rate Procedure – Zone Outdoor Airflow

$V_{oz} = V_{bz}/E_z$ (6.2.2.3)

- (E_z) The zone air distribution effectiveness shall be no greater than the default value determined using Table 6.2.2.2 (part of table shown below)

TABLE 6.2.2.2 Zone Air Distribution Effectiveness

Air Distribution Configuration	E_z
Ceiling supply of cool air	1.0
Ceiling supply of warm air and floor return	1.0
Ceiling supply of warm air 15°F (8°C) or more above space temperature and ceiling return	0.8

Ventilation Rate Procedure – Outdoor Airflow Single Zone

$$V_{ot} = V_{oz} \qquad (6.2.3)$$

- **Single-Zone Systems.** For ventilation systems wherein one or more air handlers supply a mixture of *outdoor air* and *recirculated air* to only one *ventilation zone*, the *outdoor air intake flow* (V_{ot}) shall be determined in accordance with Equation 6.2.3.

Ventilation Rate Procedure – Outdoor Airflow – 100% OA

$V_{ot} = \Sigma_{all\ zones}\ V_{oz}$ (6.2.4)

- **100% Outdoor Air Systems.** For ventilation systems wherein one or more air handlers supply only *outdoor air* to one or more *ventilation zones*, the *outdoor air intake flow* (V_{ot}) shall be determined in accordance with Equation 6.2.4.

Multiple Zone Recirculating Systems

- For ventilation systems wherein one or more air handlers supply a mixture of *outdoor air* and *recirculated air* to more than one *ventilation zone*, the *outdoor air intake flow* (V_{ot}) shall be determined in accordance with Sections 6.2.5.1 through 6.2.5.4.
- **6.2.5.4 Outdoor Air Intake.** The design outdoor air intake flow(V_{ot}) shall be determined in accordance with Equation 6.2.5.4:

$$V_{ot} = V_{ou} / E_v \qquad (6.2.5.4)$$

Multiple Zone Recirculating Systems – Uncorrected OA Intake

- **6.2.5.3 Uncorrected Outdoor Air Intake.** The design *uncorrected outdoor air intake (outdoor air used)* (V_{ou}) shall be determined in accordance with Equation 6.2.5.3:

$$Vou = D^* \Sigma_{all\ zones} R_p P_z + \Sigma_{all\ zones} R_a A_z \qquad (6.2.5.3)$$

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Multiple Zone Systems – Primary Outdoor Air Fraction

- **6.2.5.1 Primary Outdoor Air Fraction.** When Table 6-3 is used to determine system ventilation efficiency, the *zone primary outdoor air fraction* (Z_p) shall be determined in accordance with Equation 6.2.5.1:

  $$Z_p = V_{oz} / V_{pz} \qquad (6.2.5.1)$$

  where V_{pz} is the zone primary airflow, i.e., the primary airflow to the zone from the air handler including outdoor air and recirculated return air.

  Note: For VAV systems, V_{pz} is the minimum expected primary airflow.

Multiple Zone Recirculating Systems – System Ventilation Efficiency

- **6.2.5.2 System Ventilation Efficiency.** The *system ventilation efficiency* (E_v) shall be determined using Table 6.2.5.2 or Appendix A.

TABLE 6.2.5.2 System Ventilation Efficiency

Max (Z_P)	E_v
≤0.15	1.0
≤0.25	0.9
≤0.35	0.8
≤0.45	0.7
≤0.55	0.6
>0.55	Use Appendix A

Requirements - Variable Load

- **6.2.6.1 Variable Load Conditions.** Ventilation systems shall be designed to be capable of providing the required ventilation rates in the breathing zone whenever the zones served by the system are occupied, including all full- and part-load conditions.

Requirements – Dynamic Reset

- **6.2.7 Dynamic Reset.** The system may be designed to reset the design *outdoor air intake flow* (V_{ot}) and/or space or zone airflow as operating conditions change.

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6.2.7.1 Demand Control Ventilation (DCV)

- **6.2.7.1** DCV shall be permitted as an optional means of dynamic reset.
- **Exception:** CO_2-based DCV shall not be applied in zones with indoor sources of CO_2 other than occupants or with CO_2 removal mechanisms, such as gaseous air cleaners.
- ***Former Note:*** Examples of reset methods or devices include population counters, carbon dioxide (CO_2) sensors, timers, occupancy schedules or occupancy sensors.

DCV Operations

- **6.2.7.1.1** For DCV zones in the occupied mode, breathing zone outdoor airflow (Vbz) shall be reset in response to current population.
- **6.2.7.1.2** For DCV zones in the occupied mode, breathing zone outdoor airflow (Vbz) shall be not less than the building component (Ra Å~ Az) for the zone.
- **Exception**: Breathing zone outdoor airflow shall be permitted to be reduced to zero for zones in occupied standby mode for the occupancy categories indicated in Table 6.2.2.1, provided that airflow is restored to Vbz whenever occupancy is detected.
- **6.2.7.1.3** Documentation. A written description of the equipment, methods, control sequences, setpoints, and the intended operational functions shall be provided. A table shall be provided that shows the minimum and maximum outdoor intake airflow for each system.

MYTHS about CO_2 and Ventilation

- ASHRAE 62 sets 1000 ppm as the control point.
- ASHRAE 62.1 Appendix C recommends 700 ppm above outdoor levels.
- ASHRAE 62.1 Appendix C recommends using a generation rate of 0.31 L/min ≈ 0.01 cfm for CO_2 per person.
- ALL OF THE ABOVE ARE WRONG

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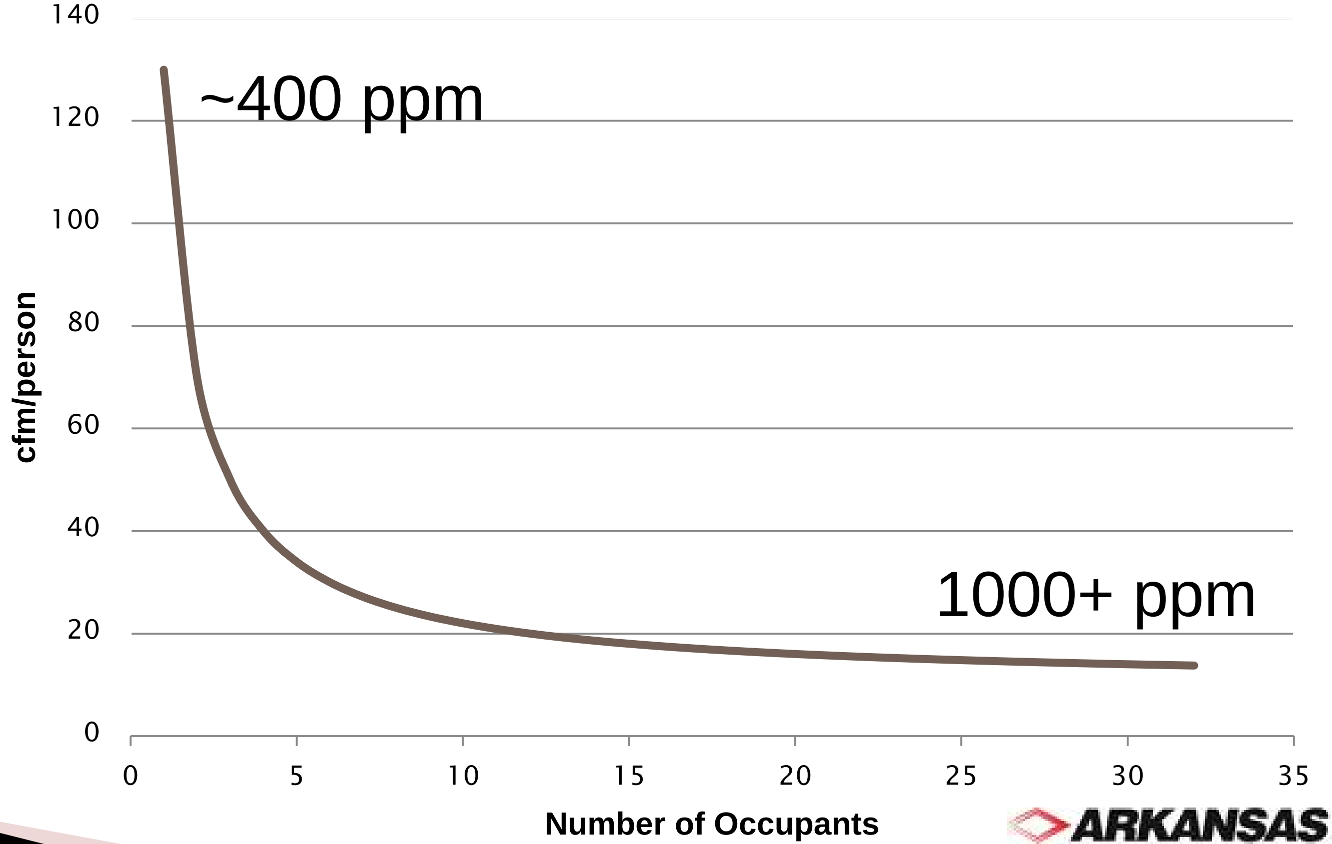
Elementary Classroom cfm/person vs Number of Occupants ventilated per ASHRAE 62.1-2016



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System Variables (affecting CO_2)

- Single Zone or DOAS
  - P_z
  - E_z (maybe)
- Multiple Zone
  - P_z
  - E_z (maybe)
  - E_v (for VAV)
  - P other connected zones
  - V_{pz}
  - V_p other zones

Requirements – Ventilation Rate

- **6.2.2.1 Breathing Zone Outdoor Airflow.** The design outdoor airflow required in the *breathing zone* of the occupiable space or spaces in a *zone*, *i.e., the breathing zone outdoor airflow* (V_{bz}), shall be determined in accordance with Equation 6-1.
- $V_{bz} = R_p \cdot P_z + R_a \cdot A_z$ (6.2.2.1)

where:

- A_z = *zone floor area*: the net occupiable floor area of the *zone* (ft^2).
- P_z = *zone population*: the largest number of people expected to occupy the zone during typical usage.
- R_p = outdoor airflow rate required per person as determined from Table 6-1.
- R_a = outdoor airflow rate required per unit area as determined from Table 6-1.

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How can CO_2 estimate people count in a room?

- People generate CO_2 at varying rates
- ASSUMING one knows (1) the generation rate of <u>the people in the room,</u>
- And one knows the (2) room air change rate,
- And one knows (3) the CO_2 concentration in the entering air,
- Then one can calculate the number of people in real time based on changes in room CO_2 concentration

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Generation Rate

- Metabolic rate variables
  - Activity
  - Age
  - Size (Height and Weight)
  - Gender
- CO_2 generated from metabolism
  - Diet
- Commonly used (or abused) value of G

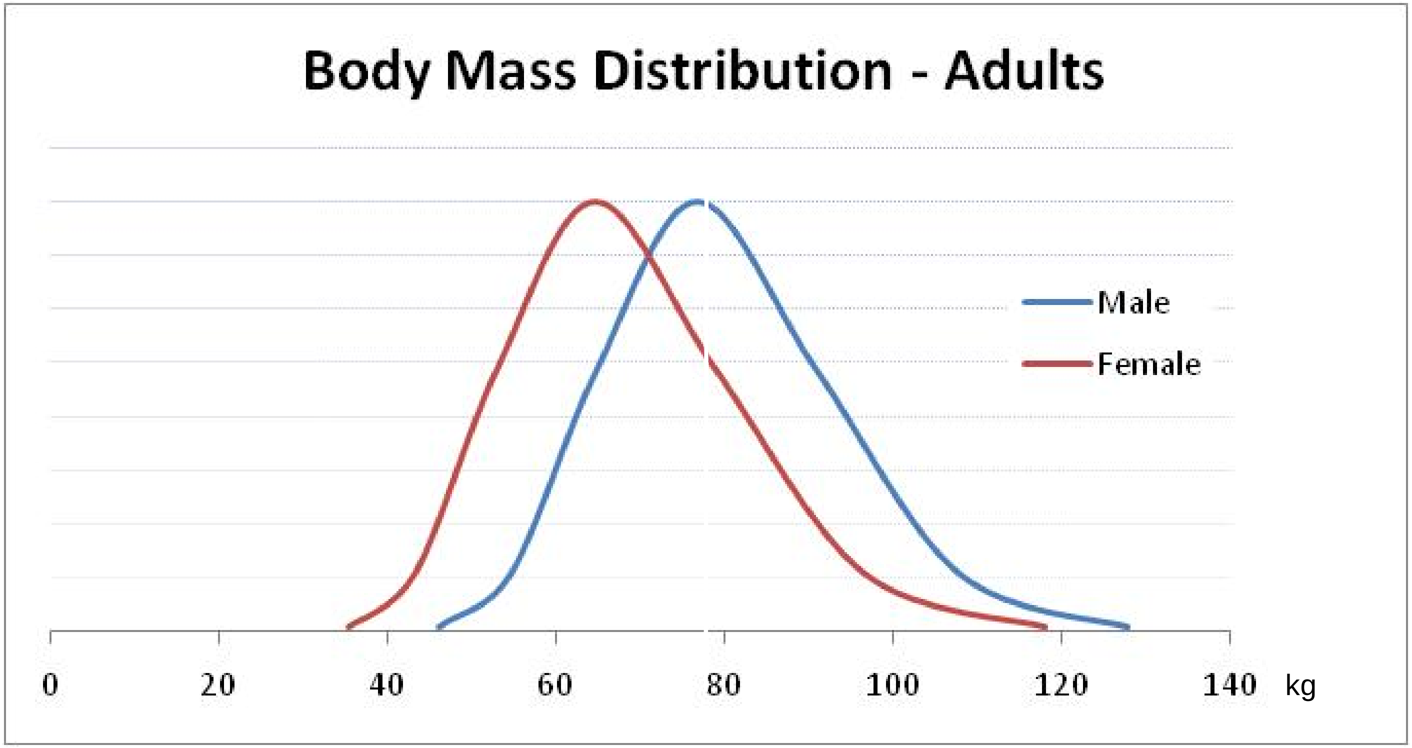
Metabolic Rate Basics

- BMR - Basal metabolic rate is energy expended at rest at neutral temperature in post-absorptive state
- RMR – Resting metabolic rate
- Several estimation formulae

- Metabolism for glucose
- $C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$

Source for following: A guide to selected algorithms, distributions, and databases used in exposure models developed by OAQPS (EPA) May 22, 2002

Body Mass by Gender



Source: A guide to selected algorithms, distributions, and databases used in exposure models developed by OAQPS (EPA) May 22, 2002

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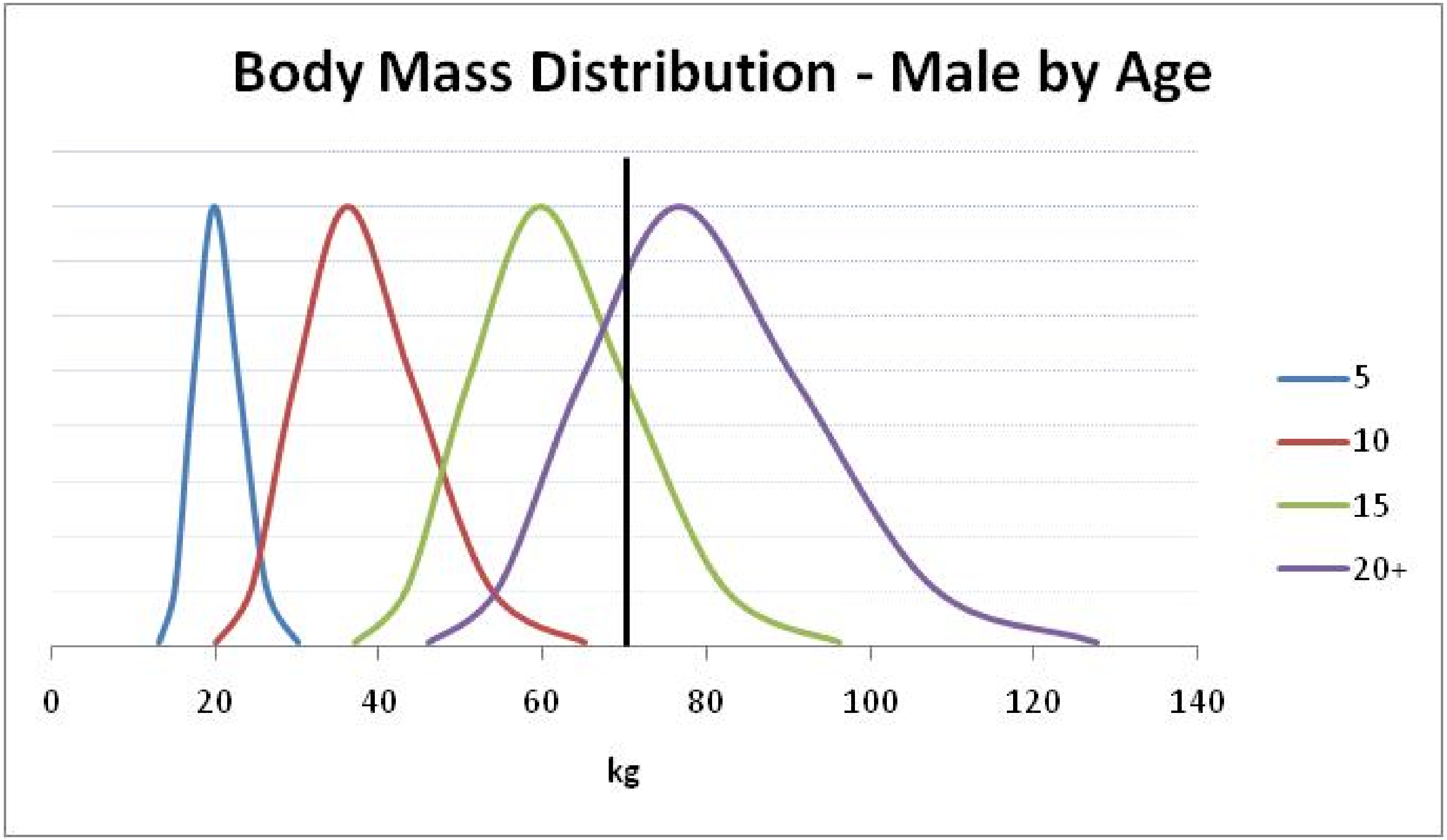
Variations in Body Mass by Age

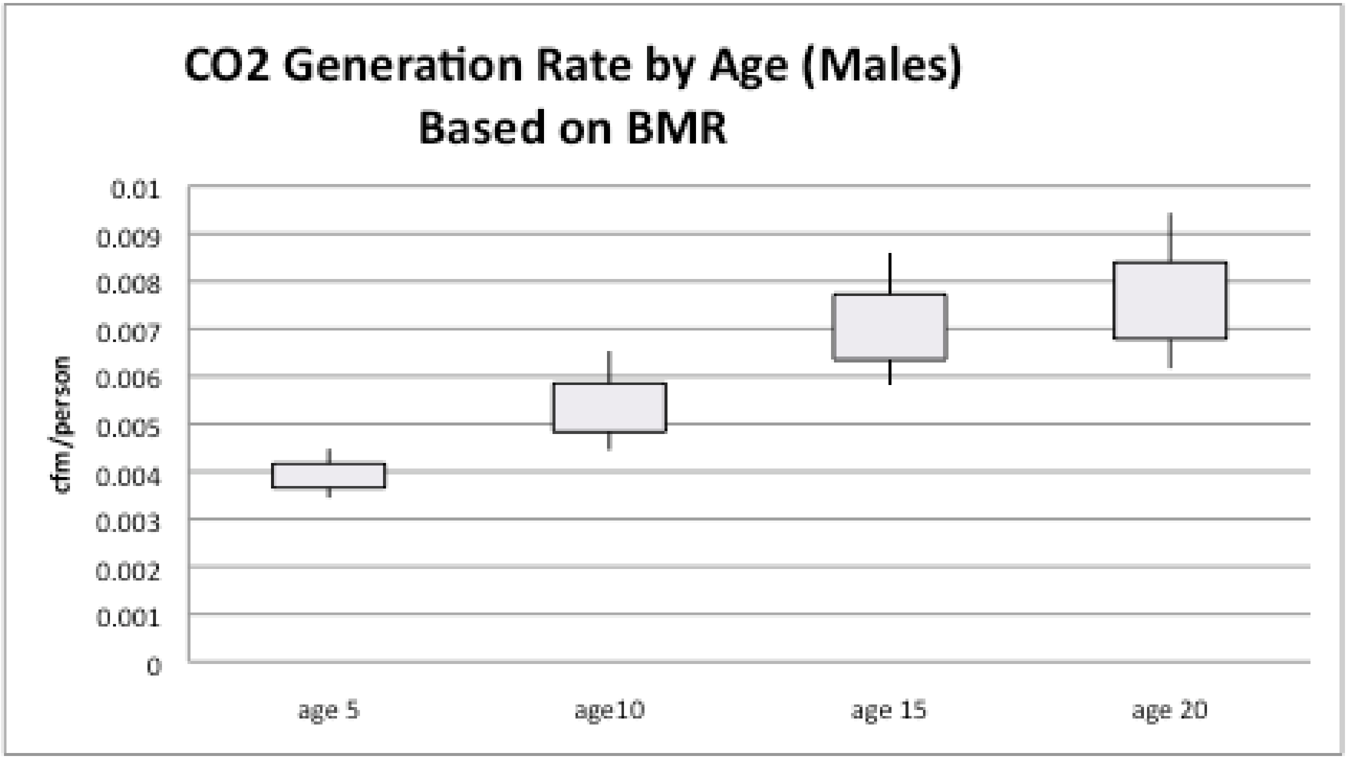


Determining Generation Rate

- Resting metabolic rate RMR
- x Energy conversion factor ECF = VO_2
- x RQ respiratory quotient = G

- Note: RQ varies from 0.7 to 1.0 depending on diet (different biochemistry for fats, proteins and carbohydrates)
- Assuming constant ECF and RQ=0.83

Comparison of G by Age



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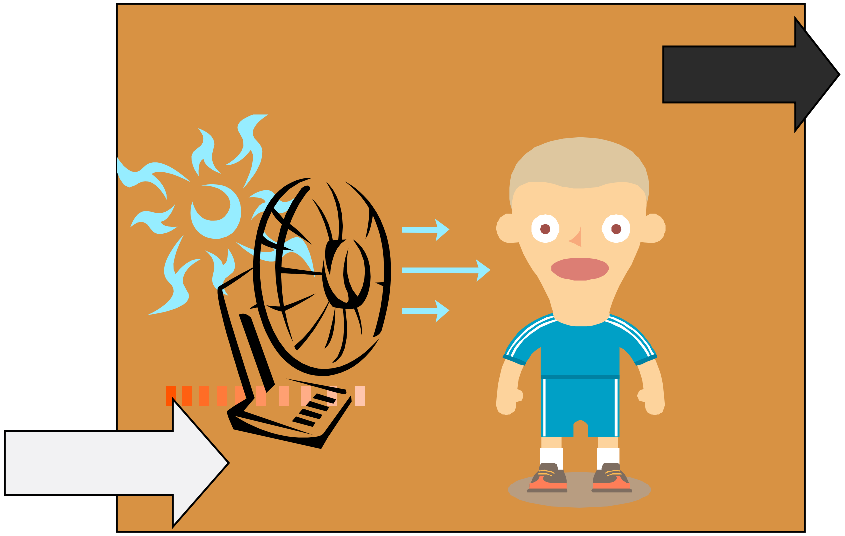
Basic Mass Balance

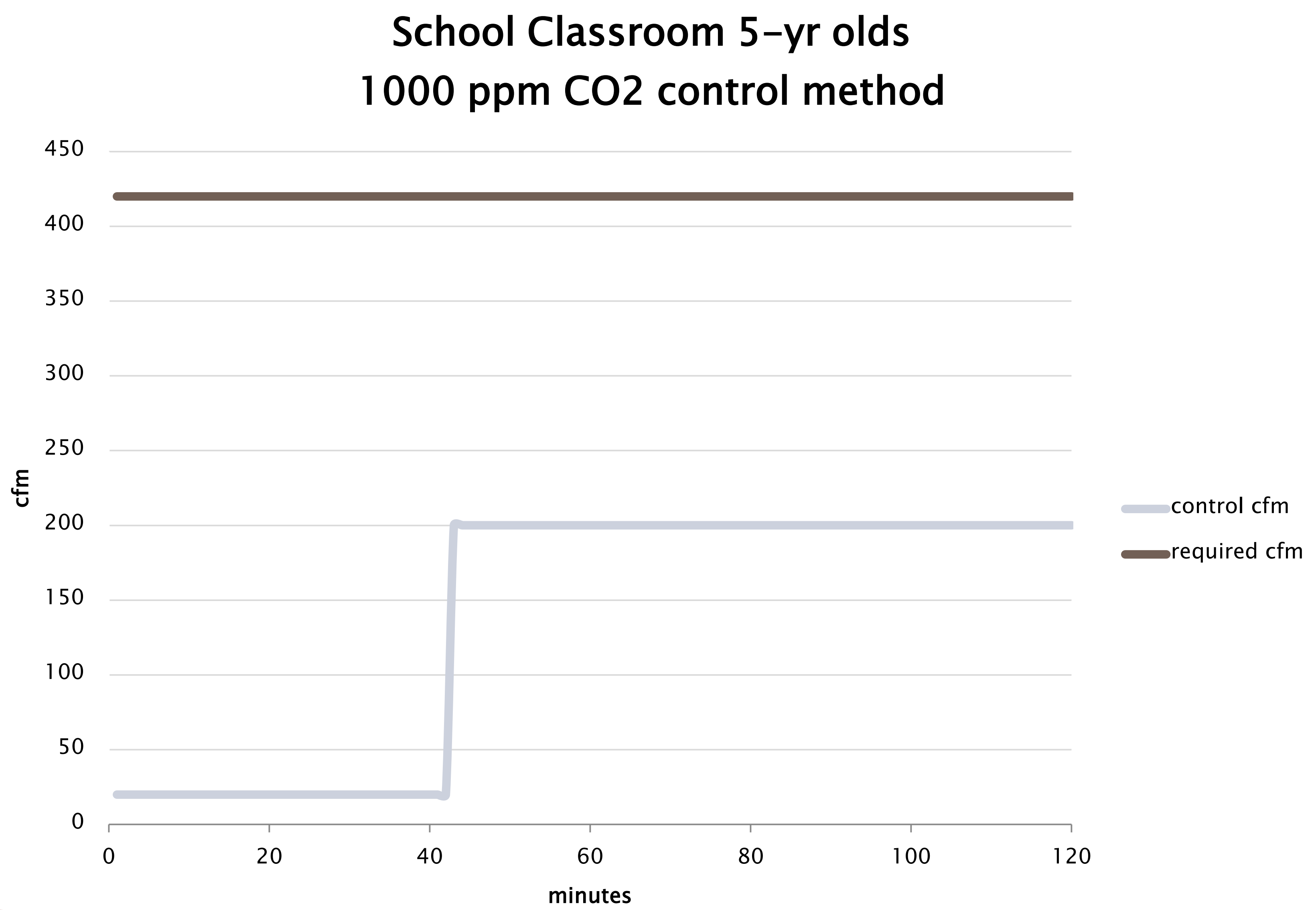
- Single Compartment Model
- Well Mixed
- Steady State
  - N – concentration in room
  - C – concentration into room
  - G – generation rate
  - SA – airflow rate



$$N = C_i + \frac{G}{SA}$$

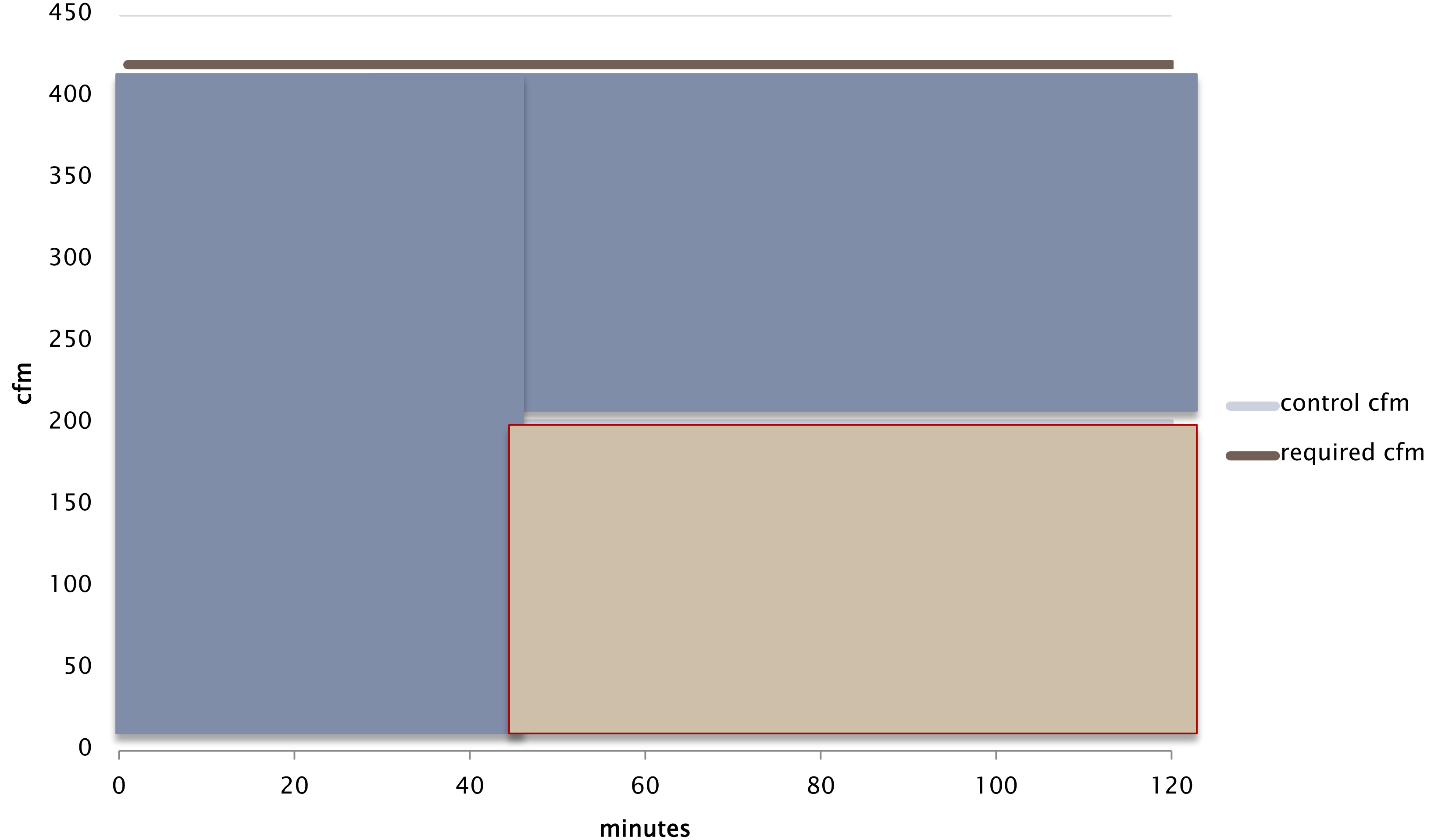
Elementary School Classroom

- 1000 sq ft
- 30 people
- R_a x A_z = 120 cfm
- R_p x P_z = 300 cfm
- V_{oz} = 420 cfm
- Note: = 14/cfm/person



School Classroom 5-yr olds
1000 ppm CO2 control method
450
400
350
300
250
200
150
100
50
0
cfm
0
20
40
60
80
100
120
minutes
control cfm
required cfm

School Classroom 5-yr olds
1000 ppm CO2 control method



What About Calibration?

- Field calibration typically involves flowing a calibration gas with a known concentration of CO_2 through the sensor's optical sensing element.
- Accurate calibration requires knowing the temperature and the pressure of the gas in the optical sensing element

1

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Accuracy

- The results from testing forty-five HVAC-grade NDIR CO2 sensors from fifteen models under accurate and repeatable conditions have shown a wider variation in sensor performance among manufacturers.
- In some cases, significant variations in sensor performance exist between sensors of the same model while in other cases, all sensors of the same model showed almost identical behavior.
- None of the sensor models meet their manufacturer specified accuracy statement for all three sensors of a given model over the full range of test conditions.

Shrestha and Maxwell, *ASHRAE Transactions* 2010

Chilled water temperature reset

- Saves some chiller energy
- Results in more humid air delivered to buildings
- May cause mold growth
- May use more fan energy than chiller energy saved (net energy penalty)

Air Side Economizer

- Good for IAQ
- Saves cooling energy during moderate temperatures
- Sometimes maintenance issues
  - Dampers
  - Controls
- Recommended control sequence

"Why Enthalpy Economizers Don't Work" *ASHRAE Journal*, November 2010

Reset VAV boxes to zero

- Response to cold calls
- Sometimes strategy when reheat does not work
- Does not result in minimum ventilation
- Thermostats are not IAQ measurement devices

Replace ventilation with air transforming devices

- Many technologies
- Similar claims
- Reduce all indoor compounds to CO_2 and H_2O
- Scant substantiation
- Do not comply with any recognized method of test
- Many anecdotes

Effects of Ventilation, IAQ and Environment on Performance in Schools and Offices

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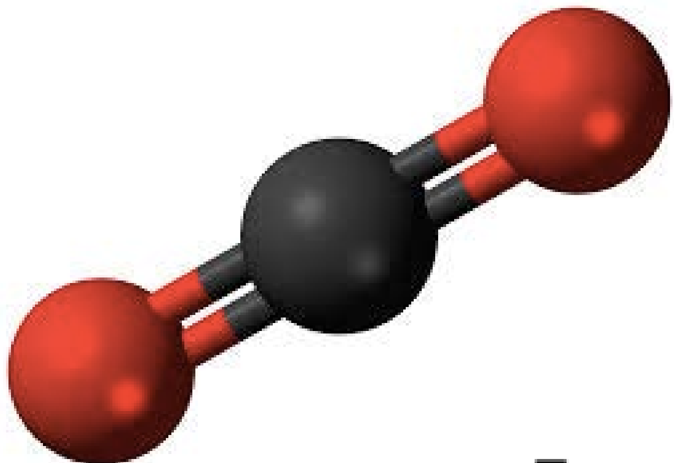
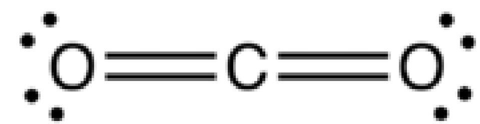
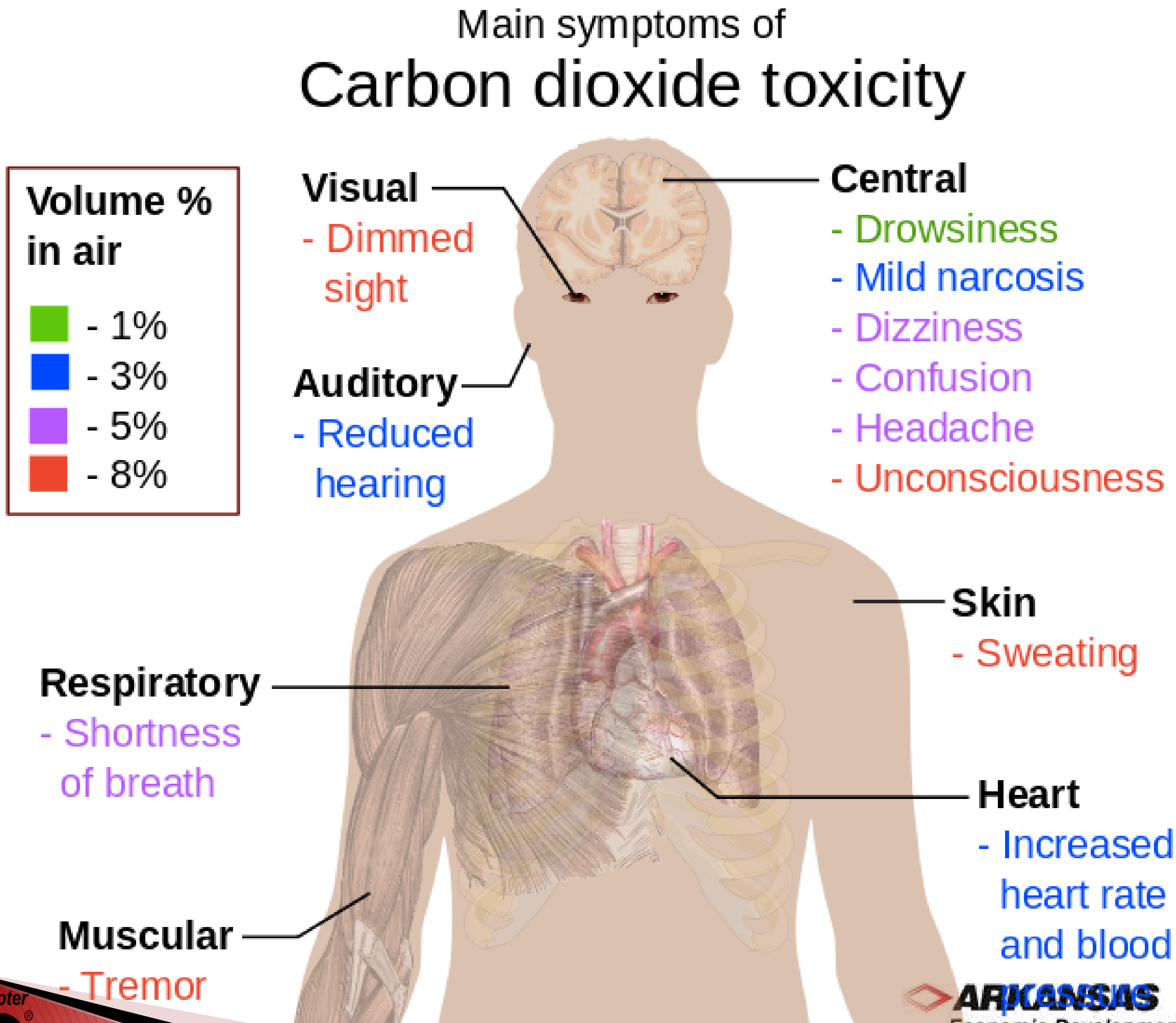
Is CO_2 a Contaminant?





	O	C	O
Formal Charge	0	0	0
Oxidation State	2–	4+	2–


Main symptoms of
Carbon dioxide toxicity
Volume % in air
- 1%
- 3%
- 5%
- 8%
Visual
- Dimmed sight
Auditory
- Reduced hearing
Central
- Drowsiness
- Mild narcosis
- Dizziness
- Confusion
- Headache
- Unconsciousness
Skin
- Sweating
Respiratory
- Shortness of breath
Heart
- Increased heart rate and blood pressure
Muscular
- Tremor

CO_2 Regulations

- OSHA: 5000 ppm
- NIOSH and ACGIH: 5000 ppm (30,000 ppm 15 minutes)
- Canada: 3500 ppm

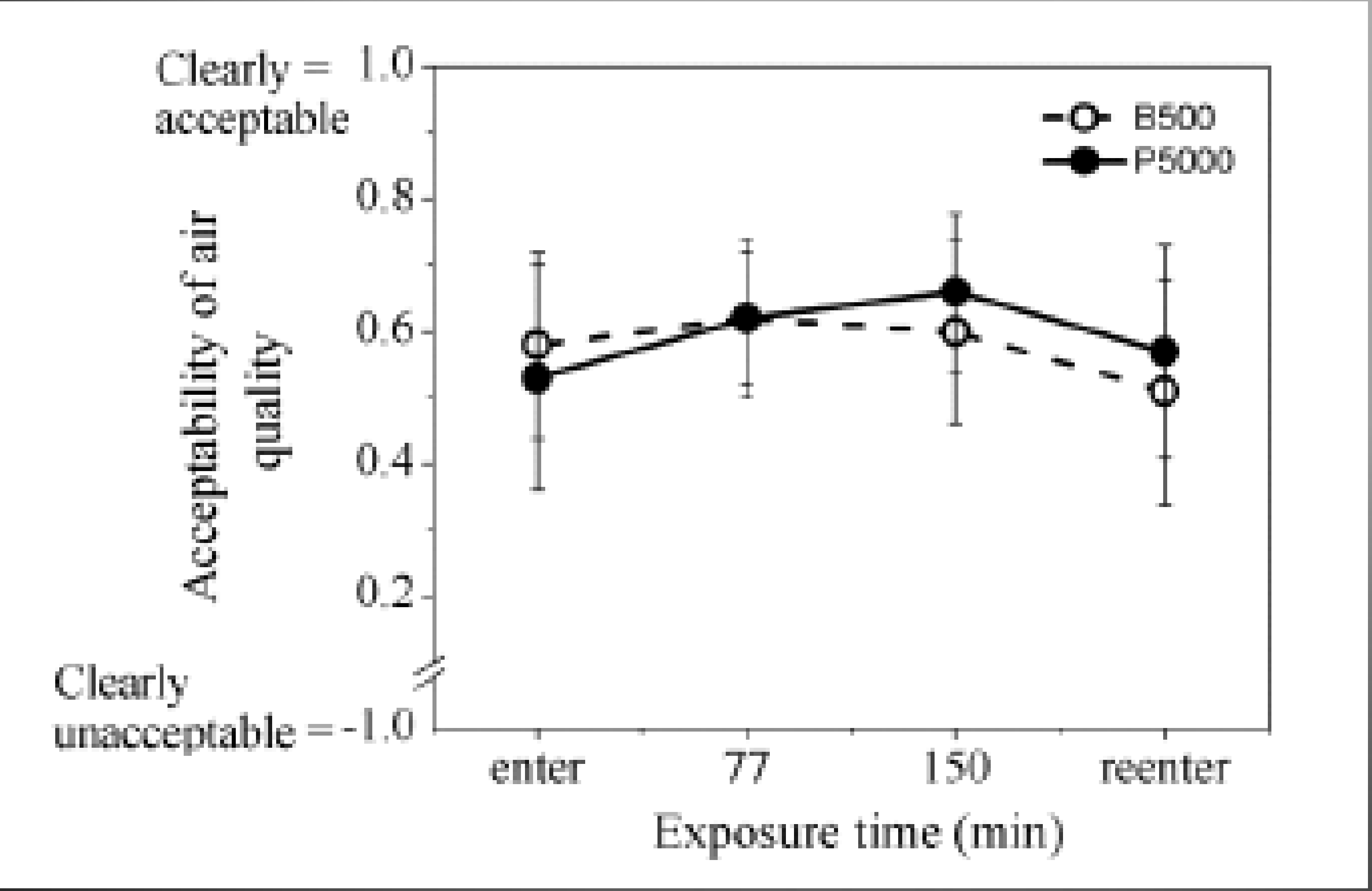
Selecting CO_2 Criteria for Outdoor Air Monitoring

By Thomas M. Lawrence, Ph.D., P.E., Member ASHRAE

provided. The California Title 24 *20*

ASHRAE Journal Dec 2008

Acceptability of IAQ



Zhang, Wargocki, Lian 2016

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	Default Values Combined Outdoor Air Rate Per Person		Assumed Activity Level	CO_2 Generation	Actual Steady-State Concentration	Monitoring Program Concentration (Alarm Level)	DCV Upper Control Limit Concentration (Caution Level)	LEED-EB IEQ Credit 1 Concentration
Occupancy Category	cfm	L/s	(met)*	(cfm per person)	(ppm)†	(ppm)†	(ppm)†,‡	(ppm)†,§
Educational Facilities								
Day Care (Through Age 4)	17	8.6	1.5	0.013	1,141	1,300	1,027	1,312
Day Care Sickroom	17	8.6	0.8	0.007	795	900	716	915
Classrooms (Age 5–8)	15	7.4	1	0.008	960	1,100	864	1,104
Classrooms (Age 9+)	13	6.7	1	0.008	1,046	1,200	942	1,203
Lecture Classroom	8	4.3	1	0.008	1,450	1,600	1,305	1,668
Lecture Hall (Fixed Seats)	8	4	1	0.008	1,450	1,600	1,305	1,668
Art Classroom	19	9.5	1.2	0.010	931	1,100	837	1,070
Science Laboratories	17	8.6	1.2	0.010	993	1,100	894	1,142
University/College Lab	17	8.6	1.2	0.010	993	1,100	894	1,142
Wood/Metal Shop	19	9.5	2	0.017	1,284	1,400	1,156	1,477
Computer Lab	15	7.4	1.2	0.010	1,072	1,200	965	1,233
Media Center	15	7.4	1.2	0.010	1,072	1,200	965	1,233
Music/Theater/Dance	12	5.9	2	0.017	1,800	1,900	1,620	2,070
Multiuse Assembly	8	4.1	1.5	0.013	1,975	2,100	1,778	2,271

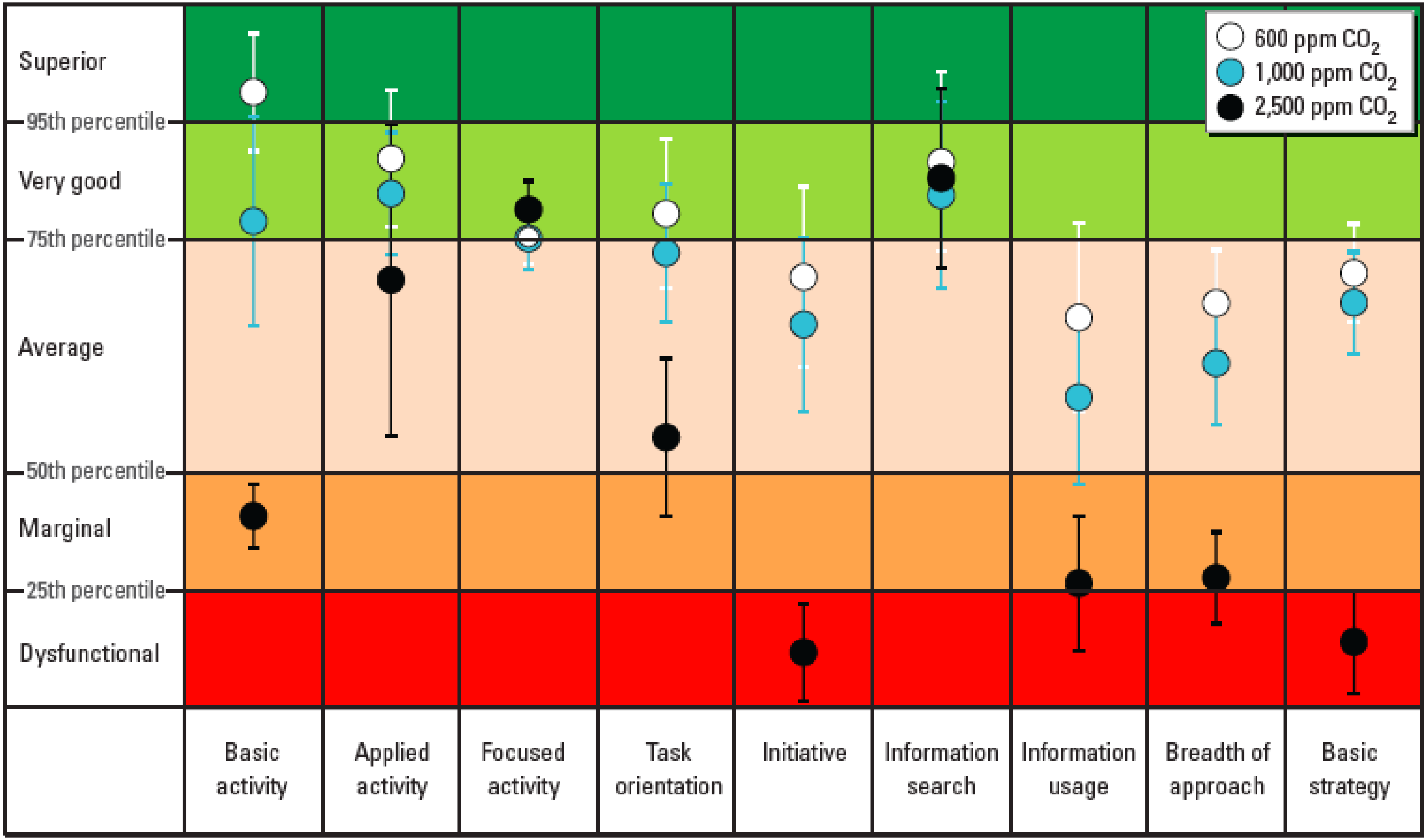
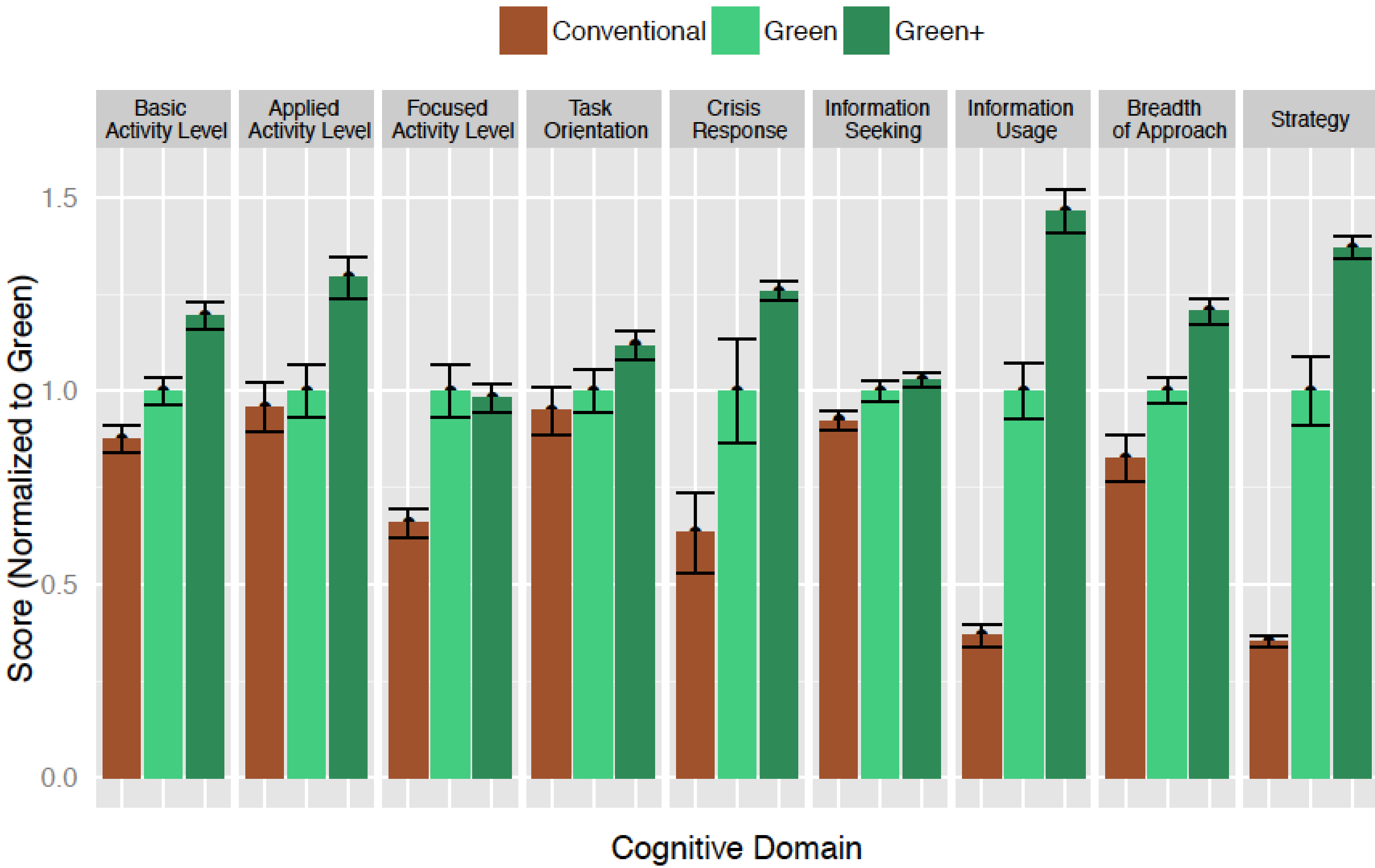
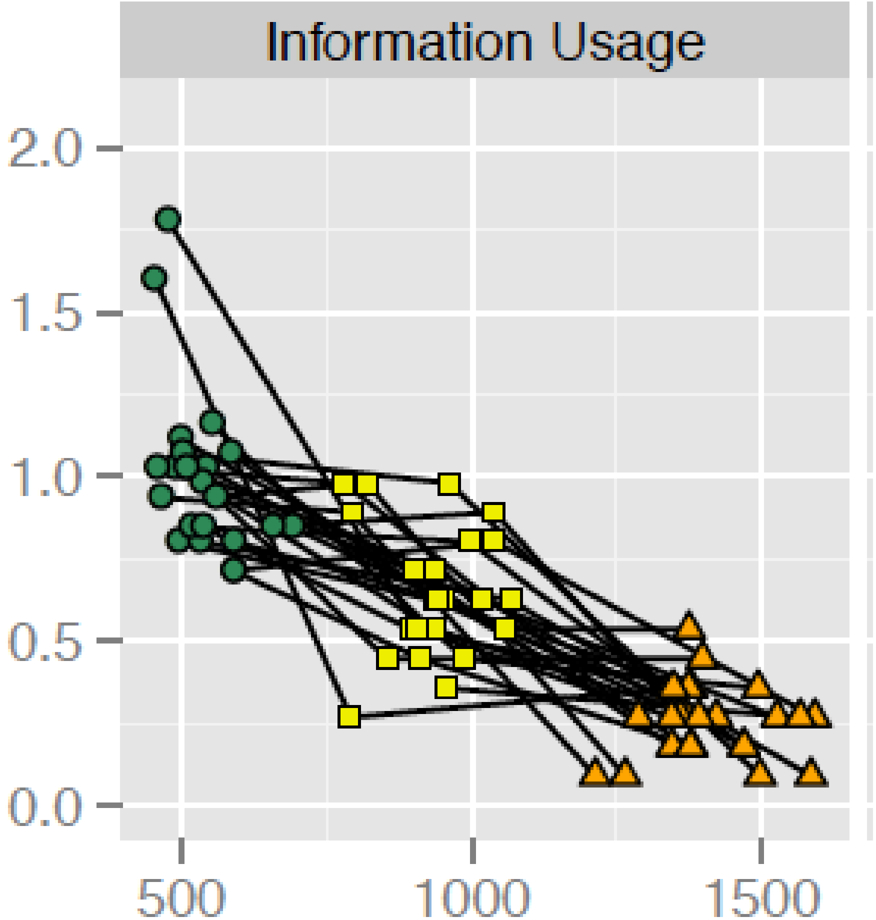


Figure 2. Impact of CO_2 on human decision-making performance. Error bars indicate 1 SD.

Satish, *et al.* *Environmental Health Perspectives,* Dec. 2012



Allen, *et al., Environmental Health Perspectives,* Oct 2015



Capacity to use both provided information and information that has been gathered toward attaining overall goals

Allen, *et al., Environmental Health Perspectives,* Oct 2015

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2006 Research Report

Research Report on

Effects of HVAC On Student Performance

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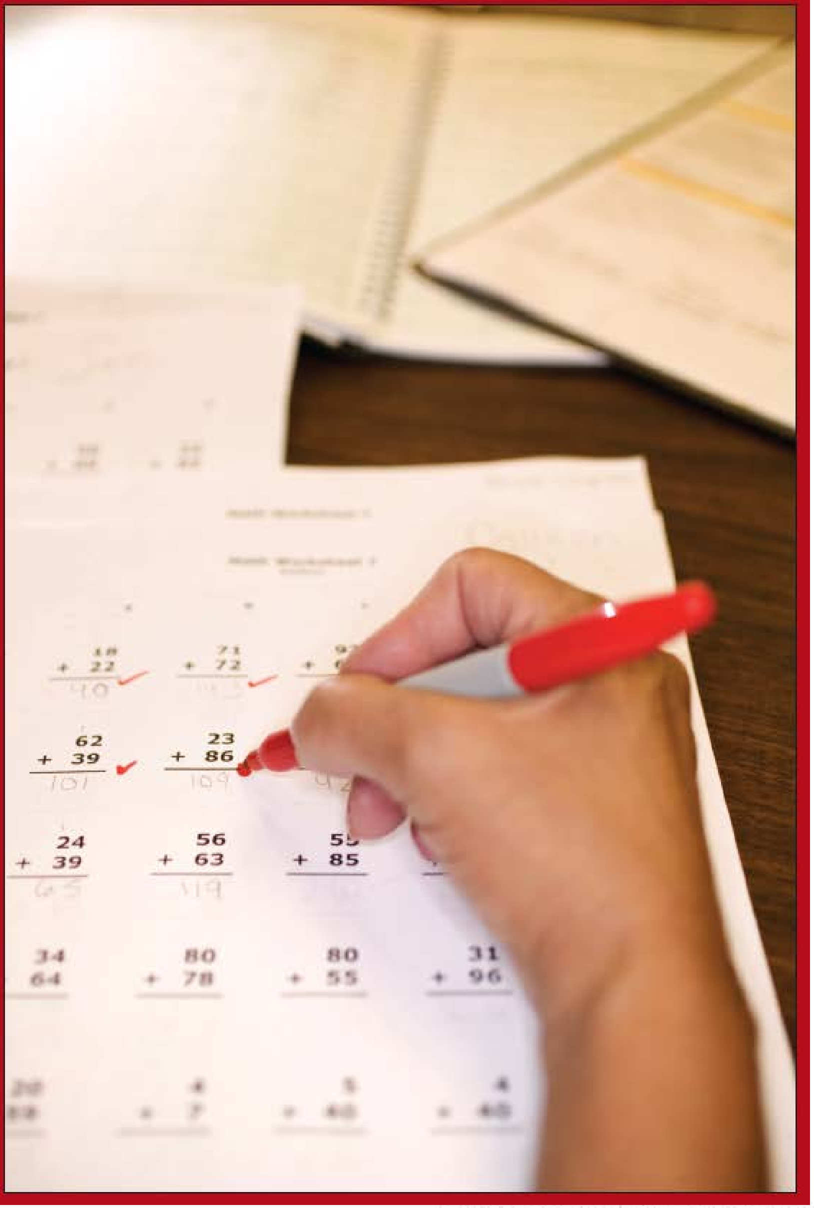
'...air quality and temperatures in classrooms are important factors in the learning process and improving them should be given as much priority as improving teaching materials and methods.'



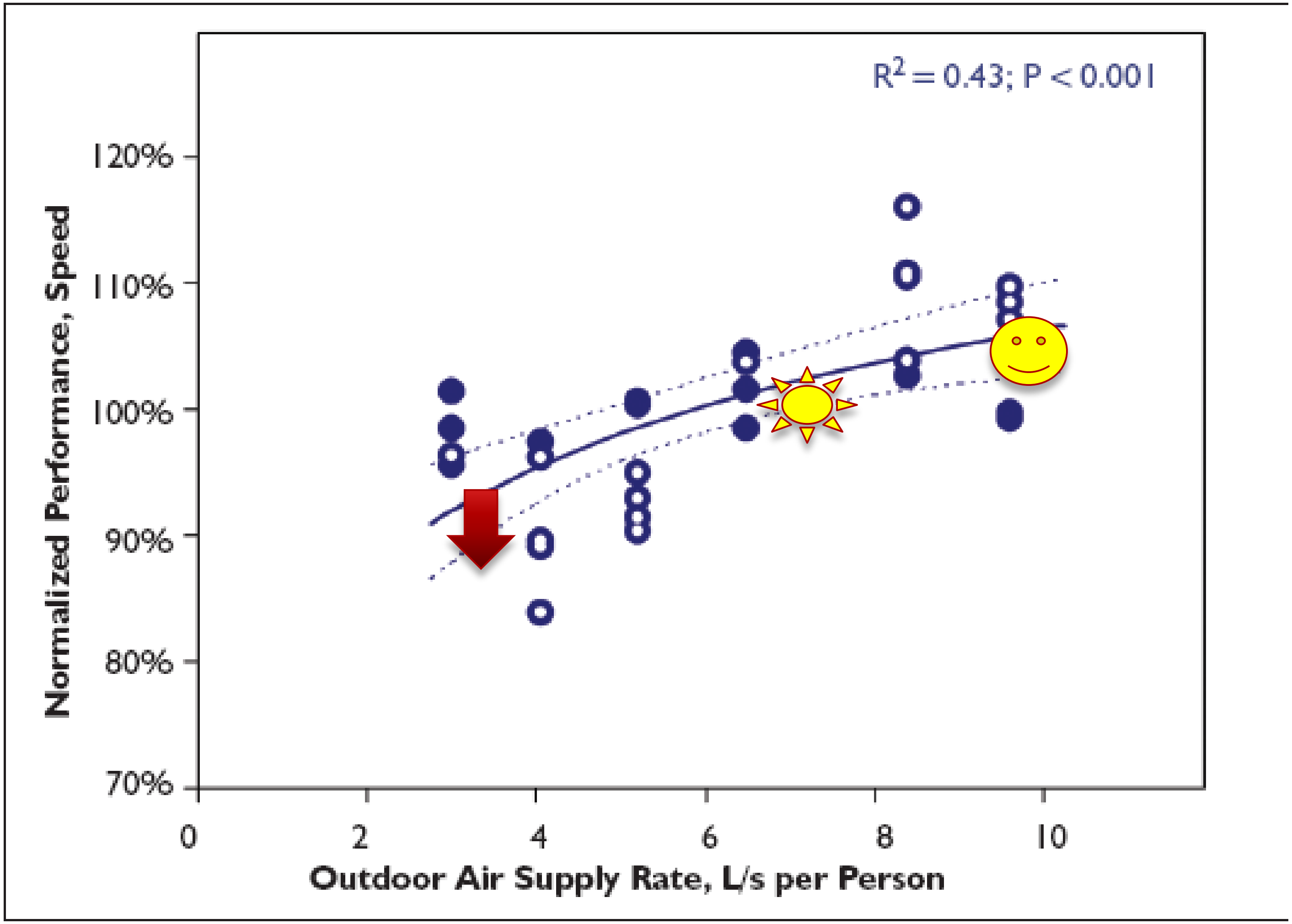
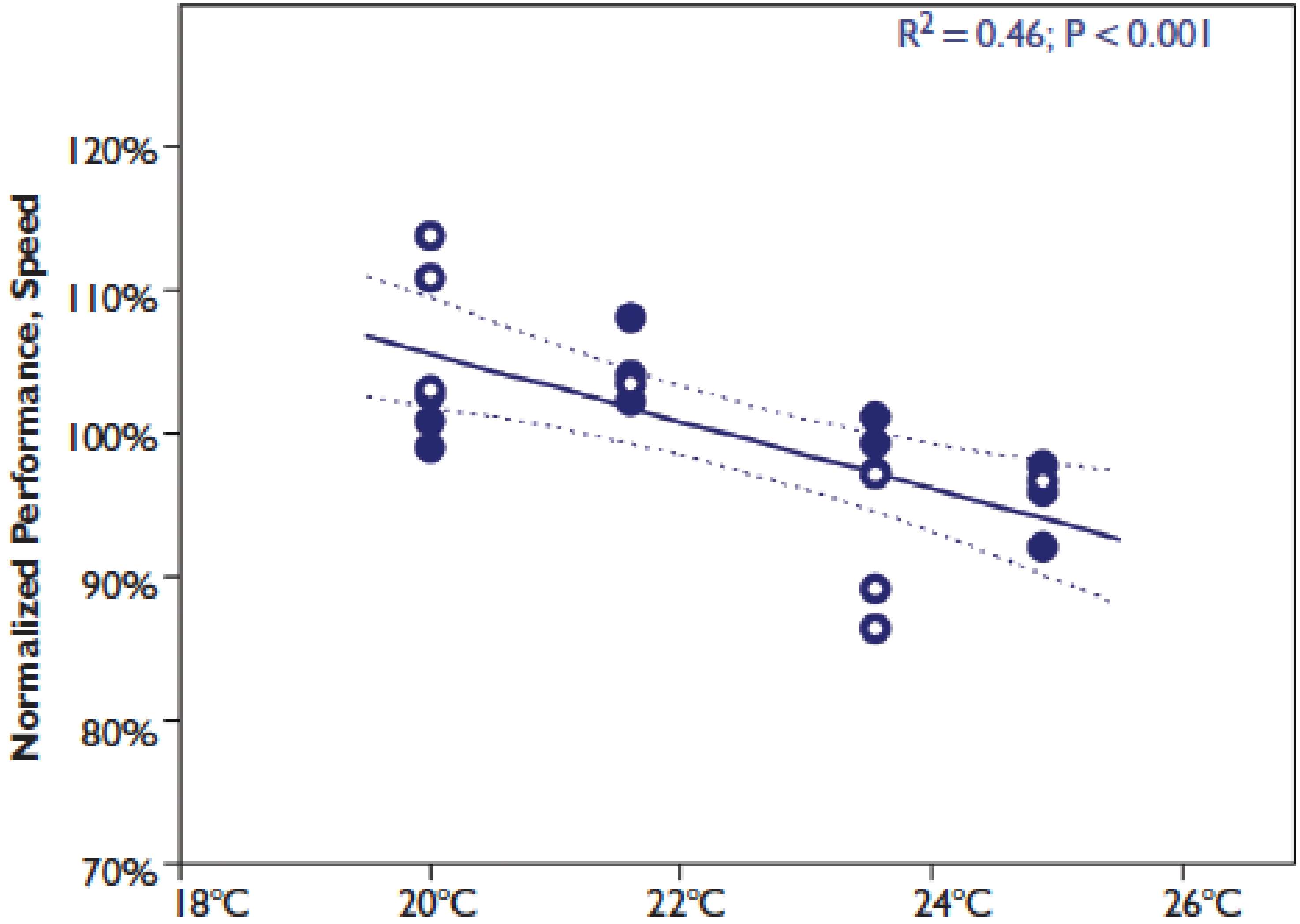


Figure 3: Performance of schoolwork as a function of outdoor air supply r



$R^2 = 0.46; P < 0.001$
120%
110%
100%
90%
80%
70%
Normalized Performance, Speed
18°C
20°C
22°C
24°C
26°C

U.S. Study (1)

- The analysis is based on measurement data from a70 elementary school district (140 fifth grade classrooms) from Southwestern United States,and student level data (N = 3109) on socioeconomic variables and standardized test scores.
- There was a statistically significant association between ventilation rates and mathematics scores, and it was stronger when the six classrooms with high ventilation rates that were indicated as outliers were filtered (> 7.1 l/s per person).

U.S. Study (2)

- The association remained significant when prior year test scores were included in the model, resulting in less unexplained variability.
- Students' mean mathematics scores (average 2286 points) were increased by up to eleven points (0.5%) per each liter per second per person increase in ventilation rate within the range of 0.9–7.1 l/s per person (estimated effect size 74 points).
- There was an additional increase of 12–13 points per each 1°C decrease in temperature within the observed range of 20–25°C (estimated effect size 67 points).

U.S. Study (3)

- Effects of similar magnitude but higher variability were observed for reading and science scores.
- In conclusion, maintaining adequate ventilation and thermal comfort in classrooms could significantly improve academic achievement of students.

- Haverinen-Shaughnessy U, Shaughnessy RJ (2015) Effects of Classroom Ventilation Rate and Temperature on Students' Test Scores. PLoS ONE 10(8): e0136165. doi:10.1371/journal.pone.0136165

Questions?

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