CO_2 MONITORING FOR OUTDOOR AIRFLOW AND DEMAND CONTROLLED VENTILATION

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EDUCATION PARTNER

CO_2 Monitoring for Outdoor Airflow and Demand-Controlled Ventilation

By Tom Lawrence

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- Course ID: 0920020152

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1

General CE hours

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Course Description:

CO2 Monitoring for Outdoor Airflow and Demand-Controlled Ventilation

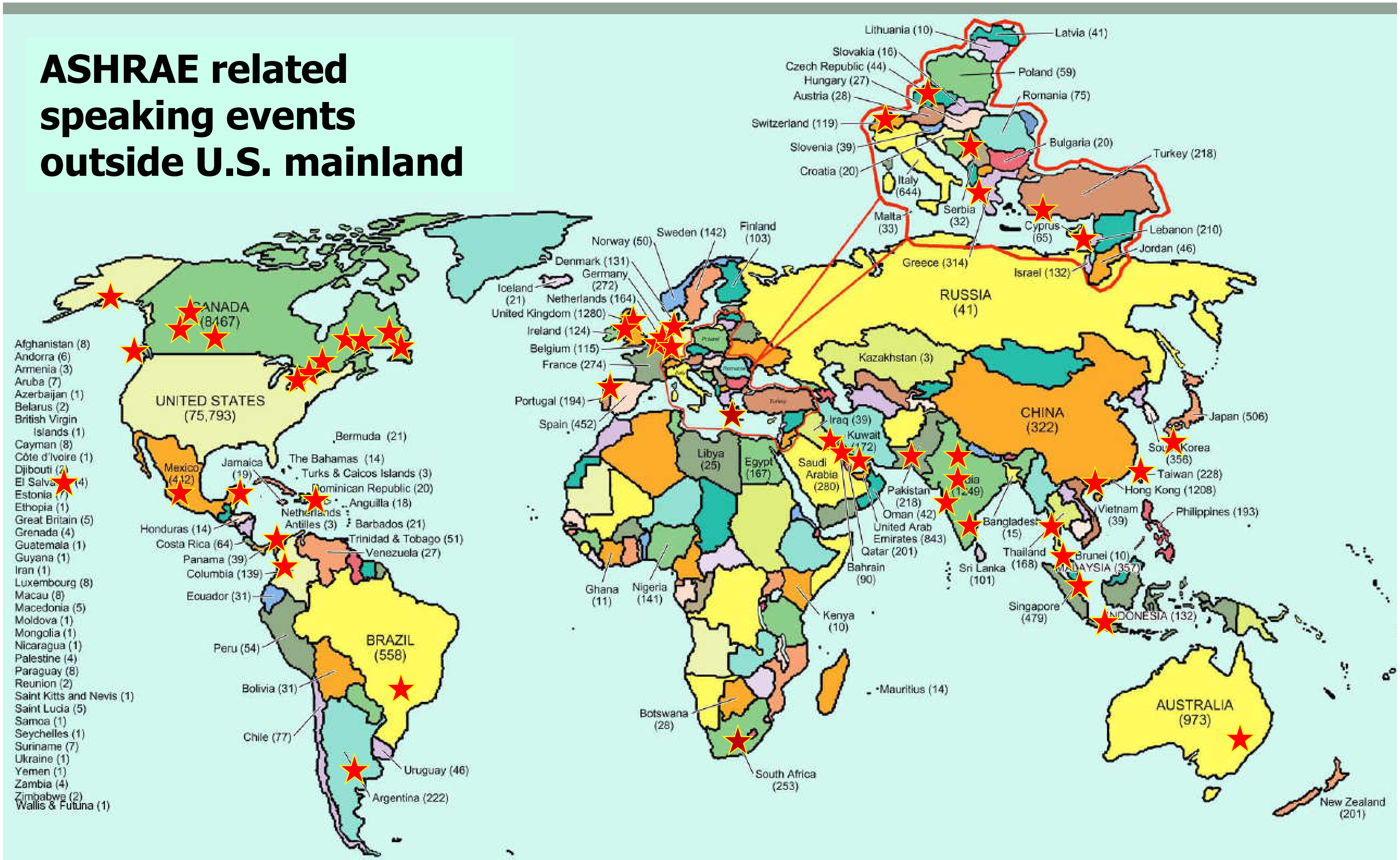
A number of programs and standards that exist for buildings today specify the use of outdoor air monitoring. Monitoring is to be done either based on CO_2 levels in the occupied space or actual measurement of outdoor airflow, depending on the space design occupancy and ventilation type (mechanical or natural). Current standards or program descriptions do not provide detailed guidance for determining what level of CO_2 should be considered the maximum concentration to expect, and those that do provide guidance are generally based on a single value above the ambient concentration. This session describes how to determine a level for CO_2 concentrations for an outdoor airflow monitoring program or as part of the upper control limit for a demand-controlled ventilation system.

Learning Objectives

1. Recognize the limitations and benefits of using CO_2 levels to monitor outdoor ventilation rates
2. Distinguish between the different expected levels of steady-state CO_2 levels for different space type
3. Explain the rationale for the different parameters in the ventilation rate procedure calculations
4. Describe the differences in requirements for outdoor air monitoring between Standard 189.1 and the LEED programs

Keywords: Ventilation rates, monitoring, steady-state CO2 level, Standard 62.1, demand-controlled ventilation

ASHRAE related speaking events outside U.S. mainland



High Performance Buildings and related topics are becoming a big focus around the globe

Overall Outline

- Brief overview of what is proper ventilation rate, and methods to introduce into the space?
- Maintaining and monitoring of indoor air quality in buildings
  - LEED existing buildings on IEQ
  - CO_2 based monitoring versus
    Direct measurement of outdoor airflow
  - What CO_2 levels are appropriate?
    - Monitoring
    - Demand-controlled ventilation setpoint
- Demand control ventilation design and issues

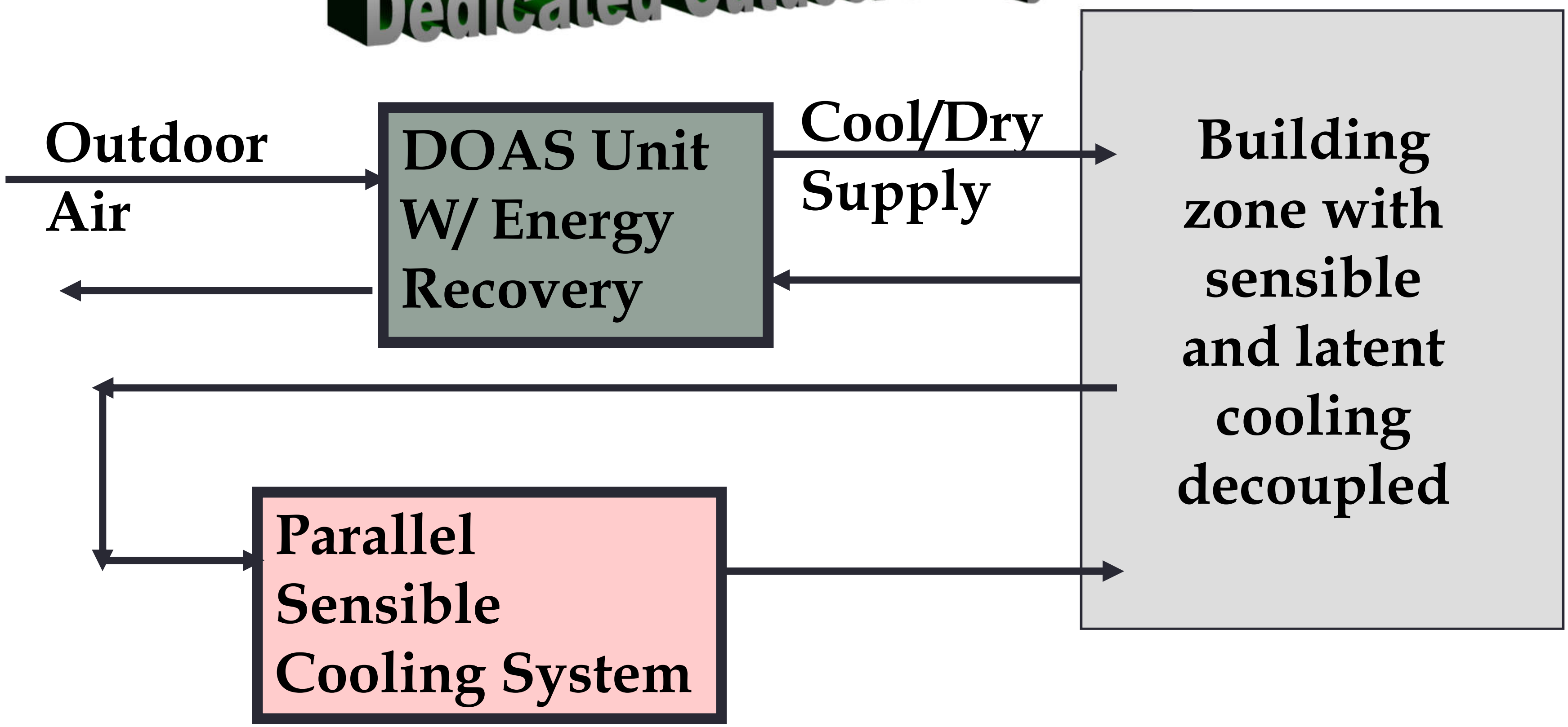
Example HVAC ‘Green’ Technology Areas for Focus and Current Trends

- **Ventilation, indoor air quality**

First, why are these so important?

- Ventilation necessary for good indoor air quality
- Energy used to condition outdoor air
- How much ventilation air is needed?
- Does it matter how ventilation is provided?

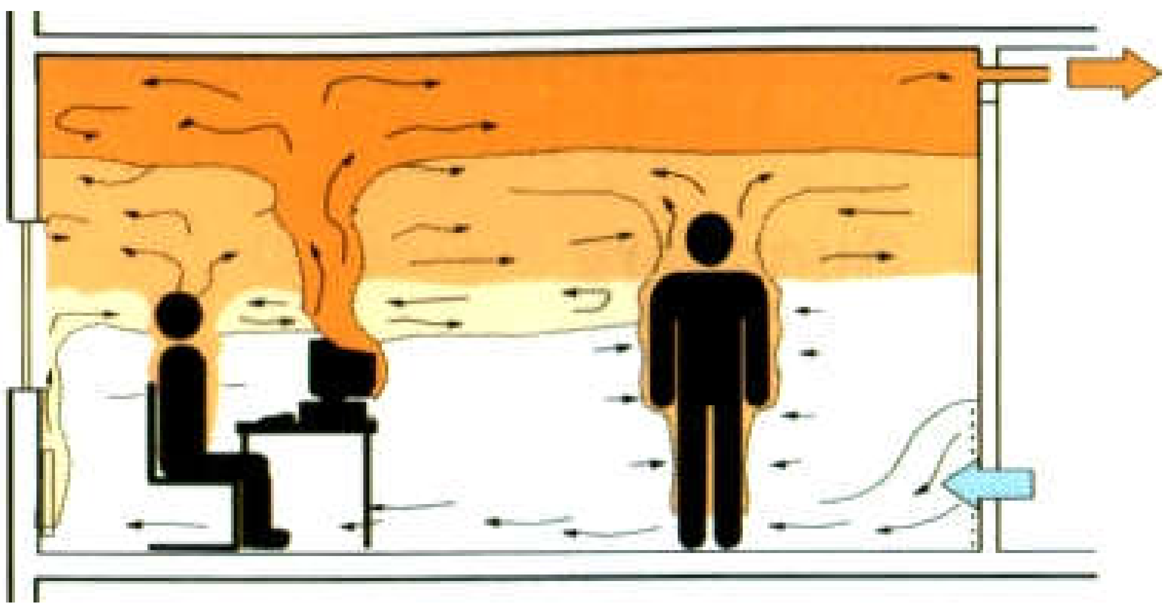
Green Tip #11: Dedicated Outdoor Air Systems



Source: Stanley A. Mumma, Ph.D., P.E. Fellow ASHRAE

Green Tip: Displacement Ventilation

- Works well in school classroom, lecture hall, auditorium, large open area
- Not same as Underfloor Air Distribution

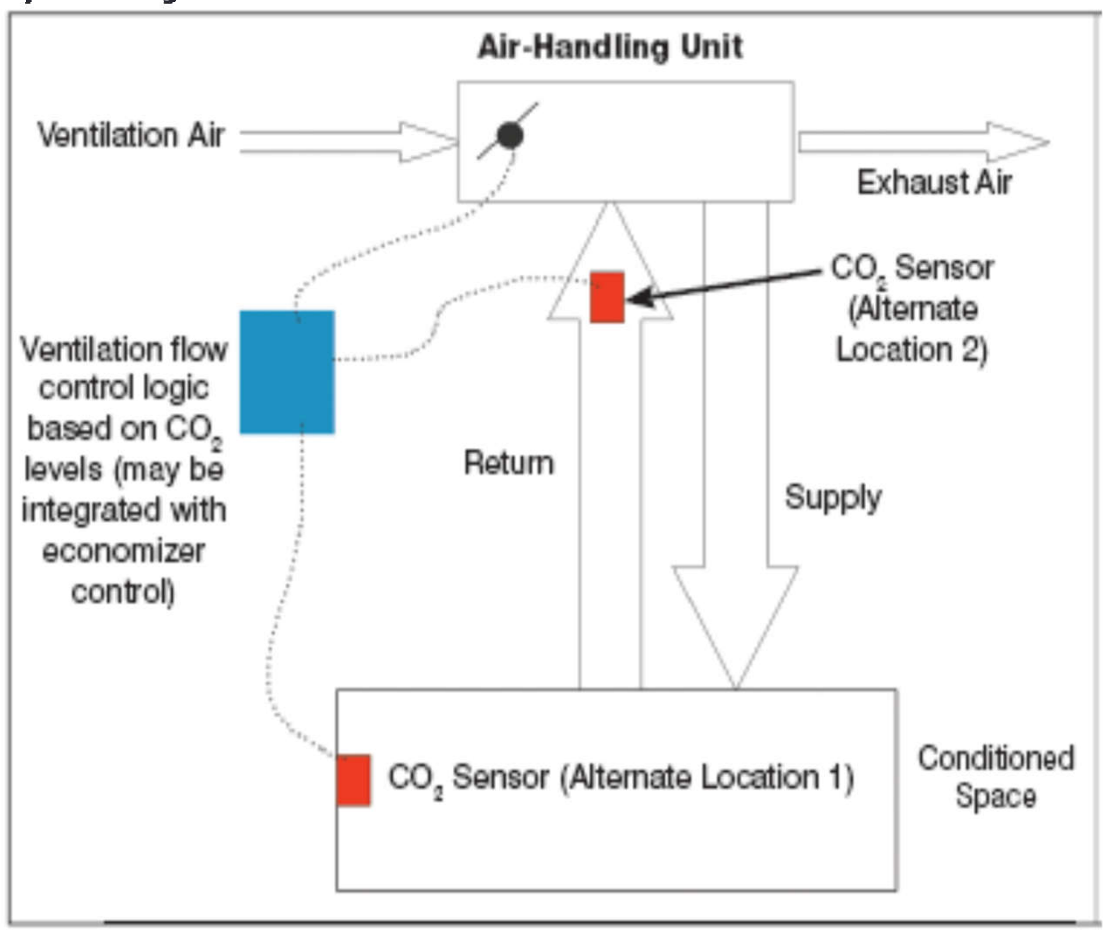


Green Tip: Demand Controlled Ventilation

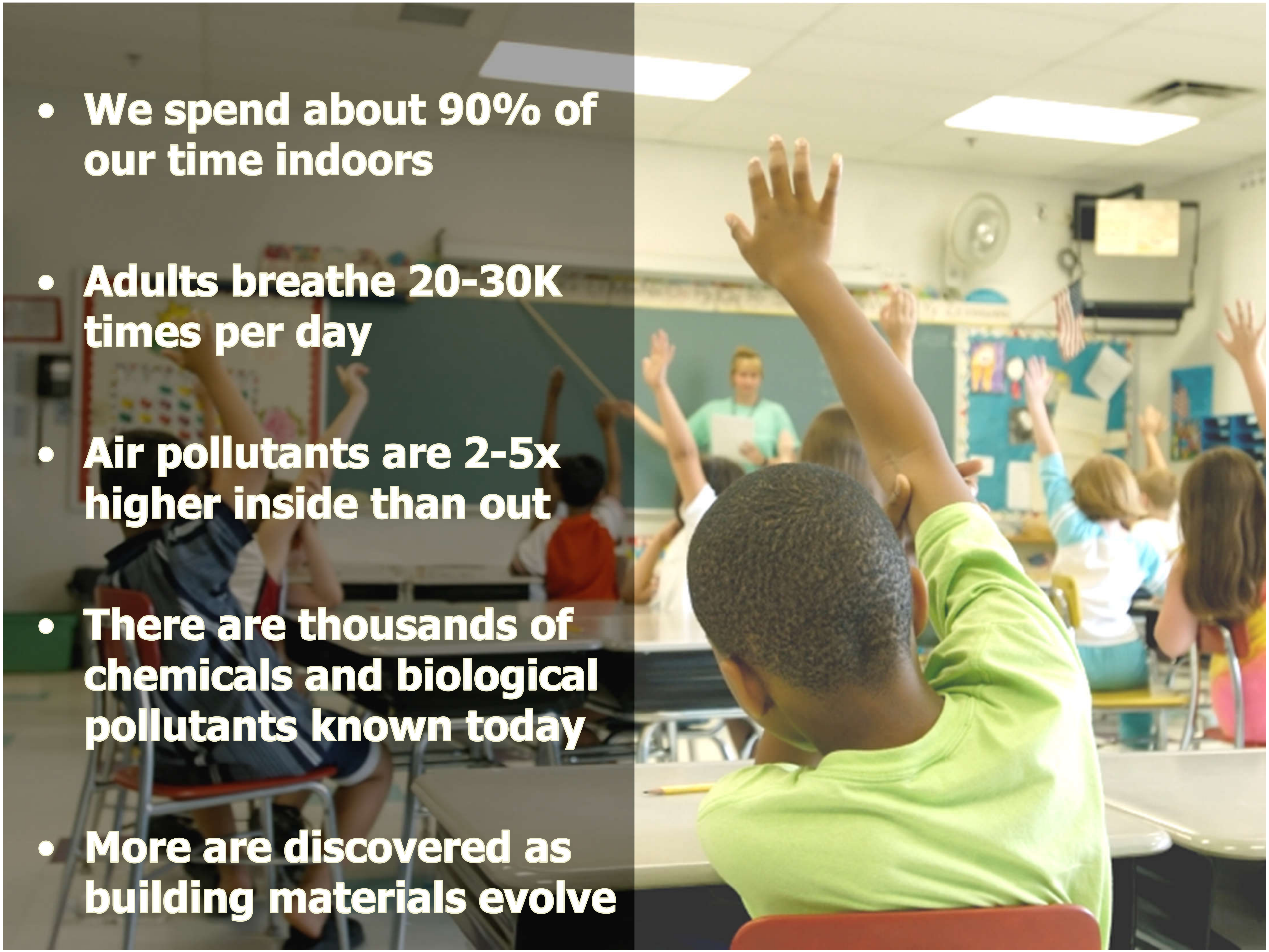
Concept

- Uses CO_2 measurement or other method to indirectly determine level of occupancy and ventilation needed

What factors are involved with CO_2 estimate of occupancy?




Why is Indoor Air Quality Important?



We spend about 90% of our time indoors
Adults breathe 20-30K times per day
Air pollutants are 2-5x higher inside than out
There are thousands of chemicals and biological pollutants known today
More are discovered as building materials evolve

What can we find in the air we breathe?

- Volatile Organic Compounds (VOCs)
- Inorganic and organic particulates, allergens
- Formaldehydes/Aldehydes
- Inorganic & combustion gases
- Mold & mildew

Clarkson University Undergrads Research Link Between Hauntings & Indoor Air Quality

A team of Clarkson University researchers is studying the possible links between reported hauntings and indoor air quality.

Associate Professor of Civil & Environmental Engineering Shane Rogers said human experiences reported in many hauntings are similar to mental or neurological symptoms reported by some individuals exposed to toxic molds. It is known that some fungi, such as rye ergot fungus, may cause severe psychosis in humans.

The links between exposure to toxic indoor molds and psychological effects in people are not well established, however, Rogers said. Notably, many hauntings are associated with structures that are prime environments to harbor molds or other indoor air quality problems.

"Hauntings are very widely reported phenomena that are not well-researched," he said. "They are often reported in older-built structures that may also suffer poor air quality. Similarly, some people have reported depression, anxiety and other effects from exposure to biological pollutants in indoor air. We are trying to determine whether some reported hauntings may be linked to specific pollutants found in indoor air."

Causes of Sick Building Syndrome

Table 1.2 Problem types identified in NIOSH building investigations.

Problem type	Buildings investigated	%
Contamination from indoor sources	80	15
Contamination from outdoor sources	53	10
Building fabric as contaminant source	21	4
Microbial contamination	27	5
Inadequate ventilation	280	53
Unknown	68	13
Total	529	100

From Seitz, T.A. 1989. *Proceedings Indoor Air Quality International Symposium: The Practitioner's Approach to Indoor Air Quality Investigations.* American Industrial Hygiene Association. Akron, OH. With permission.

What is Proper Ventilation Rate?

- Base on:
- Brief overview follows…

ANSI/ASHRAE Standard 62.1-2013
(Supersedes ANSI/ASHRAE Standard 62.1-2010)
Includes ANSI/ASHRAE addenda listed in Appendix J

Ventilation for Acceptable Indoor Air Quality

Section 3: Definitions

Acceptable indoor air quality:
Air in which there are no known contaminants at harmful concentrations and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction.

Ventilation: The process of supplying air to or removing air from a space for the purpose of controlling air contaminant levels, humidity, or temperature within a space.

Section 6 - Procedures

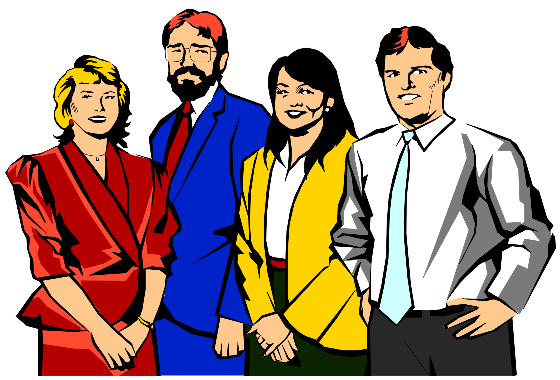
- 6.1: Use ***Ventilation Rate Procedure*** (prescriptive) or ***Indoor Air Quality Procedure*** (performance)
- 6.2: Ventilation Rate Procedure
  - 6.2.1 Outdoor air treatment for PM10 or ozone
  - 6.2.2-6.2.7 Calculation procedures [Example later]
  - 6.2.8 Exhaust requirements by space type
- 6.3: IAQ Procedure (measure it)

Rationale for Ventilation Rates

- Recognizes building as a source of indoor air pollutants
- Accounts for ventilation efficiency
- More studies to guide rate selection (almost exclusively offices)
- Rates still largely based on judgment of the ASHRAE Project Committee

Ventilation Rate Procedure

People Component — **Building Component**



Outdoor Air Ventilation Rate for Breathing Zone

$$V_{bz} = R_p P_d + R_b A_b$$

Minimum cfm/Person x **Number of People** + **Minimum cfm/sq ft** x **Building Area**

Zone Outdoor Air Flow

$$V_{oz} = V_{bz}/E_z$$

Ventilation Effectiveness

Air Distribution Effectiveness

- Standard 129 (+ lab/field experience)
- Ventilation Rate Procedure table, or test

Air Distribution Configuration (Examples)	***Ez***
Ceiling supply of cool air	1.0
Ceiling supply of warm air 15°F (8°C) or more above space temperature and ceiling return.	0.8
Floor supply of cool air and ceiling return, provided low-velocity displacement ventilation achieves unidirectional flow and thermal stratification	1.2
Floor supply of warm air and floor return	1.0
Floor supply of warm air and ceiling return	0.7
Makeup supply drawn in on the opposite side of the room from the exhaust and/or return	0.8
Makeup supply drawn in near to the exhaust and/or return location	0.5

What about this situation?

Ventilation Rate Procedure
Total Outdoor Airflow (V_{ot})

- Single zone systems

$$V_{ot} = V_{oz}$$

- 100% outdoor air systems

$$V_{ot} = \Sigma_{all\ zones} V_{oz}$$

- Multiple-zone recirculating systems

$$V_{ou} = D\Sigma_{all\ zones}(R_p \cdot P_z) + \Sigma_{all\ zones}(R_a \cdot A_z)$$

$$V_{ot} = V_{ou}/E_v$$

From Standard 62.1

TABLE 6-1 MINIMUM VENTILATION RATES IN BREATHING ZONE
(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values: Occupant Density (see Note 4)	Default Values: Combined Outdoor Air Rate (see Note 5)		Air Class
	cfm/person	L/s·person	cfm/ft^2	L/s·m^2		#/1000 ft^2 or #/100 m^2	cfm/person	L/s·person	
Educational Facilities									
Daycare (through age 4)	10	5	0.18	0.9		25	17	8.6	2
Daycare sickroom	10	5	0.18	0.9		25	17	8.6	3
Classrooms (ages 5–8)	10	5	0.12	0.6		25	15	7.4	1
Classrooms (age 9 plus)	10	5	0.12	0.6		35	13	6.7	1
Lecture classroom	7.5	3.8	0.06	0.3		65	8	4.3	1
Lecture hall (fixed seats)	7.5	3.8	0.06	0.3		150	8	4.0	1
Art classroom	10	5	0.18	0.9		20	19	9.5	2
Science laboratories	10	5	0.18	0.9		25	17	8.6	2
University/college laboratories	10	5	0.18	0.9		25	17	8.6	2
Wood/metal shop	10	5	0.18	0.9		20	19	9.5	2
Computer lab	10	5	0.12	0.6		25	15	7.4	1
General									
Break rooms	5	2.5	0.06	0.3		25	10	5.1	1
Coffee stations	5	2.5	0.06	0.3		20	11	5.5	1
Conference/meeting	5	2.5	0.06	0.3		50	6	3.1	1

Example: This Room

Outdoor Air Monitoring Options

- CO_2 based monitoring
- Direct measurement of outdoor airflow

LEEDExisting Buildings: IEQ

- **Prerequisites:**
  - Ventilation: Outdoor air per Std. 62.1 and verify exhaust fans working
  - Environmental tobacco smoke control
  - Green cleaning program

LEEDEB V4: IEQ

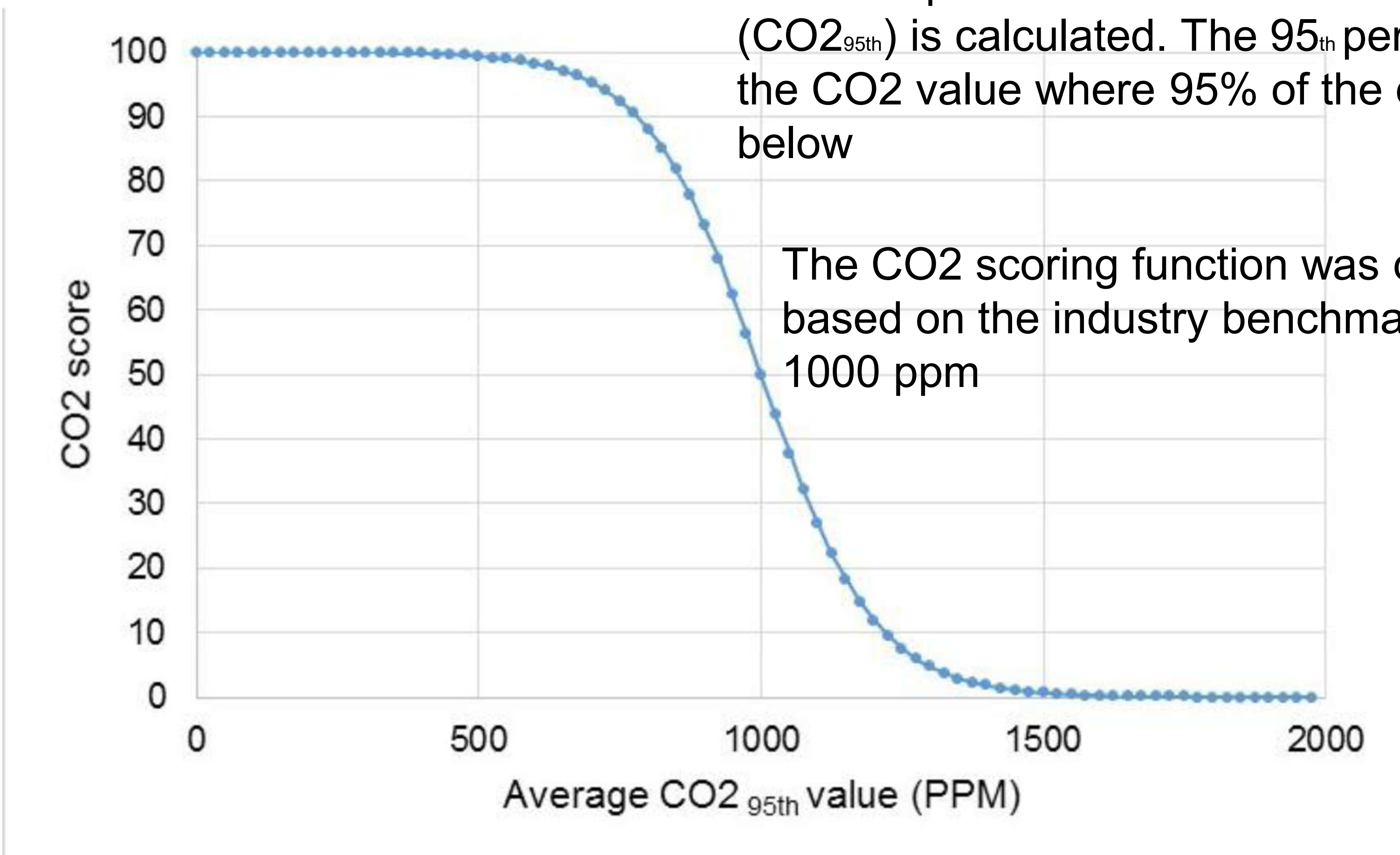
- **Credit 1.2: Outdoor Air Monitoring**
- **Case 1 – Mechanical Ventilation:**
  - For non-densely occupied, monitor to ensure outdoor air within 15% of required
- **Case 2 – Mechanical Ventilation Densely Occupied:**
  - Provide a sensor for each densely occupied (25 / 1000 ft^2) space, maintain calibration, monitor and alarm or DCV
- **Option C:** Naturally ventilated based on CO_2 sensors, 530 ppm above ambient

LEED-EB V4: IEQ

- **Credit 1.3: Increased Ventilation:** Breathing zone outdoor air increase by 30% above Std 62.1-2007 minimums
  Do you want to really do this???

V4.1: EQ ~~CREDIT~~PREREQUISITE: INDOOR ENVIRONMENTAL QUALITY PERFORMANCE

The 95th percentile value for each location ($CO2_{95th}$) is calculated. The 95_{th} percentile is the CO2 value where 95% of the data falls below



The CO2 scoring function was developed based on the industry benchmark level of 1000 ppm

Overall Outline

- Brief overview of what is proper ventilation rate, and methods to introduce into the space?
- Maintaining and monitoring of indoor air quality in buildings
  - LEED existing buildings on IEQ
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    Direct measurement of outdoor airflow
  - What CO_2 levels are appropriate?
    - Monitoring
    - Demand-controlled ventilation setpoint
- Demand control ventilation design and issues

CO_2 Monitoring Questions/Issues

- What is it, and what is the purpose?
- Anyone tried this? And was it successful?
- What should be the "setpoint" for too high CO_2 level?
- Does one size (one CO_2 level) fit all?
- Sensor accuracy – does it make a difference?
- Is this an ever moving target?
  - Occupancy variations
  - Room size, air distribution, mixing

CO_2 Monitoring Guidance

Selecting CO_2

Criteria for Outdoor Air Monitoring

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

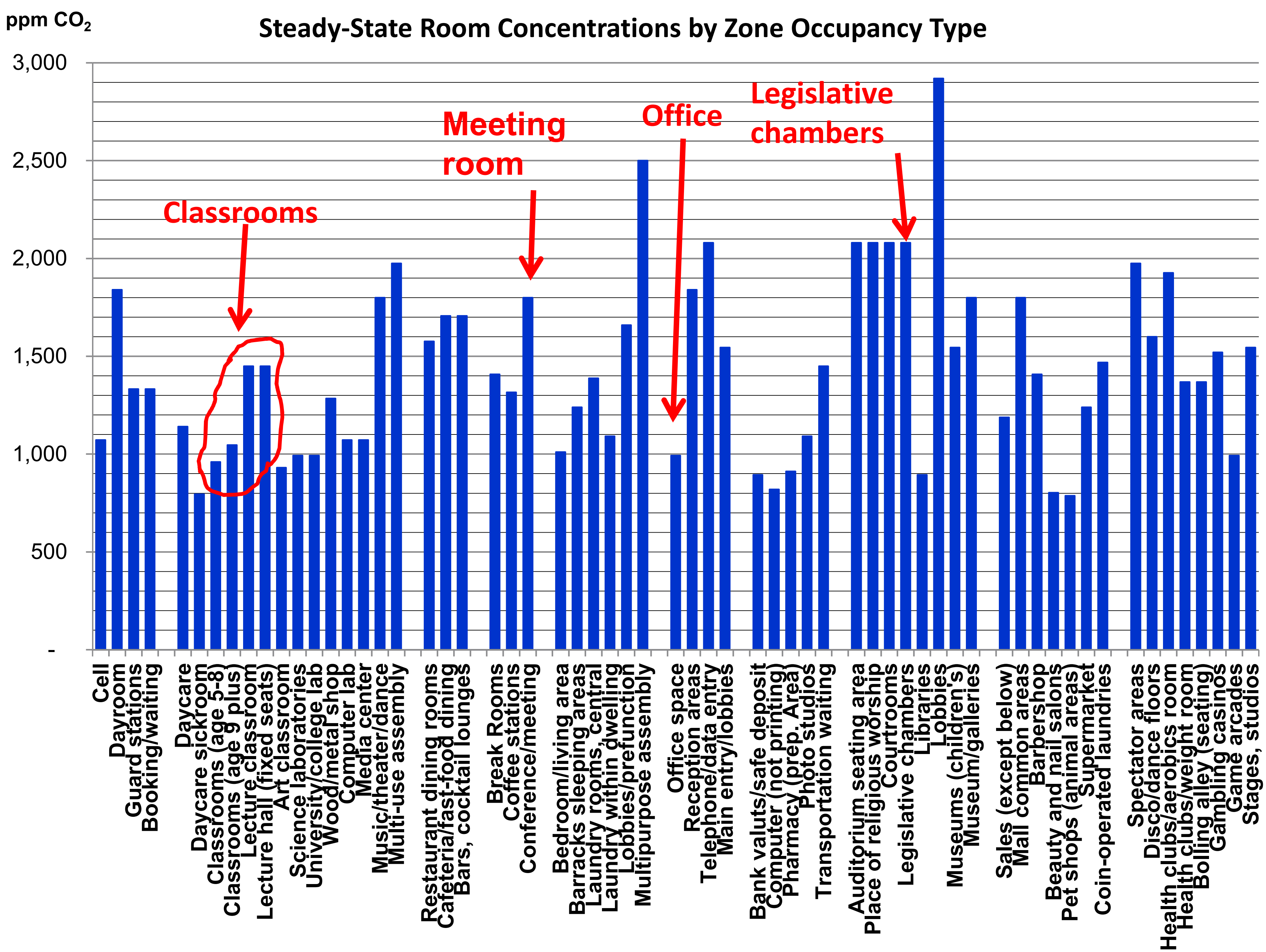
ASHRAE Journal ashrae.org December 2008

Determining Steady-State CO_2 Concentration

$$C_R = C_{OA} + \frac{\text{Rate of } CO_2 \text{ generation}}{\text{Rate of } CO_2 \text{ removal}}$$

- Generation based on # people and their activity level (@ 1 MET = 0.0084 cfm/person)
- Removal rate

<u>Also can consider as:</u>
CO_2 removal = Outdoor air flow x [outlet-inlet] CO_2 concentration


ppm CO_2
Steady-State Room Concentrations by Zone Occupancy Type
3,000
2,500
2,000
1,500
1,000
500
-
Classrooms
Meeting room
Office
Legislative chambers
Cell
Dayroom
Guard stations
Booking/waiting
Daycare
Daycare sickroom
Classrooms (age 5-8)
Classrooms (age 9 plus)
Lecture classroom
Lecture hall (fixed seats)
Art classroom
Science laboratories
University/college lab
Wood/metal shop
Computer lab
Media center
Music/theater/dance
Multi-use assembly
Restaurant dining rooms
Cafeteria/fast-food dining
Bars, cocktail lounges
Break Rooms
Coffee stations
Conference/meeting
Bedroom/living area
Barracks sleeping areas
Laundry rooms, central
Laundry within dwelling
Lobbies/prefunction
Multipurpose assembly
Office space
Reception areas
Telephone/data entry
Main entry/lobbies
Bank valuts/safe deposit
Computer (not printing)
Pharmacy (prep. Area)
Photo studios
Transportation waiting
Auditorium seating area
Place of religious worship
Courtrooms
Legislative chambers
Libraries
Lobbies
Museums (children's)
Museum/galleries
Sales (except below)
Mall common areas
Barbershop
Beauty and nail salons
Pet shops (animal areas)
Supermarket
Coin-operated laundries
Spectator areas
Disco/dance floors
Health clubs/aerobics room
Health clubs/weight room
Bolling alley (seating)
Gambling casinos
Game arcades
Stages, studios

Potential CO_2 Monitoring Situations

- Monitoring for “adequate” outdoor airflow
  - *Expected steady-state concentration, with allowance for sensor error*
- Demand-controlled ventilation, upper control limit
  - *Allowance for sensor error, system response time, etc. (steady-state – 10%)*
- Monitoring for LEED-EB Credit 1.2
  - *Expected steady-state concentration + 15%*

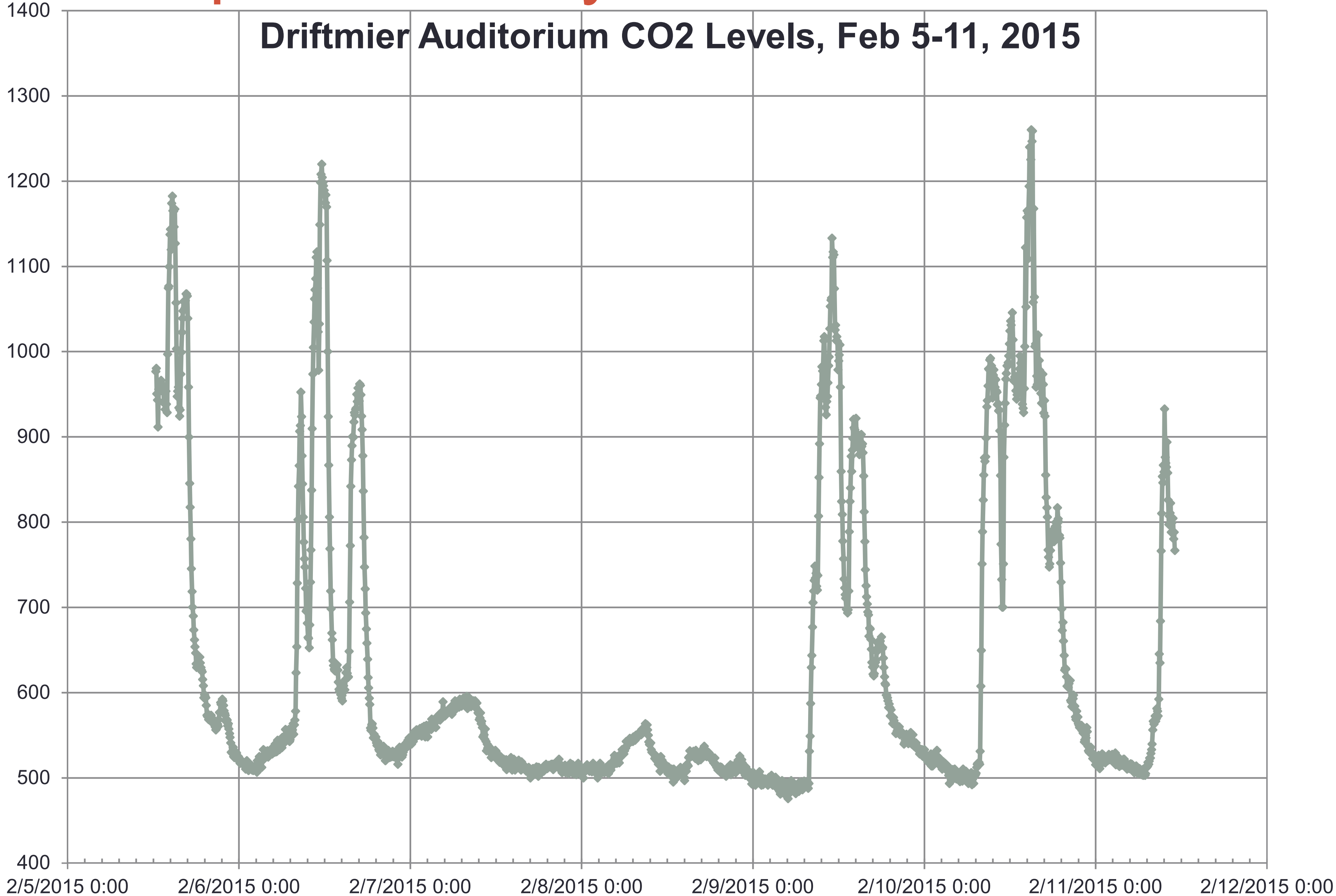
Table 1: Computed and Recommended CO_2 Concentrations for Outdoor Airflow Monitoring or DCV Upper Control Limit

	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
Office Buildings								
Office Space	17	8.5	1.2	0.010	993	1,100	894	1,142
Reception Areas	7	3.5	1.2	0.010	1,840	2,000	1,656	2,116
Telephone/Data Entry	6	3	1.2	0.010	2,080	2,200	1,872	2,392
Main Entry/Lobbies	11	5.5	1.5	0.013	1,545	1,700	1,391	1,777
Public Assembly Spaces								
Auditorium Seating Area	5	2.7	1	0.008	2,080	2,200	1,872	2,392

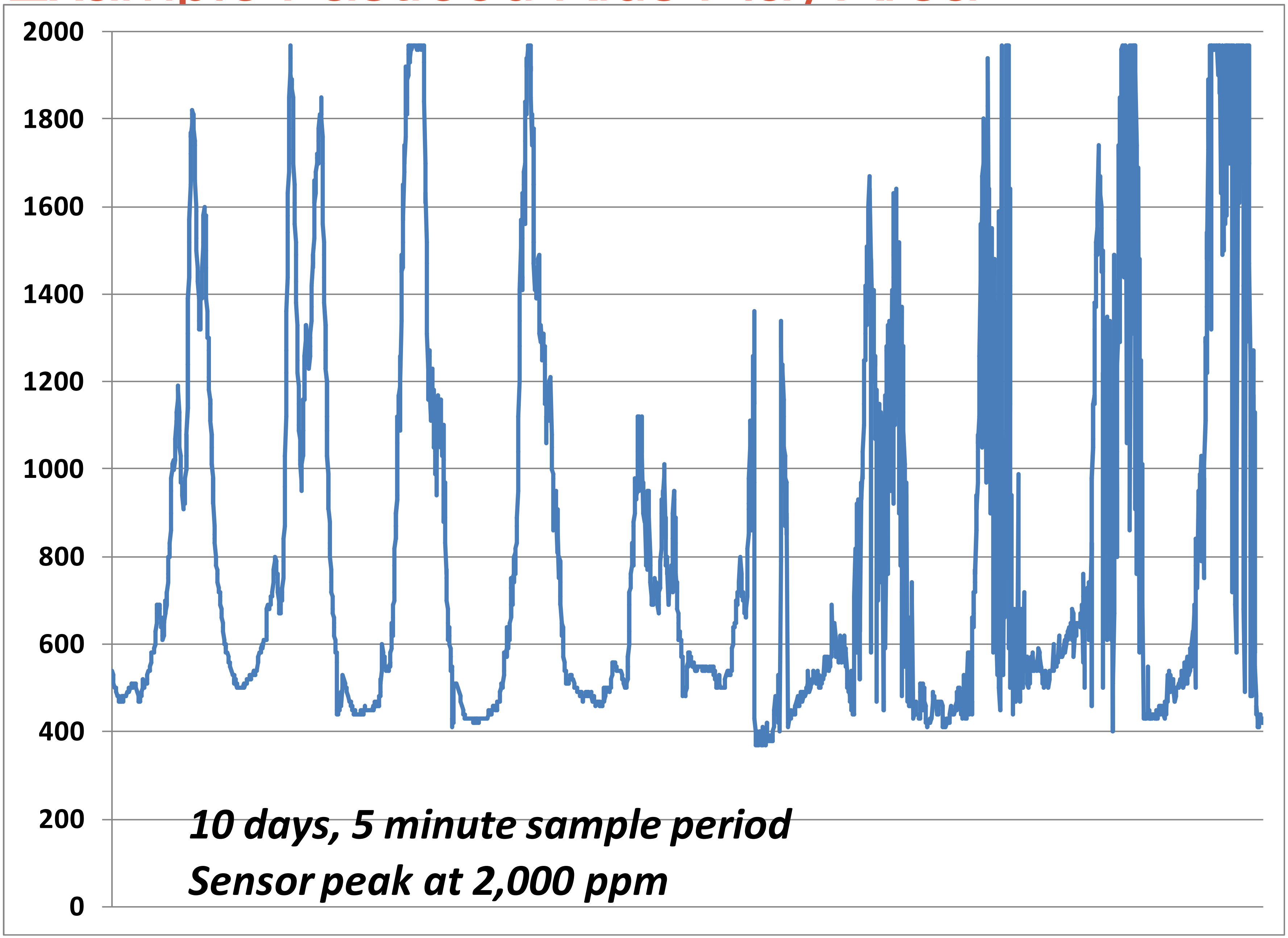
Example – This Room

0.01	# People	Total outdoor airflow		Assumed activity level	CO2 Generation	Actual Steady-State Concentration	Monitoring Program Concentration (Alarm Level)	DCV Upper Control Limit Concentration (Caution Level)	LEED-EB IEQ Credit 1 Concentration
For this room:		cfm	l/s						
	80	460		1	0.0084	**1,861**	1,936	1,675	2,140

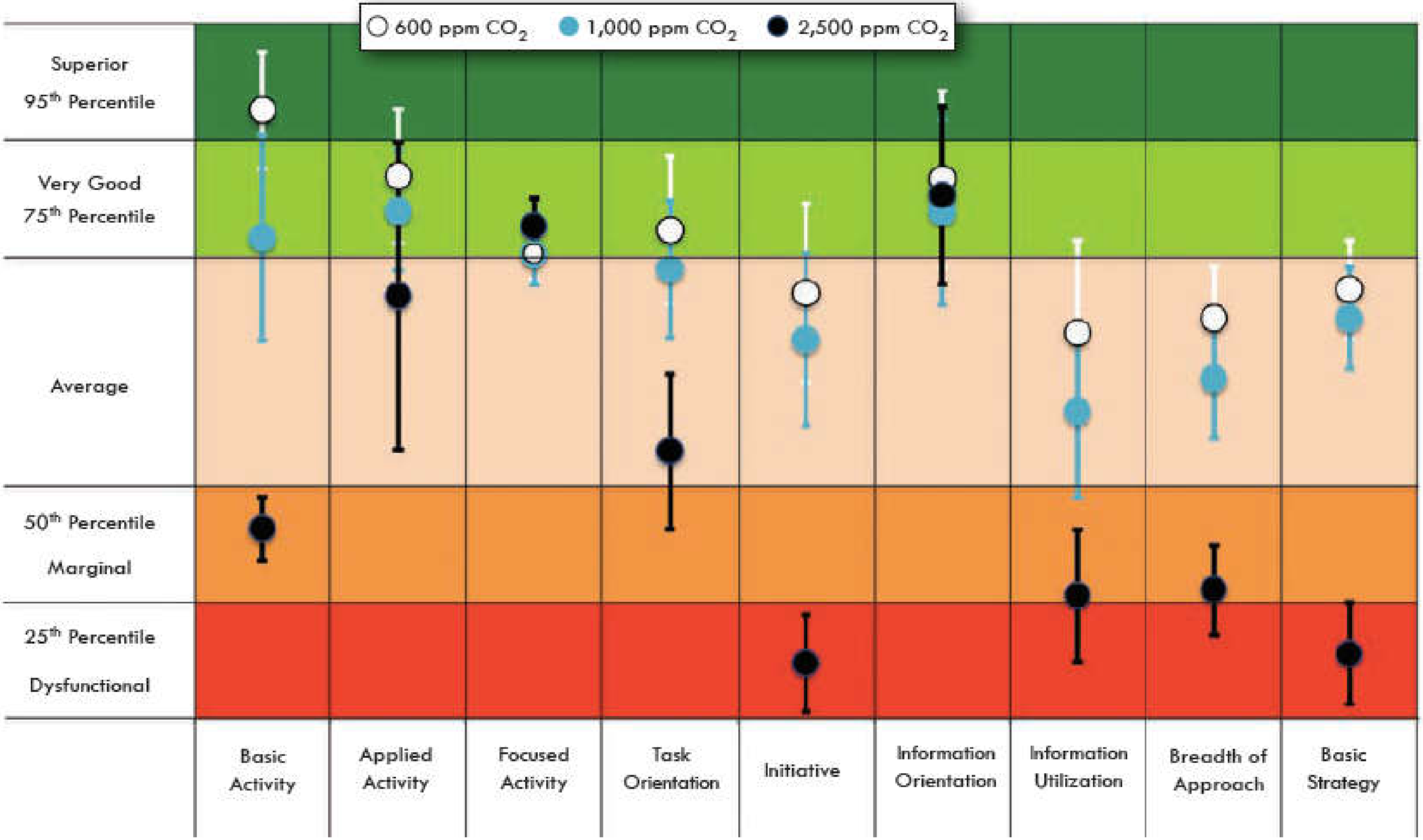
Example University Classroom



Example Fastfood Kids Play Area



Is CO_2 an Indoor Pollutant?



Fisk, et al., ASHRAE Journal March 2013

Outdoor Air Monitoring: Potential Responses to Alarm

- Do nothing…
  "Ignore problems as they will likely go away"
- Increase (if possible) outdoor air intake flow
- Schedule a system inspection
- Immediate response to check outdoor air intakes, damper positions
- Review room usage and expected occupancy, was this a fluke?

ASHRAE Standard 189.1 Outdoor Air Monitoring and IEQ

Indoor Environmental Quality

§8.3.1 IAQ

- Minimum ventilation design outdoor airflow rate per Standard 62.1, using Ventilation Rate Procedure

§8.3.2 Outdoor Air Monitoring

- Permanently mounted,
  direct outdoor airflow measurement
  ±~~15~~10% of ***minimum outdoor airflow***
  (Differs from LEED in that CO_2 monitoring for densely occupied spaces not specified)
- Constant volume air supply, damper position feedback allowable instead

High Performance Building Operation Plan

Indoor Environmental Quality

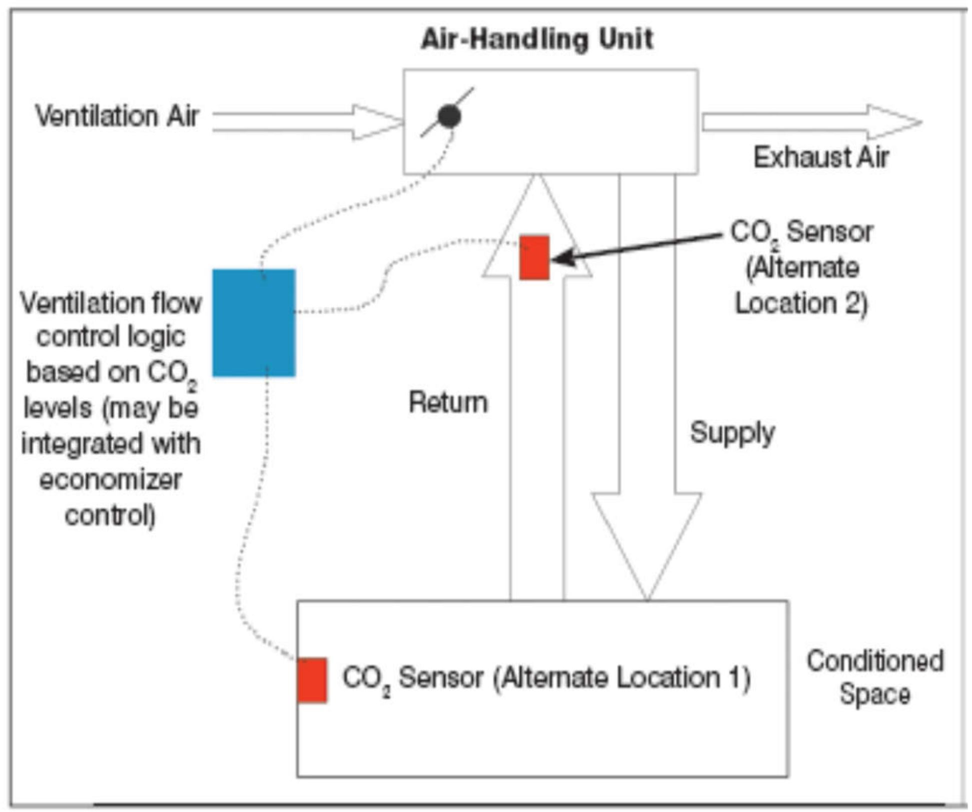
- Outdoor airflow measurement using handheld or permanently installed stations
  - Procedure to react if 10% lower than *minimum outdoor airflow rate*
- Indoor air quality
  - Air cleaning equipm’t in non-attainment areas
  - Biennial monitoring through testing, occupant perception or complaint/response programs
- Green cleaning

Demand Control Ventilation - Concept

- Primary method is to use CO_2 levels or other methods to indirectly determine level of occupancy and ventilation needed

Alternative and more inclusive term: Outdoor air reset

What factors are involved with CO_2 estimate of occupancy?



Demand Control Ventilation – Pro / Con Summary

Demand-Controlled Ventilation and Sustainability

By Tom Lawrence, Ph.D., P.E., Member ASHRAE

ASHRAE Journal, December 2004

Pro

- Reduces building's energy use through not conditioning 'unnecessary' outdoor air
- Maintains adequate ventilation through monitoring

Con

- Additional first cost
- Sensors need calibration

Another reference:

Demand-Controlled Ventilation

May 2006

CO_2-Based DCV Using 62.1-2004

By Steven T. Taylor, P.E., Fellow ASHRAE

Std. 62.1

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

$$V'_{ot} = \frac{V'_{bz}}{E_z}$$

Mass balance of CO2

$$\dot{N} = V'_{ot} (C_R - C_{OA})$$

$$\dot{N} = V_{pz} (C_{RA} \quad C_s) + V'_{ot} (C_R - C_{RA})$$

$$\dot{N} = k m P_z$$

k = 0.0084 cfm/met/person

$$V'_{ot} = \frac{R_a A_z}{E_z = \frac{R_p (C_R - C_{OA})}{8400m}}$$

Design Decisions

- Sensor location
- # of sensors
  - Should we include an outdoor air CO_2 sensor?
  - How many… one for each room? Per zone?
- Control integration
- Design + installation, commissioning
- Alternatives to CO_2 based control

Design Decisions

- **Sensor location**
  - **Ideally in the zone, at breathing height**
- # of sensors
  - Should we include an outdoor air CO_2 sensor?
  - How many… one for each room? Per zone?
- Control integration
- Design + installation, commissioning
- Alternatives to CO_2 based control

Sensor Location ?

Design Decisions

- Sensor location
- **# of sensors**
  - Should we include an outdoor air CO_2 sensor?
  - How many… one for each room?
    Per zone?
  - Don't locate CO_2 sensor below t-stat (heat)
  - Include occupancy sensor also, controls VAV minimum setpoint
- Control integration
- Design + installation, commissioning
- Alternatives to CO_2 based control

Issues with # of Sensors

- Accuracy

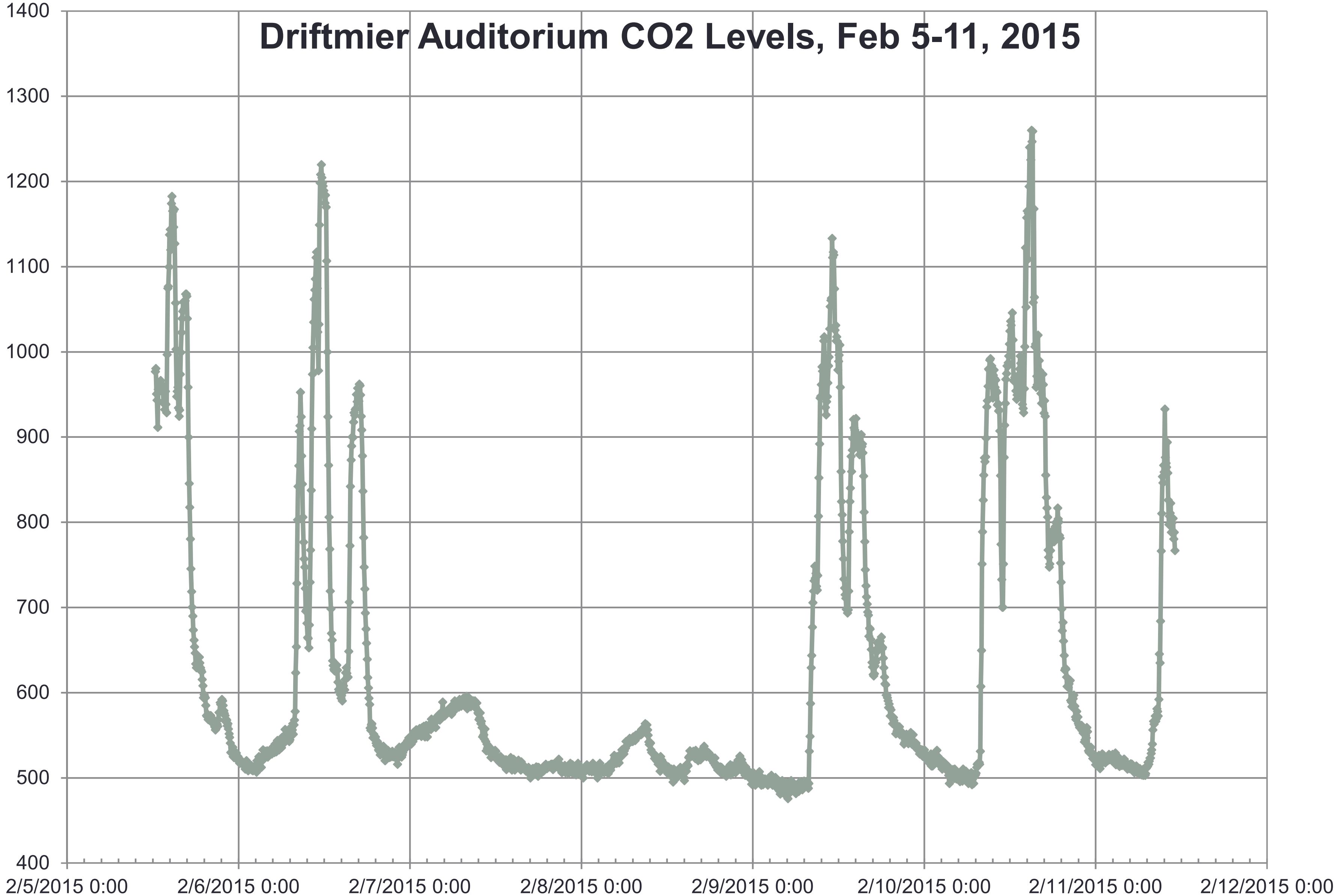
What is typical sensor accuracy (as quoted by mfr's)?

- Calibration and drift
- Do they work as promised?
- Need for good commissioning of the components and system as a whole

Design Decisions

- Sensor location
- # of sensors
  - Should we include an outdoor air CO_2 sensor?
  - How many… one for each room? Per zone?
- **Control integration**
  - Zone CO_2 sensor does not account for VAV box signals
  - Upper limit set on outdoor air? (mitigates failure of sensor, potential freezing, etc.)
  - Interaction with air side economizing
  - Minimum OA flow = building zone component of ventilation rate procedure
  - Building pressurization issues …
  - What CO_2 setpoint to use
- Alternatives to CO_2 based control

Allowing Response Time and CO_2 Changes



CO2 DCV in Multi-Zone Systems

- The Standard 62.1 User's Manual (2010) one DCV approach for single-zone systems, but states that DCV for multiple-zone recirculating systems (MZS) have not been adequately developed or researched
- ASHRAE research project RP1547 studied single-path VAV system control logic for CO_2 based dynamic reset.
  - CO_2-based dynamic reset, now combined with a zone primary airflow set-point reset
  - zone primary airflow rate minimum set-point is first reset to increase system ventilation efficiency, which leads to a reduced system outdoor airflow rate
- **STILL COMPLICATED!**

Xingbin Lin & Josephine Lau (2015) Demand-controlled ventilation for multiple-zone HVAC systems—Part 2: CO_2-based dynamic reset with zone primary airflow minimum set-point reset (RP-1547), Science and Technology for the Built Environment, 21:8, 1100-1108, DOI: 10.1080/23744731.2015.1072043

Design Decisions

- Sensor location
- # of sensors
  - Should we include an outdoor air CO_2 sensor?
  - How many… one for each room? Per zone?
- Control integration
- **Design + installation, commissioning**
  - **Who is the responsible party for design and integration?**
  - **Commission (and then re-commission 1-2 years later)**
- Alternatives to CO_2 based control

Design Decisions

- Sensor location
- # of sensors
  - Should we include an outdoor air CO_2 sensor?
  - How many… one for each room? Per zone?
- Control integration
- Design + installation, commissioning
- **Alternatives to CO_2 based control**
  - **Improved IR sensor occupancy detection**
  - **Scheduled occupancy**
  - **Smart buildings, smart controls concepts**

Thank you!

- Comments, questions, concerns, advice …

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