HOW TO IMPLEMENT DEMAND CONTROL VENTILATION & COMPLY WITH ASHRAE STANDARDS

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HOW TO IMPLEMENT DEMAND CONTROL VENTILATION & COMPLY WITH ASHRAE STANDARDS

- Course Description
- ASHRAE standards 90.1 and 189.1 require demand control ventilation in some instances. ASHRAE standard 62.1 allows demand control ventilation but places restrictions on its application. Many existing installations do not comply with the requirements of ASHRAE Standard 62.1. What is required and what strategies and technologies can be used to meet the requirements of the all the standards?

LEARNING OBJECTIVES

- After attending this presentation, participants will be able to:
  - Explain the minimum building ventilation requirements prescribed by ANSI/ASHRAE 62.1
  - Identify a common ventilation control design that does not meet the minimum requirements
  - Distinguish between buildings where advanced DCV control techniques are feasible and those where they are not
  - Describe current research showing relationships between ventilation and peoples' performance

VENTILATION RATES (CFM/PERSON)

- ASHVE (1895) 30 cfm/person
- IAQ = f(T, Volume, RH) ?
- Yaglou (1936) Adults 12-20 cfm/p Children 17-25 cfm/p
- ASHRAE 62-1973 15 minimum, 20 recommended

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- ASHRAE 62-1973 15 minimum, 20 recommended
- ASHRAE 62-1981 5 cfm/person

VENTILATION RATES (CFM/PERSON)

- ASHVE (1895) 30 cfm/person
- IAQ = f(T, Volume, RH) ?
- Yaglou (1936) Adults 12-20 cfm/p Children 17-25 cfm/p
- ASHRAE 62-1973 15 minimum, 20 recommended
- ASHRAE 62-1981 5 cfm/person
- ASHRAE 62-1989 Offices 20, Classrooms 15
- ASHRAE 62.1-2004 Offices ~17 Classrooms ~13-17 *estimated because rates are no longer just cfm/person*

DEMAND CONTROL VENTILATION STANDARDS

- ANSI/ASHRAE/IESNA 90.1-2016
- ANSI/ASHRAE/USGBC/IES 189.1-2014
- ANSI/ASHRAE 62.1-2016

DEFINITIONS

- 90.1-2016 ***demand control ventilation (DCV)***: a ventilation system capability that provides the automatic reduction of outdoor air intake below design rates when the actual occupancy of spaces served by the system is less than design occupancy.
- 189.1-2014 ***demand control ventilation (DCV):*** see ANSI/ASHRAE/IESNA Standard 90.1.
- 62.1-2016 ***demand controlled ventilation (DCV):*** any means by which the breathing zone outdoor air flow (V_{bz}) can be varied to the occupied space or spaces based on the actual or estimated number of occupants and/or ventilation requirements of the occupied zone.

ANSI/ASHRAE/IESNA 90.1-2016

- **6.4.3.8 Ventilation Controls for High-Occupancy Areas.** Demand control ventilation (DCV) is required for spaces larger than 500 ft² and with a design occupancy for ventilation of greater than **25** people per 1000 ft² of floor area and served by systems with one or more of the following:
  a) an air-side economizer
  b) automatic modulating control of the outdoor air damper or
  c) a design outdoor airflow greater than 3000 cfm

  Excludes correctional cells, daycare sickrooms, science labs, barbers, beauty, and bowling

ANSI/ASHRAE/USGBC/IES 189.1-2014

- **7.4.3.2 Ventilation Controls for Densely Occupied Spaces.** *DCV* is required for *densely occupied spaces.*
- ***densely occupied space:*** those spaces with a design occupant density greater than or equal to 25 people per 1000 ft² (100 m²).

90.1 VS 189.1 – EDUCATION FACILITY

90.1-2010 Densely Occupied Spaces	189.1-2014 and 90.1-2016 Densely Occupied Spaces - Add to 90.1-2010
Lecture Classroom Lecture Hall Multi-Use Assembly	Daycare Daycare sickroom* Classrooms (ages 5-8) Classrooms (age 9 plus) Science laboratories* University/college laboratories Computer lab Media Center Music/theater-dance Gym, stadium (play area)

90.1 VERSUS 189.1 – OFFICE

90.1 Densely Occupied Spaces	189.1-2014 and 90.1-2016 Densely Occupied Spaces - Add to 90.1-2010
Conference/meeting Data entry	Break rooms Reception areas

ANSI/ASHRAE/USGBC/IES 189.1-2014

- The *DCV* system shall be designed to be in compliance with ANSI/ASHRAE Standard 62.1. Occupancy assumptions shall be shown in the design documents for spaces required to have *DCV.* All CO_2 sensors used as part of a *DCV* system or any other system that dynamically controls outdoor air shall meet the following requirements:
  - a through d

VARYING VENTILATION RATES – 62.1

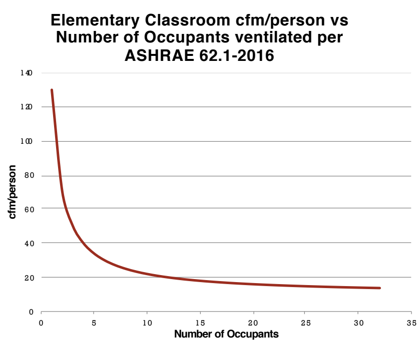
- Requirements of Standard 62
  - Ventilation Rates
  - Variable Load Conditions
  - Dynamic Reset
- Dynamic Reset
- Using CO_2 for Dynamic Reset
  - Must estimate number of people
  - Errors in assumptions for many applications
  - How to address multiple spaces

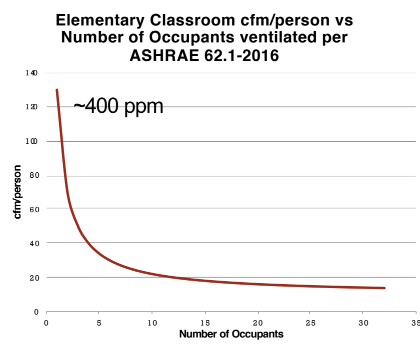
REQUIREMENTS – VENTILATION RATE

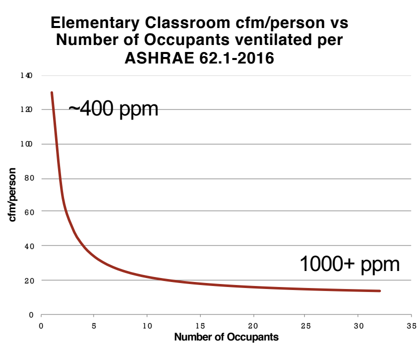
- **6.2.2.1 Breathing Zone Outdoor Airflow.** The design outdoor airflow required in the *breathing zone* of the occupiable space or spaces in a *zone, i.e., the breathing zone outdoor airflow* (V_{bz}), shall be determined in accordance with Equation 6.2.2.1.
- $V_{bz} = R_p \cdot P_z + R_a \cdot A_z$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







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

$V_{ot} = V_{oz}$ (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:

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

$Vou = D^* \Sigma_{all\ zones} R_pP_z + \Sigma_{all\ zones} R_aA_z$ (6.2.5.3)

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:

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

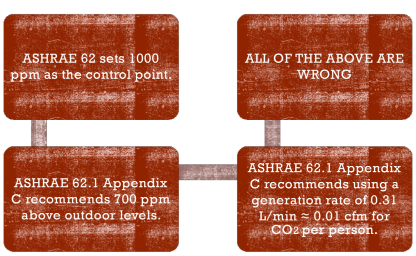
6.2.7.1 DEMAND CONTROL VENTILATION (DCV)

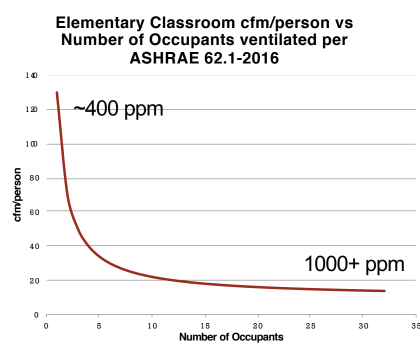
- **6.2.7.1** DCV shall be permitted as an optional means of dynamic reset.
- **Exception:** CO_2-based DCV shall not be applied in zones with indoor sources of CO_2 other than occupants or with CO_2 removal mechanisms, such as gaseous air cleaners.
- ***Former Note:*** Examples of reset methods or devices 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 Â~ 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





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.

COMPLYING WITH 62.1-2016 AND CO_2

- Option 1
  - Ventilation rate procedure
  - Determine the number of people in the zone
- Option 2
  - IAQ Procedure
  - Choose CO_2 as contaminant of concern

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 the people in the room,
- 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

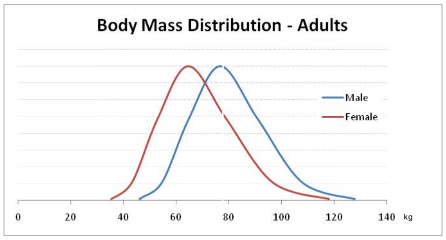
GENERATION RATE

- 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

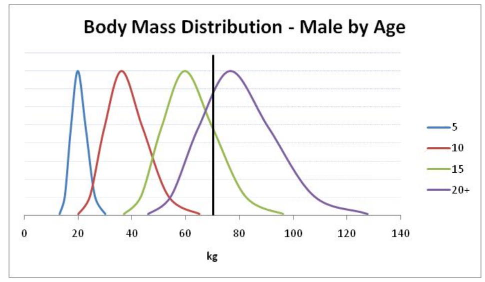
- BMR - Basal metabolic rate is energy expended at rest at neutral temperature in post-absorptive state
- RMR – Resting metabolic rate
- Several estimation formulae
- Metabolism for glucose
- $C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$

BODY MASS BY GENDER



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

VARIATIONS IN BODY MASS BY AGE

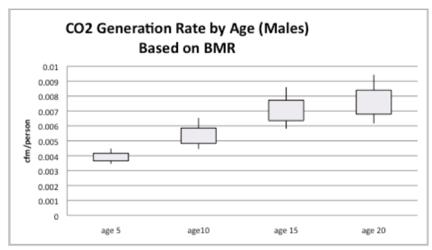


DETERMINING GENERATION RATE

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

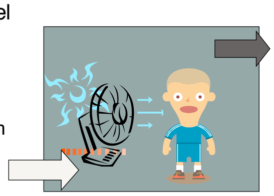
- Note: RQ varies from 0.7 to 1.0 depending on diet (different biochemistry for fats, proteins and carbohydrates)
- Assuming constant ECF and RQ=0.83

COMPARISON OF G BY AGE



BASIC MASS BALANCE

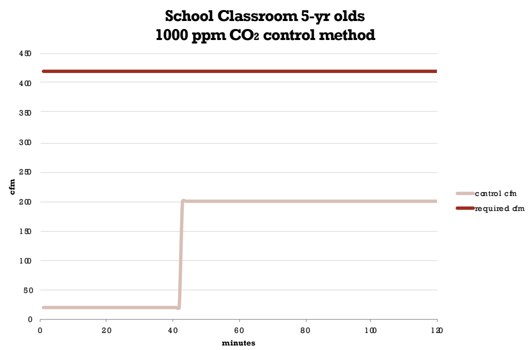
- Single Compartment Model
- Well Mixed
- Steady State
  - N – concentration in room
  - C – concentration into room
  - G – generation rate
  - SA – airflow rate

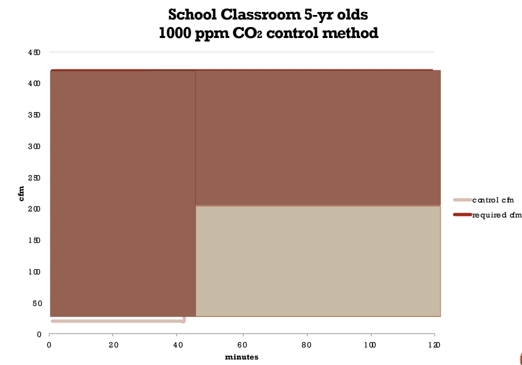


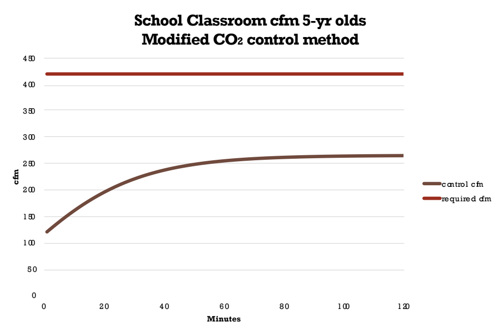
$$N = C_i + \frac{G}{SA}$$

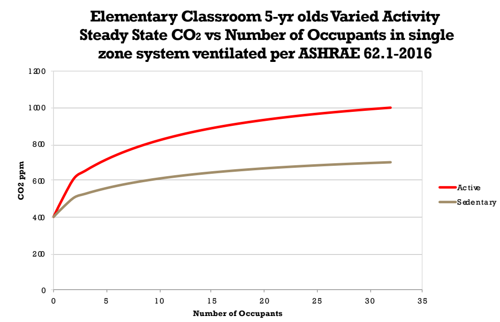
ELEMENTARY SCHOOL CLASSROOM

- 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









FOR NON-STEADY STATE

- "Transient Occupancy Ventilation By Monitoring CO_2," *IAQ Applications*, Winter 2004, by Stanley A. Mumma, Ph.D., P.E., Fellow ASHRAE
- Measure variables
  - Supply airflow
  - CO_2 concentration
  - Room air CO_2 concentration
  - Time
- Constants – room volume, generation rate

$$Pep = \frac{(V \times (N - N_{-1}) / \Delta\tau + SA \times (N - C_i))}{(G \times 1{,}000{,}000)}$$

Pep = number of occupants
V = space air volume, ft³
N = space CO_2 concentration at the present time step, ppm
N_{-1} = space CO_2 concentration one time step back, ppm
$\Delta\tau$ = the time step, min
SA = the supply airflow rate, scfm
C_i = the CO_2 concentration in the supply air, ppm
G = the CO_2 generation rate per person, scfm

DYNAMIC RESET

- Substitute *Pep* as P_z and calculate
- $V_{bz} = R_p \cdot P_z + R_a \cdot A_z$ (6-1)
- Assuming $E_z = 1$, for a single zone, or 100% OA system, or DOAS, then the outdoor air intake can be adjusted to the dynamically calculated $V_{ot} = Vbz$
- It is possible if all of the math is worked out that this method might be applied to multiple spaces, using calculation outputs as inputs into control algorithms

DYNAMIC RESET

- Method was tested in a design studio of 3200 ft^2 with a design occupancy of 45
- "Walk-through occupancy counts have been made during several months and compared with the computed occupancy. The actual occupancy count agrees with estimated occupancy within two people. It also gives accurate counts when there is a rapid change in occupancy."

MEASURING SUPPLY AIR CO_2

- For single supply systems, the value of C_i is the system supply CO_2 concentration in ppm
- For systems with complex pathways, multiple measures may be required

MEASURING ROOM AIR CO_2

For zones with return ducts, the return concentration should represent the average room concentration *N* ppm

For other systems, an averaging grid of monitors may be required

A PROCESS FOR USING CO_2 FOR DEMAND CONTROL

- Estimate generation rates based on assumed occupancy
- Use equations and arrangement proposed by Mumma for calculating number of people in real time
- Dynamic reset ventilation rate to zone based on calculated number of people
- Functional test and calibrate system during occupancy by the real (not assumed) occupants and adjust so that counts are accurate

BENEFITS OF THIS APPROACH

- Complies with ASHRAE 62.1-2016
- Does not over ventilate (saving energy)
- Readings are readily understood and verified by owners, operators, and occupants

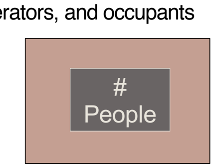


Table 1
Estimated annual benefits and costs of the scenarios.

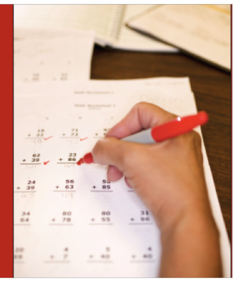
Scenario	Benefits and Costs[b]	Economic Benefits ($ billion)[b]
1) Increase minimum VR from 8 to 10 L/s per person	Average 0.33% increase in performance	$10.1
	Average 5.2% decrease in weekly SBS symptoms[a]	$0.09
	9.4 million days of short-term absence prevented	*$2.9*
	Increased energy consumption	-$0.05
	Total economic benefit	$13.0

IMPACT OF INCREASED VENTILATION

Fisk et al. *Building and Environment* 2012

EFFECTS OF HVAC ON STUDENT PERFORMANCE

'...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.'



Wargocki and Wyon, ASHRAE Journal, October 2006

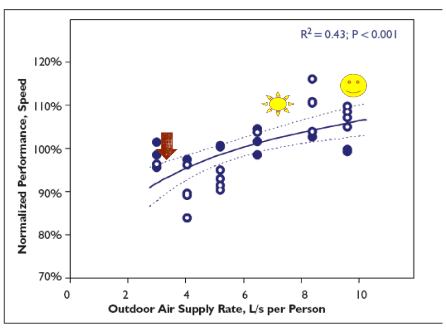


Figure 3: Performance of schoolwork as a function of outdoor air supply r

Selecting CO_2
Criteria for Outdoor Air Monitoring

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

ASHRAE Journal Dec 2008

Occupancy Category	Default Values Combined Outdoor Air Rate Per Person cfm	L/s	Assumed Activity Level (met)*	CO_2 Generation (cfm per person)	Actual Steady-State Concentration (ppm)†	Monitoring Program Concentration (Alarm Level) (ppm)†	DCV Upper Control Limit Concentration (Caution Level) (ppm)†,‡	LEED-EB IEQ Credit 1 Concentration (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

PRIESTLEY 1770

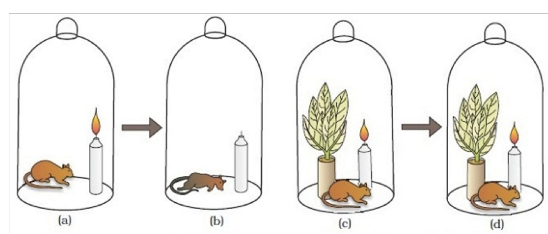


Figure 1. Priestley's experiment

The *Department Committee Appointed to Enquire into the Ventilation of Factories and Workshops Report* (1907) in England reported on the effects of restricted ventilation. Seventeen subjects were kept for periods of two hours to 13 days in small, 189 ft³ (5 m³) chambers. Air was circulated slowly while temperature was controlled externally. Carbon dioxide was usually more than 3,500 ppm (0.35%). Subjects felt comfortable as long as the chamber was kept adequately cool Other tests reported by the *Departmental Committee on Humidity and Ventilation in Cotton Weaving Sheds* (1909, 1911) confined subjects in an uncooled chamber of 106 ft³ (3 m³). Carbon dioxide reached 3% to 4%, oxygen fell to 17%, and the wet-bulb temperature rose to 80° F to 85° F (27° C to 29° C). Breathing was deepened by the high CO_2.

Janssen, *ASHRAE Journal,* October 1999

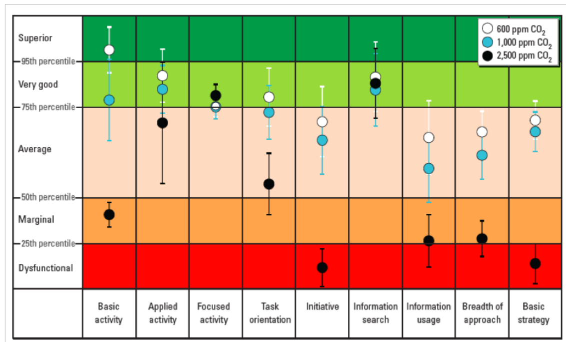
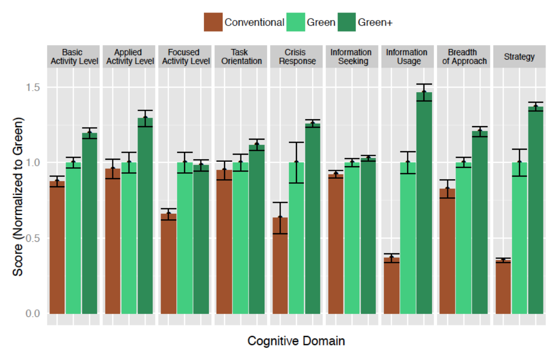
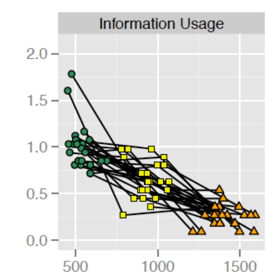


Figure 2. Impact of CO_2 on human decision-making performance. Error bars indicate 1 SD.

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

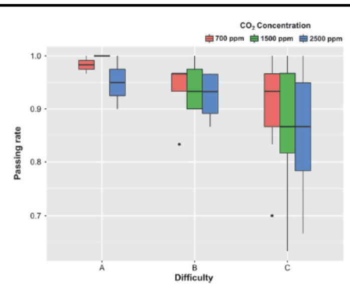


Fig. 2 Passing rates of pilots on each maneuver by maneuver difficulty and CO_2 conditions in the flight simulator

Allen, et al., Airplane pilot flight performance on 21 maneuvers in a flight simulator under varying carbon dioxide concentrations, *Journal of Exposure Analysis & Environmental Epidemiology* Jun 2018

Harvard Business Review

WORKSPACES

Research: Stale Office Air Is Making You Less Productive

by Joseph G. Allen

MARCH 21, 2017

CONCLUSIONS 62.1

- There are several ways to vary ventilation rates allowed in 62.1
- One is not allowed to under ventilate with dynamic reset
- Make sure that you understand assumptions if using CO_2
- A dynamic method is available for calculating number of occupants using CO_2
- Functional test and calibrate CO_2 system under occupied conditions

CONCLUSIONS DCV

- 90.1 and 189.1 require DCV
- Neither require CO_2 for control
- 62.1-2016 allows for
- ***Note:*** Examples of reset methods or devices include population counters, carbon dioxide (CO_2) sensors, timers, occupancy schedules or occupancy sensors

QUESTIONS?