Air Infiltration and Ventilation Centre Webinar

Recent Standards and Guidelines on CO_2 Application and Interpretation

March 17, 2025

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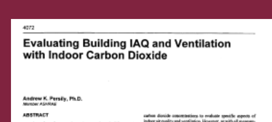
Webinar motivation and objectives

CO_2 part of ventilation & IAQ discussions since 1600s

- Impacts on occupants
- Bioeffluent odor perception
- Ventilation rate estimation
- Ventilation control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Evaluating Building IAQ and Ventilation with Indoor Carbon Dioxide

Andrew K. Persily, Ph.D.

ABSTRACT


Don't Blame Standard 62.1 for 1,000 ppm CO_2

Misapplication and misinterpretation of CO_2 for decades

More recently: more interest, more measurement, more confusion

Standards and guidance have been developed to clarify

Webinar focused on standards and guidance

Sensor performance will be addressed in a future webinar

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Agenda (CET)

16:00 | Welcome & Introduction, Andrew Persily (NIST, USA)

16:05 | Background on the application of indoor CO_2: ASHRAE Position Document and ASTM Standard D6245, Andrew Persily

16:25 | Demand controlled ventilation in ISO 17772-1 (EN 16798-1) and ASHRAE Standard 62.1, Bjarne Olesen (Technical University of Denmark)

16:45 | Indoor CO2 values in guidelines and standards, Mark Mendell (Lawrence Berkeley National Laboratory, USA)

17:05 | ISO 16000-26, Sampling strategy indoor CO_2 and a review of sensing technology, John Saffell (NosmoTech Ltd., UK)

17:30 | End of Webinar

Background on the Application of Indoor CO_2: ASHRAE Position Document (2025) and ASTM Standard D6245 (2024)

ASHRAE Shaping Tomorrow's Global Built Environment Today

ASHRAE Position Document on

INDOOR CARBON DIOXIDE

ASTM INTERNATIONAL Designation: D6245 – 24

Standard Guide on the Relationship of Indoor Carbon Dioxide Concentrations to Indoor Air Quality and Ventilation[1]

Andrew Persily
National Institute of Standards and Technology
Gaithersburg, Maryland USA

ASHRAE's Position Document on Indoor Carbon Dioxide

ASHRAE Shaping Tomorrow's Global Built Environment Today

ASHRAE Position Document on

INDOOR CARBON DIOXIDE

First approved February 2022
Revised February 2025

Position Document Committee:
Andrew Persily (Chair), William P. Bahnfleth, Howard Kipen, Josephine Lau, Corinne Mandin, Chandra Sekhar, Pawel Wargocki, Lan Chi Nguyen Weekes

First meeting: 26 March 2020

Motivations

CO_2 part of ventilation and IAQ discussions for centuries
Commonly misinterpreted by industry, researchers, public

Recent trends

- Research on impacts of CO_2 on human performance.
- Standards and regulations for indoor CO_2 in non-industrial workplaces.
- Concerns about accuracy of indoor CO_2 concentration measurements.
- More widespread application of less expensive sensors.
- Indoor CO_2 monitoring promoted as indicator for managing risks of airborne disease transmission.

Outline

Indoor Carbon Dioxide is a Public Interest Issue
Why ASHRAE Takes Positions on Indoor Carbon Dioxide

POSITIONS (abbreviated)

Indoor CO_2 concentrations are not comprehensive indicators of IAQ, but can be useful.

Differences between indoor and outdoor CO_2 concentrations can be used to evaluate ventilation using established tracer gas methods, but assumptions and inputs.

Evidence for CO_2 impacts on health, well-being, learning, sleep, and performance is inconsistent and doesn’t justify changes to ventilation and IAQ standards & guidelines.

Use of CO_2 to assess risks of airborne disease transmission must account for space ventilation and occupants, and recognize differences between CO_2 and aerosols.

Sensor accuracy, location and calibration are critical.

Air cleaning technologies that remove only CO_2 will not necessarily improve IAQ

Research recommendations (also abbreviated)

Indoor CO_2 exposure as a modifier of human responses to other environmental factors such as thermal comfort.

IAQ metrics that cover range of indoor contaminants and sources.

Health, comfort, productivity, learning, and sleep impacts of indoor CO_2 at concentrations typical of non-industrial indoor environments.

Physiological impacts of exposure to CO_2 at typical indoor concentrations.

Significance of indoor CO_2 concentration as an indicator of the risks of airborne infectious disease transmission

CO_2 sensor performance and locations for different applications.

Occupant-generated CO_2 as a tracer gas to estimate ventilation rates.

Strategies for DCV using CO_2 and other indicators of occupancy.

Surveys of indoor CO_2, ventilation rates and occupancy in different building types.

Recommended activities

Development of guidance and standards on indoor CO_2 concentration measurement and sensor selection.

Development of educational programs, conference sessions and workshops, and guidance documents to help practitioners and researchers understand the application of indoor CO_2.

Guidance on HVAC equipment and controls employing CO_2 monitoring.

Guidance on the use of CO_2 as a tracer gas for measuring building ventilation rates and outdoor air distribution.

Appendix

Detailed discussion to supports positions and recommendations in the document.

- The history of the role of indoor CO_2 concentrations in the context of building ventilation and IAQ
- Health and cognitive impacts of exposure to CO_2
- Existing standards and regulations for indoor CO_2 concentrations
- CO_2 as an indicator of IAQ and ventilation
- Use of CO_2 as a tracer gas for estimating ventilation rates
- Increases in outdoor CO_2 concentrations
- Air cleaning directed at CO_2 removal alone
- CO_2 as an indicator of the risk of airborne disease transmission

Conclusion

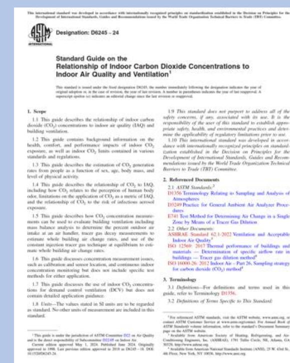
ASHRAE position document clarifies relationship of indoor CO_2 to ventilation and IAQ for practitioners, researchers and policymakers.

Additional research and new guidance will advance application of indoor CO_2 to improve IAQ.

https://www.ashrae.org/file%20library/about/position%20documents/pd_indoorcarbondioxide_2025.pdf

Search on “ASHRAE indoor carbon dioxide”

ASTM Standard D6245-2024


Designation: D6245 – 24

Standard Guide on the Relationship of Indoor Carbon Dioxide Concentrations to Indoor Air Quality and Ventilation

Standard Guide on the Relationship of Indoor Carbon Dioxide Concentrations to Indoor Air Quality and Ventilation

First published in 1998 as a provisional standard
Latest version published in 2024
Partial revision in progress

ASTM Standard D6245-2024

Scope

Background on health, comfort, and performance impacts of CO_2 exposure, as well as indoor CO_2 limits in standards and regulations.

Estimation of CO_2 generation rates from people as a function of sex, age, body mass, and level of physical activity (Section 6).

Relationship of CO_2 to IAQ, including how CO_2 relates to the perception of human body odor, limitations on CO_2 as a metric of IAQ, and the relationship of CO_2 to the risk of infectious aerosol exposure (Section 7).

How CO_2 concentrations can be used to evaluate building ventilation and the use of indoor CO_2 concentrations for demand control ventilation (DCV) but not a detailed application guide (Section 8).

Concentration measurement issues, such as calibration and sensor location, and continuous indoor concentration monitoring but does not include specific test methods for either application (Sections 9 and 10).

ASTM Standard D6245-2024

Section 6: CO_2 Generation Rates

(Persily and de Jonge, Indoor Air, 2017)

Equation to estimate rate of CO_2 generation of an individual Based on concepts in the fields of human metabolism and exercise physiology

Inputs Individual sex, age and body mass; level of physical activity (met rate)

Standard contains input data from literature

Tables of CO_2 generation rates by sex and age

Alternative to equation in ASHRAE Fundamentals No explanation of technical basis; old metabolic rate data; sex and age only considered indirectly

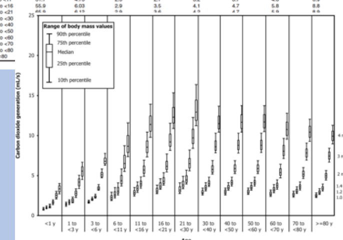
TABLE 2 Metabolic Rates (*M* in Met) for Various Physical Activities (15)

Activity	M (Met)
Calisthenics – light effort	2.8
Calisthenics – moderate effort	3.8
Calisthenics – vigorous effort	8.0
Child care	
Cleaning, sweeping – moderate effort	3.8
Custodial work – light	2.3
Dancing – aerobic, general	7.3
Dancing – general	7.8
Health club exercise classes – general	5.0
Kitchen activity – moderate effort	3.3
Lying or sitting quietly	
Sitting reading, writing, typing	1.3
Sitting at sporting event as spectator	1.5
Sitting tasks, light effort (for example, office work)	1.5
Sitting quietly in religious service	1.3
Sleeping	0.95
Standing quietly	1.3
Standing tasks, light effort (for example, store clerk, filing)	3.0
Walking, less than 2 mph, level surface, very slow	2.0
Walking, 2.8 mph to 3.2 mph, level surface, moderate pace	3.5

TABLE 4 Carbon Dioxide Generation Rates as a Function of Occupant Sex, Age, and Met Level (Based on Body Mass Data in (18))

NOTE 1—These CO_2 generation rates are based on an air temperature of 273 K and an air pressure of 101 kPa.

Age (y)	Mean Mass (kg)	BMR (MJ/day)	CO_2 Generation Rate (L/s)						
			Level of Physical Activity (met)						
			1.0	1.2	1.4	1.6	2.0	3.0	4.0
Males									
<1	8.0	1.86	0.9	1.1	1.3	1.4	1.8	2.7	3.6
1 to <3	12.8	3.05	1.5	1.8	2.1	2.4	3.0	4.4	5.9
3 to <6	18.8	3.90	1.9	2.3	2.6	3.0	3.8	5.7	7.5
6 to <11	31.9	5.14	2.5	3.0	3.5	4.0	5.0	7.5	10
11 to <16	57.6	7.02	3.4	4.1	4.8	5.4	6.8	10	13.6
16 to <21	77.3	7.77	3.7	4.5	5.3	6.0	7.5	11	15
21 to <30	84.9	8.24	3.9	4.8	5.6	6.4	8.0	12	16
30 to <40	87.0	7.83	3.7	4.6	5.3	6.1	7.6	11	15
40 to <50	90.5	8.00	3.8	4.6	5.4	6.2	7.7	12	16
50 to <60	89.5	7.95	3.8	4.6	5.4	6.2	7.7	12	15
60 to <70	89.5	6.84	3.3	4.0	4.6	5.3	6.6	9.9	13
70 to <80	83.9	6.57	3.1	3.8	4.5	5.1	6.4	9.5	13
≥80	76.1	6.19	3.0	3.6	4.2	4.8	6.0	9.0	12
Females									
<1	7.7	1.75	0.8	1.0	1.2	1.4	1.7	2.5	3.4
1 to <3	12.3	2.88	1.4	1.7	2.0	2.2	2.8	4.2	5.6
3 to <6	18.3	3.59	1.7	2.1	2.4	2.8	3.5	5.2	7.0
6 to <11	31.7	4.73	2.3	2.7	3.2	3.7	4.6	6.9	9.2
11 to <16	55.9	6.03	2.9	3.5	4.1	4.7	5.8	8.8	11
16 to <21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12
21 to <30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
30 to <40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
40 to <50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
50 to <60	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
60 to <70	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
70 to <80	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
≥80	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

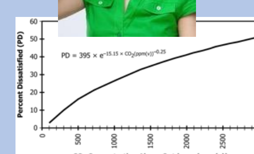


ASTM Standard D6245-2024

Section 7: CO_2 and Indoor Air Quality

Relation of CO_2 to perception of human body odor

Multiple studies showing CO_2 concentrations of about 700 ppm(v) above ambient corresponds to 80 % perceived odor acceptability by unadapted visitor



Limitations of CO_2 as a metric of IAQ

Many other important pollutants independent of occupants, e.g., outdoor air, building materials, cleaning products.

Relationship of CO_2 to risk of infectious aerosol exposure

Indicator of ventilation or risk?

ASTM Standard D6245-2024

Section 8: Ventilation

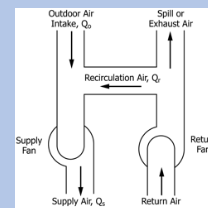
Percent outdoor air at air handler based on CO_2 concentrations in outdoor, return and supply airstreams

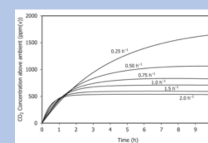
Tracer gas measurements of air change rates using occupant generated CO_2 as a tracer (ASTM E741 and ISO 12569)

- Key assumptions, including single zone
- Constant injection, CO_2 concentration at steady-state

Indicator of ventilation adequacy relative to target ventilation rate, depends on space and occupants (Persily 2022)

Short discussion of using CO_2 for demand control ventilation (DCV), but does not contain detailed application guidance





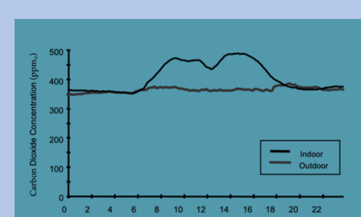
ASTM Standard D6245-2024

Section 9: CO_2 Concentration Measurement

Short discussions of the following:

- Sources of measurement error
- Calibration
- Warm-up
- Interferents
- Outdoor concentration measurement
- Indoor concentration, including sensor location

Courtesy of David Meyer
Shenandoah University



Section 10: Continuous Monitoring of CO_2 Concentrations

Timing and duration; Occupancy; Data archiving and display

Conclusion

ASTM D6245 is a guide not a test method or practice, but hopefully it contains useful information for practitioners

And hopefully it can reduce misapplication and misinterpretation of indoor CO_2 concentrations

Still need formal methods of test for measurement and analysis

Reading List

ASHRAE. 2025. *Position Document on Indoor Carbon Dioxide*..

ASTM. 2024. D6245 Standard Guide on the Relationship of Indoor CO_2 Concentrations to Indoor Air Quality & Ventilation.

ASTM. 2011. E741 Standard Test Method for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution.

ISO. 2017. 12569: Thermal performance of buildings and materials — Determination of specific airflow rate in buildings — Tracer gas dilution method, International Standards Organization.

Kappelt, Russel, Kwiatkowski, Afshari. and Johnson. 2021. Correlation of Respiratory Aerosols and Metabolic Carbon Dioxide, *Sustainabilty*, Online 5 November 2021.

Lu, et al. 2022. The nexus of the indoor CO_2 concentration and ventilation demands underlying CO2-based demand-controlled ventilation in commercial buildings: A critical review. Building and Environment **218**.

Peng and Jimenez. 2021. Exhaled CO_2 as a COVID-19 Infection Risk Proxy for Different Indoor Environments and Activities, *Environmental Science & Technology Letters*, **8**, 392-397.

Persily, 1997. Evaluating Building Ventilation with Indoor Carbon Dioxide. ASHRAE Transactions, 103(2).

Persily and de Jonge. 2017. Carbon Dioxide Generation Rates of Building Occupants, *Indoor Air*, **27**, 868-879.

Persily, 2021. Don’t Blame Standard 62.1 for 1000 ppm CO2, ASHRAE Journal, 63(2).

Persily, 2022. Development and Application of an Indoor Carbon Dioxide Metric. *Indoor Air*. DOI: 10.1111/INA.13059

Persily and Polidoro. 2022. *Indoor Carbon Dioxide Metric Analysis Tool*. NIST Technical Note 2213, National Institute of Standards and Technology.

QICO2 tool: https://pages.nist.gov/CONTAM-apps/webapps/CO2Tool/#/

Demand Control Ventilation based on CO2 ISO17772-1/2, EN16798-1/2 and ASHRAE 62.1

Professor Bjarne W. Olesen, Ph.D., Dr.h.c., R.1.
ASHRAE Fellow, Presidential Member
International Centre for Indoor Environment and Energy
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Technical University of Denmark

Demand Control Ventilation based on CO_2

- ASHRAE 62.1-2022 includes an addendum ab from 2023 on DCV
- ISO 1772-1/2 and EN 16798-1/2 is being revised and a new part on operation and DCV will be included
- General use of CO_2 as an indicator of the ventilation needs of people
- Often a fixed set-point of 1000 ppm is used.
- Issues
  - For the same IAQ level the CO_2 setpoint depends on level of building emissions and people density.
  - Outdoor concentration is not considered (350-550 ppm)
  - CO_2 concentration in a room is not uniform. Position of the CO_2 sensor?

Concept for calculation of design ventilation rate according to ISO 17772-1 & EN16798-1 & ASHRAE 62.1 Method 1

People Component

Building Component

Breathing Zone Outdoor Airflow

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

- R_p: Minimum l/s/Person
- P_z: Number of People
- R_a: Minimum l/s/m²
- A_z: Building Area

Concept for calculation of design ventilation rate ISO 17772-1 (EN 16798-1)

Table 1: Design ventilation rates for non-adapted persons for diluting emissions (bio effluents) from people and for buildings for different categories

		People component, q_p	Building Component, q_B		
Indoor Environmental Category	Expected Percentage Dissatisfied %	Airflow per non-adapted person l/(s.pers)	Very low polluting building l/(s m^2)	Low polluting building l/(s m^2)	Non low polluting building l/(s m^2)
IEQ_I	15	10	0,5	1,0	2,0
IEQ_{II}	20	7	0,35	0,7	1,4
IEQ_{III}	30	4	0,2	0,4	0,8
IEQ_{IV}	40	2,5	0,15	0,3	0,6

People component for sedentary in ASHRAE 62.1 is 2,5 l/(s.pers)

Design ventilation rates (ISO17772-172 AND EN 16798-1/2)

Type of building or space	Category	Floor area m²/person	q_p	q_p	q_B	q_{tot}		q_B	q_{tot}		q_B	q_{tot}	
			minimum ventilation rate										
			l/(s m²)	l/s pers.	l/s, m²	l/s, m²	l/s,pers	l/s, m²	l/s, m²	l/s,pers	l/s, m²	l/s, m²	l/s,pers
			for occupancy only		Tekst for very low-polluted building			for low-polluted building			for non-low-polluted building		
Single office	I	10	1	10	0,5	1,5	15	1	2,0	20,0	2	3,0	30
	II	10	0,7	7	0,35	1,1	11	0,7	1,4	14,0	1,4	2,1	21
	III	10	0,4	4	0,2	0,6	6	0,4	0,8	8,0	0,8	1,2	12
	IV	10	0,25	2,5	0,15	0,4	4	0,3	0,6	5,5	0,6	0,9	9
Landscaped office	I	15	0,7	10	0,5	1,2	18	1	1,7	25,0	2	2,7	40
	II	15	0,5	7	0,35	0,8	12	0,7	1,2	17,5	1,4	1,9	28
	III	15	0,3	4	0,2	0,5	7	0,4	0,7	10,0	0,8	1,1	16
	IV	15	0,2	2,5	0,15	0,3	5	0,3	0,5	7,0	0,6	0,8	12
Conference room	I	2	5	10	0,5	5,5	11	1	6,0	12,0	2	7,0	14
	II	2	3,5	7	0,35	3,9	8	0,7	4,2	8,4	1,4	4,9	10
	III	2	2	4	0,2	2,2	4	0,4	2,4	4,8	0,8	2,8	6
	IV	2	1,25	2,5	0,15	*(1,4)* 1,8	*(3)* 4	0,3	*(1,6)* 2	*(3,1)* 4	0,6	1,9	4

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Table B2.5 - Example of equivalent increase in CO_2 levels indoor for the total ventilation rates specified in Table B2.3

CO_2 emission 20 l/h per person, sedentary)

Type of building or space	Category	occupancy	ΔCO_2 [ppm]		
		person/m²	Very low-polluting	low-polluting	Not low-polluting
Single office	I	0,1	370	278	185
	II	0,1	529	397	265
	III	0,1	926	694	463
	IV	0,1	1389	1010	654
Land-scaped office	I	0,07	317	222	139
	II	0,07	454	317	198
	III	0,07	741	556	347
	IV	0,07	1235	794	483
Conference room	I	0,5	505	463	397
	II	0,5	722	661	567
	III	0,5	1263	1157	992
	IV	0,5	*1462*	*1389*	1502
Auditorium	I	1,33	535	517	483
	II	1,33	765	738	690
	III	1,33	1347	1300	1208
	IV	1,33	*1576*	*1398*	*1576*

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CO_2 emissions rates

- ISO 17772-1/2 and EN 16798-1/2
  - Sedentary 20,0 l/h per person
  - Kindergarten 23,3 l/h per person
  - Department store 26,6 l/h per person
- ASHRAE 62.1-2022 Addendum ab
  - Refer to ASTM D6245-2018.
  - Influenced by activity level, gender, body mass, and age.

Recommended set-points for DCV control

Room	Person per m²		CO_2 above outdoor, ppm	
	ISO 17772	ASHRAE 62.1	ISO 17772	ASHRAE 62.1
Landscape office	0,07	0,05	320	600
Conference room	0,5	0,5	660	1500
Auditorium	1,33	1,50	740	1800

Method 2 Individual Pollutants (IAQ procedure)

The ventilation rate required to dilute a pollutant shall be calculated by this equation:

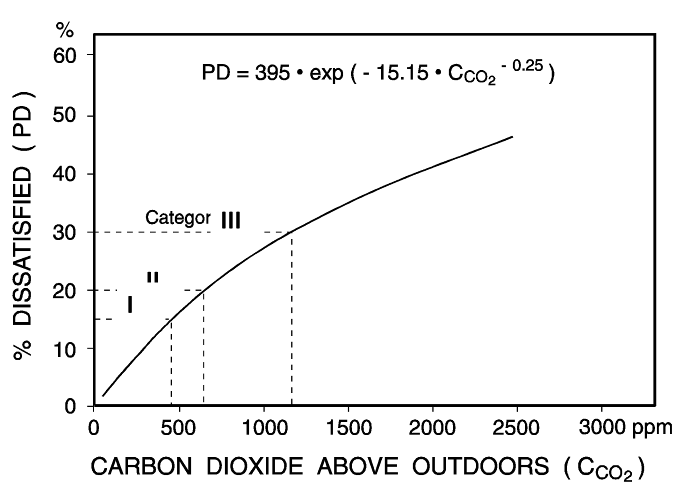
$$Q_h = \frac{G_h}{C_{h,i} - C_{h,o}} \cdot \frac{1}{\varepsilon_v} \qquad \text{Eq (2)}$$

where:

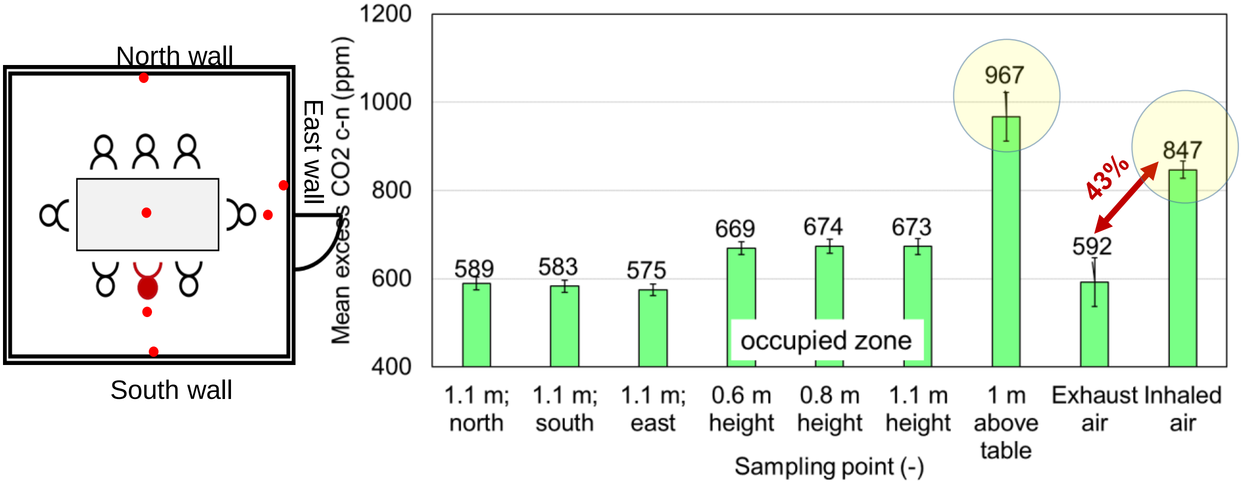
Q_h is the ventilation rate required for dilution, in litre per second;
G_h is the pollution load of a pollutant, in micrograms per second;
$C_{h,i}$ is the guideline value of a pollutant, see Annex B6 , in micrograms per m^3;
$C_{h,o}$ is the supply concentration of pollutants at the air intake, in micrograms per m^3;
ε_v is the ventilation effectiveness

NOTE. $C_{h,i}$ and $C_{h,o}$ may also be expressed as ppm (vol/vol). In this case the pollution load G_h has to be expressed as l/s.

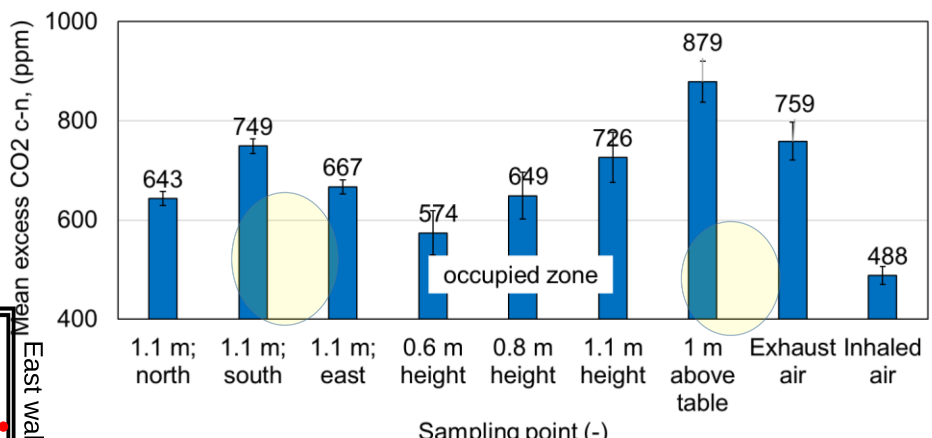
CO_2 as a reference from ISO 17772-1 (EN 16798-1)

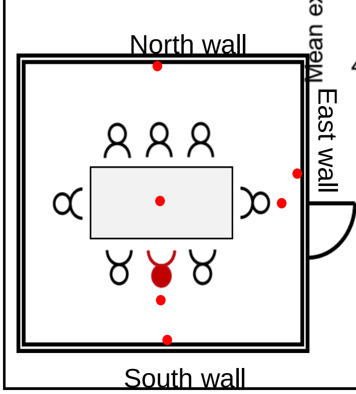


CO_2 spread with Mixing Air Distribution



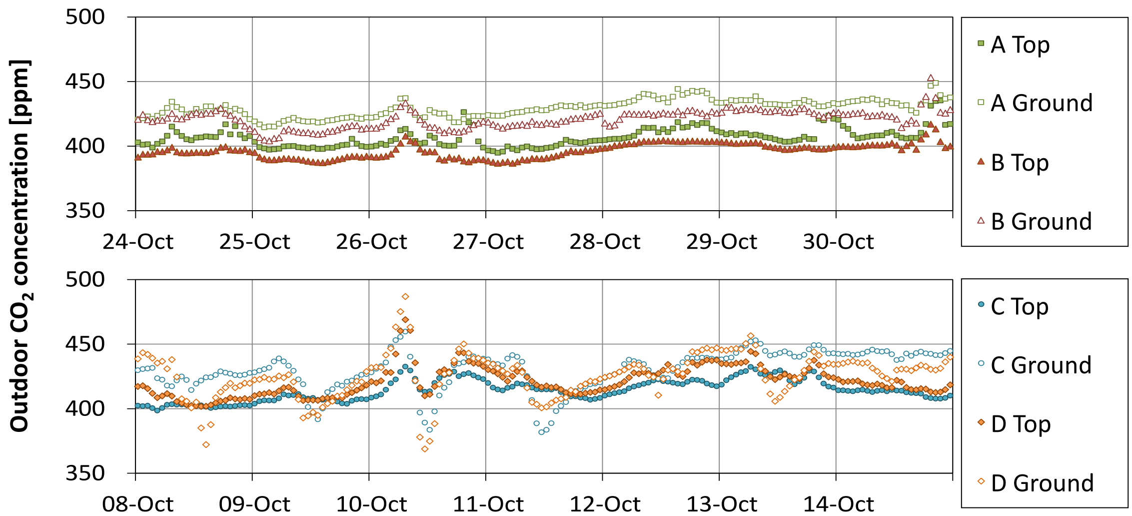
CO2 spread with Displacement Air Distribution





- The CO2 c-n at the walls at 1.1 m height was higher (up to 42%) compared to the one in the inhaled air.

Outdoor CO_2 measurements in Copenhagen



Default concentration in ASHRAE 62.1 = 400 ppm

Non-uniformity in outdoor CO_2 concentration in city of Copenhagen

Hiroki Takahashi, Mariya Petrova Bivolarova, Athanasia Keli, Jürgen Nickel and Arsen Krikor Melikov

Required ventilation rate – calculations

$$q = \frac{G_{CO_2}}{C_{h,i} - C_{h,o}} * 10^6$$

q: required ventilation rate (m^3/h)
G_{CO_2}: CO_2 generation rate in the room at room conditions (m^3/h)
$C_{h,i}$: maximum allowed volume fraction of CO_2 in indoor air (ppm)
$C_{h,o}$: CO_2 volume fraction in outdoor air (ppm)

Outdoor CO_2 concentration [ppm]	Indoor CO_2 concentration [ppm]	Indoor CO_2 generation rate* [m^3/h/person]	Required ventilation rate [m^3/h/person]
400	1000	0.019	31.7
450	1000	0.019	34.5
500	1000	0.019	38.0
550	1000	0.019	42.2

*Standard CEN

A change by 50 ppm in the outdoor CO_2 concentration causes **a change by approximately 10%** in the required ventilation rate.

V entilation
I nformation
P aper
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International Energy Agency's
Energy in Buildings and Communities
Programme

Air Infiltration and Ventilation Centre

The Concept for Substituting Ventilation by Gas Phase Air Cleaning

Bjarne W. Olesen, DTU, Denmark
Chandra Sekhar, National University of Singapore, Singapore
Pawel Wargocki, DTU, Denmark

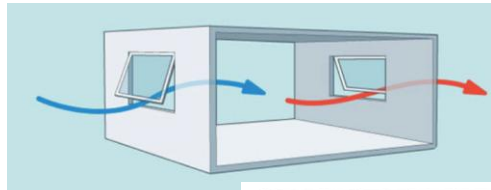
Influence of using gas phase air cleaner with 30% efficiency

Space type	Occupancy [pers/m²]	Category	Derived from Method 1 q_{tot}	
			Low-polluting building **No air cleaning**	Low-polluting building **With air cleaning** 30% efficiency
			ΔCO_2 [ppm]	
Single office	0.1	I	278	397
		II	397	567
		III	694	992 (**817**)
		IV	1010 (**794**)	1443 (**911**)

Demand Control Ventilation based on CO_2

- General use of CO_2 as an indicator of the ventilation needs of people
- Often a set-point of 1000 ppm is used.
- Issues
  - For the same IAQ level the CO_2 setpoint depends on level of building emissions and people density.
  - Outdoor concentration is not considered (350-550 ppm)
  - CO_2 concentration in a room is not uniform. Position of the CO_2 sensor?
  - An air cleaner with a CADR (clean air delivery rate) will influence the set-point)
- ASHRAE 62.1-2022 Addendum 2ab include requirements/guideline for DCV
- ISO 17772-1/2 and EN 16798-1/2 a revision will include requirements/guideline.

Worldwide CO_2 Guidelines for IAQ: A Review



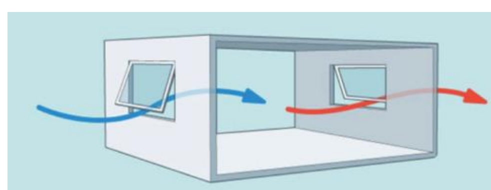
Mark J. Mendell, Wenhao Chen, Dilhara R Ranasinghe, Rosemary Castorina,[1] Kazukiyo Kumagai

Air Quality Section, California Dept of Public Health
[1] also School of Public Health, UC Berkeley

2025 March 17
(rev 2025/2/25)

Outdoor air ventilation is critical for IAQ

- Ventilation dilutes indoor-generated air pollutants
- Ventilation reduces indoor exposures
  - including viral bioaerosols
- Minimum ventilation rate limits
  - historically, <u>health-based</u>
  - recently, <u>odor-based</u>
- COVID → renewed recognition, ventilation important for health



We reviewed worldwide CO_2 guidelines for IAQ

- Measuring VRs often difficult
- Many VR guidelines specify indoor CO_2 limits as proxy for VR
- Basis for various CO_2 limits set not clear.
- We reviewed worldwide CO_2 guidelines and supportive evidence provided
- Goal – assess scientific support for current CO_2 guidelines as protective from health effects, e.g., airborne infectious disease transmission

Approach: Review of worldwide CO_2 guidelines for IAQ

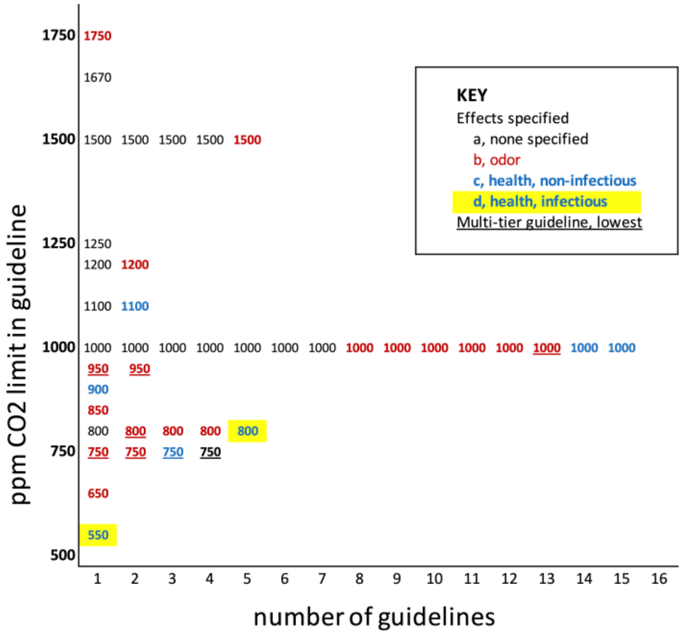
- ISIAQ STC34 database -- international IAQ guidelines*
- + current literature review
- Excluded occupational limits 5,000+ ppm
- 43 CO_2 guidelines, nations/ organizations
- All maximum values
  - one-time ←→ time-averaged
  - single value ←→ multiple tiers
  - absolute indoor ←→ differential (above outdoor)

Pollutants	Value	Averaging Ti...	Countries
Carbon Dioxide (CO2)	700 ppm above outdoor	8 hour	Singapore
Carbon Dioxide (CO2)	5000 ppm		Norway
Carbon Dioxide (CO2)	1000 ppm		Norway
Carbon Dioxide (CO2)	1000 ppm	Ceiling limit	Malaysia
Carbon Dioxide (CO2)	15000 ppm	15 minutes	United Kingdom
Carbon Dioxide (CO2)	5000 ppm TWA	8 hour	United Kingdom
Carbon Dioxide (CO2)	1000 ppm		Denmark
Carbon Dioxide (CO2)	1200 ppm		Denmark
Carbon Dioxide (CO2)	1000 ppm	24 hour	Canada

Example Data from ISIAQ IEQ Guidelines Database*

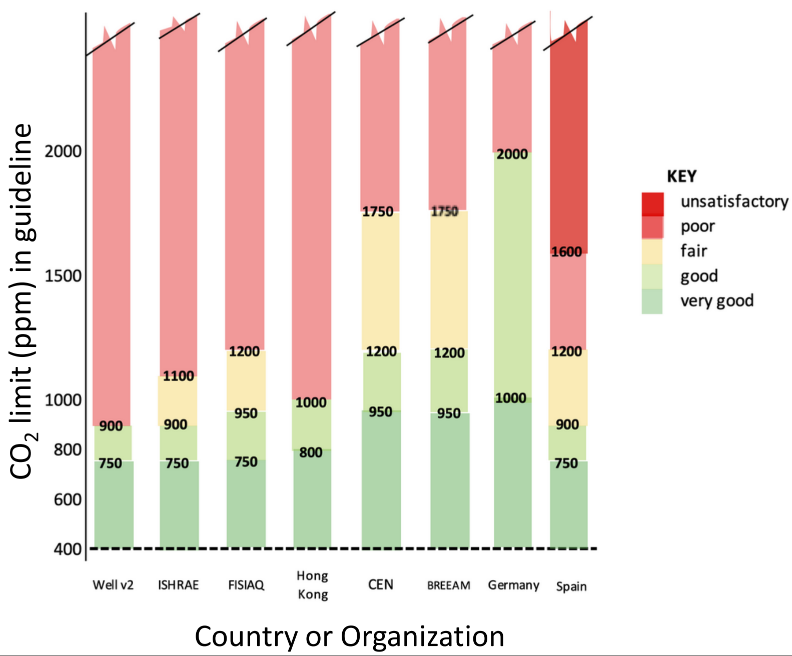
* https://ieqguidelines.org/

Plot of worldwide indoor CO_2 limit guideline values



- Multi-tier guidelines: only lowest tier shown, underlined
- "Differential" limits shown here with estimated 400 ppm outdoors added
- Color in plot shows effects to be controlled by limit
- One guideline with 17 values omitted here

Eight CO_2 guidelines setting multi-tier (2, 3, 4) limits, by country or organization*



* generic category labels used here; guidelines used diverse category labels

Current worldwide CO_2 guidelines for IAQ/VR – evidence basis?

- Few provide evidence for limits set
  - Most with evidence --> odor
- 1000 ppm: maybe popular because outdoor + 700 ppm controlled occupant odors
- Few provide evidence that protect from health effect
- Most show no understanding of scientific basis for CO_2-based VR limit
- Some set averaged CO_2 limits (e.g., 8-hr), suggesting confusion about basis

Evidence provided		
None	Limited/ Insufficient	Substantial
25	10	8

Note: After completion of this review, ASHRAE 241 set minimum limits for equiv. clean airflow rate (but not CO2 limits) to control airborne disease transmission. Also, ASHRAE 62.1 addendum ab set △CO2 limits corresponding to 62.1 airflow standards, which are arguably odor-based.

Worldwide CO_2 guidelines: human effects targeted for control, and supportive evidence provided for the limits set

Effects to be controlled	Number of guidelines	Evidence provided: None	Evidence provided: Limited/ Insufficient	Evidence provided: Substantial
None specified	16	16	0	0
Odor dissatisfaction	19	6	6	7
Health effects, non-infectious	5	2	3	0
Health effects, infectious (airborne)	3	1	1	1
ALL	43	25	10	8

Only 1 guideline set limits to control a health risk, based on scientific principles

<u>Nordic Ventilation Group</u> (+ adopted by '<u>REHVA</u>'):
Proposal for post-COVID target ventilation rates

- Clear goals, approach, assumptions
- 17 example limits for defined spaces / occupancies

(1) set minimum VR limits
to control risks of indoor long-range transmission of airborne COVID transmission
per model of airborne infection

(2) then set corresponding CO_2 limits
steady state CO_2 estimated at minimum VR limit
per mass balance model

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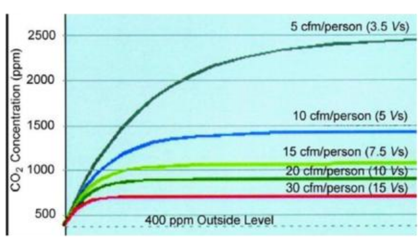
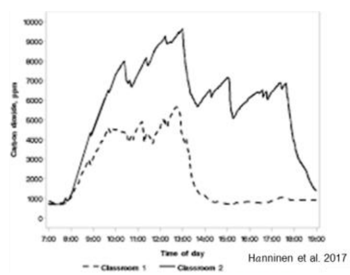
Even the best-supported CO_2-based limits for IAQ have limitations



IDEAL INDOOR CO2



REAL INDOOR CO2

- Technical limitations
  - frequent failure to reach steady-state CO_2
  - invalid assumptions: constant VR, occupancy, CO_2 emission, outdoor CO2
  - CO2 measurement errors
- Practical limitations
  - Different space uses/types have different expected steady-state CO_2 levels at recommended VRs
  - no single limit – e.g., 1000 -- correct for all spaces

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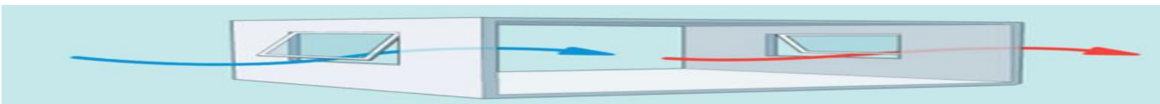
Conclusions

- Of 43 identified CO_2 guidelines, 16 specified no adverse effect for control
- 19 specified = odor; 8 specified health, but only 3 of the 8 specified control of infectious disease
- Evidence-based CO_2 guidelines rare -- 25/43 provided no supportive evidence. 8/43 provided persuasive evidence
- Only 1 CO_2 guideline developed from scientific models to control airborne COVID-19 transmission
- Most showed no understanding of scientific basis of setting CO2 limit for IAQ



- 3 common practices with no scientific basis --
  - setting one CO_2 limit for IAQ across all buildings
  - setting CO_2 limit for IAQ as extended time-weighted average
  - using any arbitrary one-time CO_2 measurement to verify a desired VR

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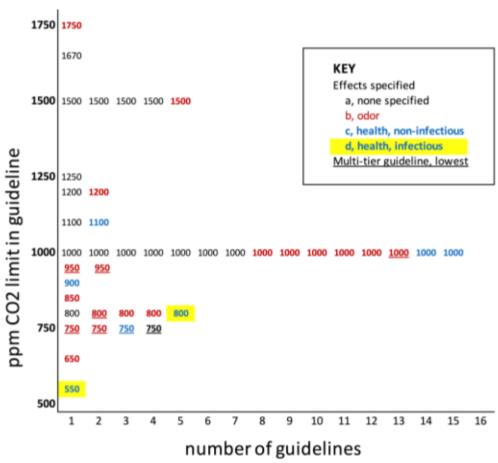
Questions?



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For pdf, contact mark.mendell@cdph.ca.gov

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We thank STC34 of ISIAQ for assembling the first international database of IEQ guidelines (http://www.ieqguidelines.org/), which inspired and facilitated this review.

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EXTRA SLIDES

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Table S4. Infection-risk-based CO2 concentration limits from Nordic Ventilation Group (NVG) proposed guideline for post-COVID target ventilation rates*

Space Use	Floor Area (m^2)	Room Height (m)	Number of Occupants	Infection-risk-based Indoor CO_2 Concentrations (ppm)
Small classroom	31.6	3.5	13	1097
Classroom	42.5	2.9	25	941
Classroom	56.5	2.9	25	962
reduced occupancy	56.5	2.9	20	999
Teaching space, large	129.5	2.9	50	776
reduced occupancy	129.5	2.9	40	801
Office, 2-person	21.0	2.6	2	1535
Office, open plan	56.7	2.6	6	736
Office, open plan	173.0	2.6	17	619
Meeting room	29.2	2.6	10	563
reduced occupancy	29.2	2.6	6	584
Meeting room	52.5	3.2	24	521
reduced occupancy	52.5	3.2	12	534
Restaurant	259.5	2.9	154	486
reduced occupancy	259.5	2.9	50	494
Gym	173.5	3.5	12	657
Gym, school	217.5	6.0	25	604

* from "Health-based target ventilation rates and design method for reducing exposure to airborne respiratory infectious diseases," NVG, 2022. Available at: http://www.scanvac.eu

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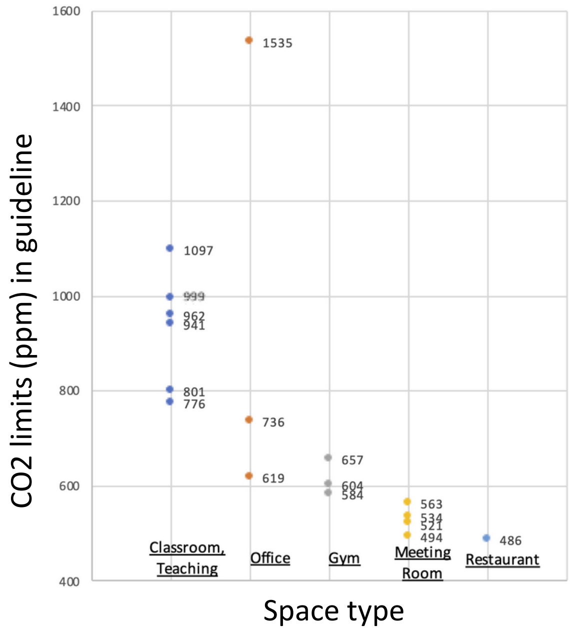
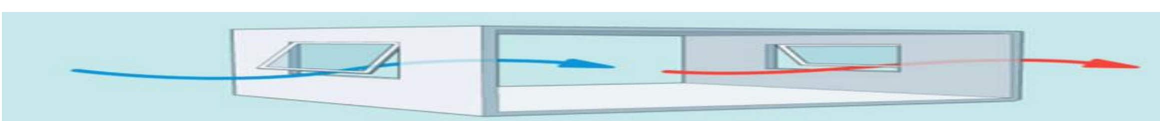
Example NVG* proposed CO_2 concentration limits, based on target minimum VR airflows calculated to control risk of airborne COVID-19 infections**



*NVG, Nordic Ventilation Group
** Because guideline limits depend on space size and occupancy, different examples of the same space type, such as offices with different space sizes and numbers of occupants, have different limits.

Conclusions

- Many CO_2 guidelines for IAQ specified no adverse effect for control.
- Most frequently specified = odor; few specified health; three specified control of infectious disease.
- Evidence-based CO_2 guidelines rare. Most provided no supportive evidence. Few provided persuasive evidence.
- Only one CO_2 guideline developed from scientific models to control airborne COVID-19 transmission.



- No scientific basis apparent for
  - setting one CO_2 limit for IAQ across all buildings
  - setting CO_2 limit for IAQ as extended time-weighted average
  - using a random one-time CO_2 measurement to verify a desired VR.

ISO 16000-26 and sampling strategy for indoor CO_2 and a review of sensing technology

John Saffell

NosmoTech Ltd.

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AIVC Webinar March 17th, 2025

1

ISO 16000-1 and ISO16000-26

- Indoor environment characteristics
- Investigating the ventilation system
- Sampling duration
- Sampling location
- Parallel measurements of the outdoor air and metaparameters
- Analysis and data quality

CO_2 detection technologies

- Diffusion tubes or NDIR?
- Current state of NDIR for CO_2 detection
- Steady state or tracer gas decay?

2

Indoor environment characteristics

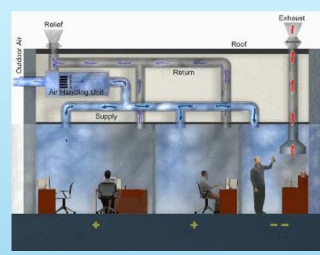
An indoor environment is rarely static: human activity, ventilation rate, cleaning and cooking, air purifiers, emissions and sinks from surfaces create a dynamic environment.

Heated ventilation frequently causes stratification

People are very close to polluting sources, unlike outdoor air

Air composition varies between rooms and is less homogeneous than outdoor air:
- Oxidizing gases (chlorine, ozone, NO2) react with VOCs
- Particle composition is very different than outdoor air
- VOCs are a major concern: cleaning, cooking, pets, health products, DIY

Investigating the ventilation system



Do we need to measure in various locations in a space? Maybe not in large spaces (auditoria, open plan offices).

We cannot assume homogeneity in complex spaces or with mechanical ventilation in small spaces. There may be “dead zones” with reduced air exchange rates.

Ventilation effectiveness is achieved when the concentrations in the extract air and in the indoor air at the sampling point are identical.

The homogeneity of the air distribution in a room can be investigated using CO_2 concentration measurements, following extract air and the sampling point closely in time at differing points in the room.

Sampling duration

Measurement starts after the room has been vigorously ventilated- the initial CO_2 concentration is set by the ambient air.

In mechanically ventilated rooms, operate the VAC equipment for one hour before first taking the base reading in an unoccupied room and then in the presence of the users of the room, also for a room with free ventilation.

For tracer gas air change measurements, recording starts about 15 to 30 min after injection of the additional CO_2 into the room air. A simple table fan encourages circulation (ISO 16000-8) in small-medium volume spaces.

If the ventilation effectiveness is to be determined by the steady state concentration in a mechanically ventilated occupied room, the CO_2 concentration is measured at various points about 2 h after starting up the VAC plant.

If the emission characteristics of a source are to be recorded or if an unknown source of combustion exhaust gases is suspected in a room, the CO_2 concentration is continuously recorded over a longer period.

Sampling location

For rooms with a surface area of up to 50 m^2, locate a single sampling point at 1.5 m height and at least 1 to 2 m from the walls.

For larger rooms, more sampling sites are needed to determine any concentration gradients.

The measuring device must not be near the sampling point and people should be at least 1.5 to 2 m from the sampling point.

When searching for an unknown source of combustion exhaust gases, the intake probe of the measuring device is moved every 5 to 10 min, to find the site of the highest concentration.

When measuring in mechanically ventilated rooms, the point at which the supply air enters the room must be measured to determine the outdoor pollution concentrations.

Parallel measurements of the outdoor air and metaparameters

Outdoor air samples should be measured near the building, but not closer than 1 m.

In making such measurements, remember that vertical concentration gradients may occur.

If the building is equipped with an HVAC system, the outdoor air should be sampled near the air intake.

Wind direction, wind velocity and other weather conditions are useful information.

Always measure accurately temperature and humidity, and barometric pressure can be used to improve reading accuracy.

Analysis and data quality

Measurement uncertainties inevitably occur. They are caused by the limits of the measurement device and procedure, and by uncertainties in sampling and analysis.

You must establish how to describe the measurement uncertainty and which performance characteristics are to be used to describe the results in the measurement report. There is no generic method for calculating Uncertainty, it depends on the equipment and protocol.

When calculating Uncertainty, refer to the Guide to the Expression of Uncertainty in Measurement (GUM).

Summary ISO 16000-26 (and 16000-1)

The built environment is dynamic and different from outdoor air.

Characterize the ventilation effectiveness.

Determine the baseline concentration, wait 2 hours for steady state CO_2 measurement, and sample regularly for tracer decay testing.

Measure at 1.5 m height and 1 to 2 m from walls; keep yourself and your equipment away from the measuring point.

Monitor the outdoor air: (outdoor-indoor) CO_2 concentration is the critical measurement. Also- T/RH/p should be recorded and wind speed/wind direction can be important.

Calculating Uncertainty is not simple. Refer to the GUM document.

CO_2 measurement technologies

Diffusive and pumped samplers

The diffusive surface allows the target molecule to pass through to the adsorbing surface. Easy and low initial cost, but ongoing sampler maintenance ands analysis costs rapidly increase the cost of ownership

Non-dispersive Infrared (NDIR) Three grades of performance:

±30 ppm ±3% reading ($40 to $10)

±50 ppm ±5% reading ($150 to $50)

±200 ppm (see Amazon devices)

Cavity Ring-Down (CRD and Tunable Diode Laser Absorption (TDLAS)

The Gold Standard, but cost $6,000 to $80,000

Non-dispersive Infrared- NDIR

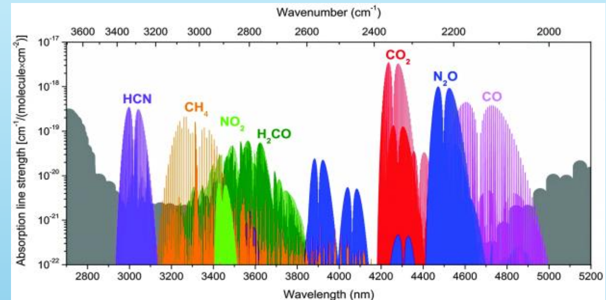
NDIR sensors perform well and the price has dropped from \$100 to \$15-\$40

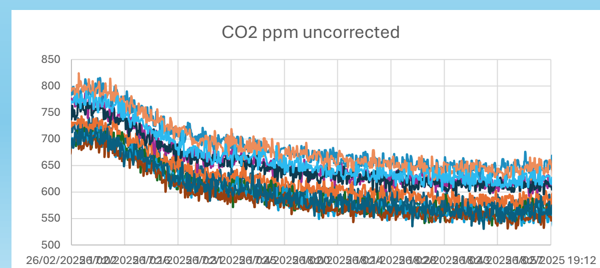
Sensitivity follows Beer-Lambert Law

Bright NIR and MIR LEDs provide new opportunities

Detector can be photodiode or microphone (Photoacoustic- PA sensor)

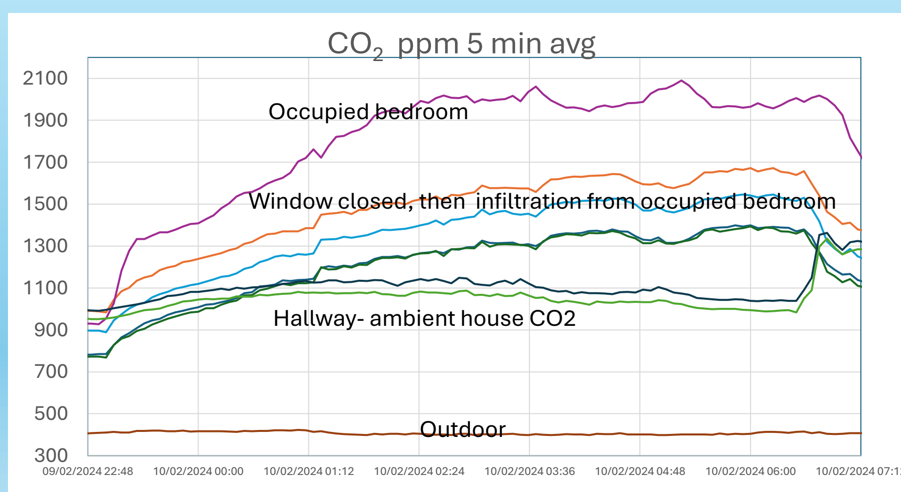
Power has dropped from 200mW to <2mW as the optical source has moved from tungsten bulb to LEDs and lasers.





Steady state CO_2 as a tracer gas requires careful consideration

- Steady state measurements have many inherent assumptions including:
- Level of occupancy
- Ventilation state
- Gaussian distribution of error



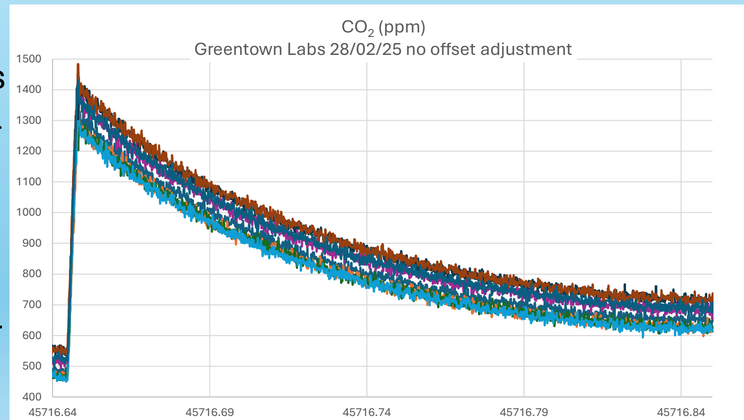
Pittcon 2024 28th February 2024

Using gas decay when measuring ACH

A bit more analysis compared to steady state, but has fewer assumptions

Can be analyzed several times during the day, giving a diurnal picture of airflow.

Ventilation Information collected at different times allows calculation of different sections of the mechanical or natural ventilation system



NDIR Sensor Summary

LED NDIR is now dominating CO_2 measurements:
low cost, low power, stable, and acceptable data quality

Good quality NDIR sensors (accuracy + precision) will be:
±60 to ±120 ppm from 425 to 1000 ppm CO_2
Lowest cost sensors will be ±150 to ±300 ppm CO_2

Correction for barometric pressure is advised

Steady state or tracer decay to determine ACH? This author prefers tracer decay, recorded whenever the room environment changes