Using CO_2 Monitoring to Manage Ventilation in Buildings

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ISIAQ Webinar
Managing buildings in the era of COVID-19
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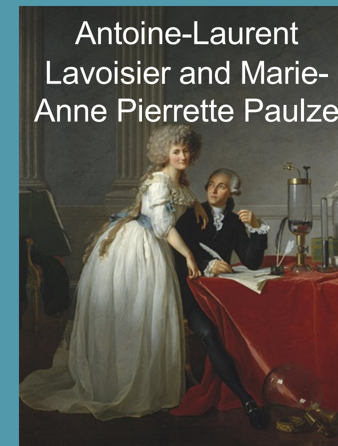
Background

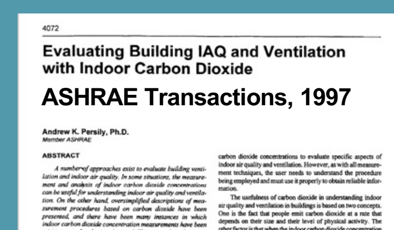
CO_2 part of ventilation & IAQ discussions since 17th century

- Impacts on occupants
- Bioeffluent odor perception
- Ventilation rate estimation
- Ventilation control



Misinterpretation of CO_2 for years

More recently: more interest, more measurement, more confusion



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Evaluating Building IAQ and Ventilation with Indoor Carbon Dioxide

ASHRAE Transactions, 1997

Andrew K. Persily, Ph.D.
Member ASHRAE

ABSTRACT

A number of approaches exist to evaluate building ventilation and indoor air quality. In some situations, the measurement and analysis of indoor carbon dioxide concentrations can be useful for understanding indoor air quality and ventilation. On the other hand, oversimplified descriptions of measurement procedures based on carbon dioxide have been presented, and there have been many instances in which indoor carbon dioxide concentration measurements have been misinterpreted and misunderstood. This paper describes vari-

carbon dioxide concentrations to evaluate specific aspects of indoor air quality and ventilation. However, as with all measurement techniques, the user needs to understand the procedure being employed and must use it properly to obtain reliable information.

The usefulness of carbon dioxide in understanding indoor air quality and ventilation in buildings is based on two concepts. One is the fact that people emit carbon dioxide at a rate that depends on their size and their level of physical activity. The other factor is that when the indoor carbon dioxide concentration

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

Indoor concentrations of carbon dioxide (CO_2) have been widely promoted as metrics of indoor air quality (IAQ) and ventilation, in many cases without a sound explanation of what they are intended to characterize or an adequate discussion of the specific application and any limitations. Many practitioners and researchers use 1,800 mg/m^3 (roughly 1,000 ppm$_v$) as a criteria for defining good IAQ and cite ASHRAE Standard

CO_2 Monitoring to Manage Ventilation

Long-term: Demand control ventilation

Short-term: Today's focus

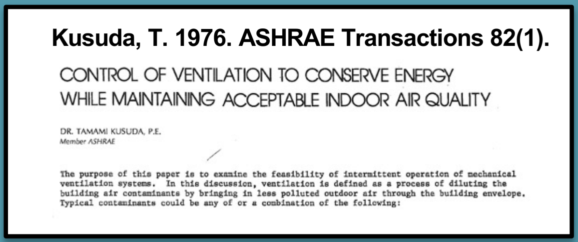
Multiple purposes & approaches

- IAQ assessment
- Ventilation rate estimation
- Infection risk

Not always clear to user or listener

Long Term Indoor CO_2 Monitoring Demand Control Ventilation

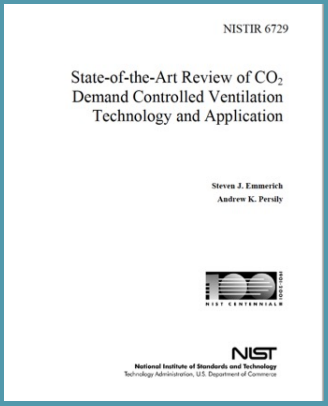
- Earliest references from 1970s
- To avoid over- and under- per person ventilation rate
- Required by building energy efficiency standards
- Most relevant in spaces with unpredictable occupancy variations


Kusuda, T. 1976. ASHRAE Transactions 82(1).

CONTROL OF VENTILATION TO CONSERVE ENERGY
WHILE MAINTAINING ACCEPTABLE INDOOR AIR QUALITY

DR. TAMAMI KUSUDA, P.E.
Member ASHRAE

The purpose of this paper is to examine the feasibility of intermittent operation of mechanical ventilation systems. In this discussion, ventilation is defined as a process of diluting the building air contaminants by bringing in less polluted outdoor air through the building envelope. Typical contaminants could be any of or a combination of the following:


NISTIR 6729

State-of-the-Art Review of CO_2 Demand Controlled Ventilation Technology and Application

Steven J. Emmerich
Andrew K. Persily

NIST CENTENNIAL 1901–2001

NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

Short-Term CO_2 Monitoring

IAQ Metric

Ventilation Rate

Infection Risk

Courtesy of David Meyer,
Shenandoah University

IAQ Metric

Maybe for contaminants related to # of occupants & activities

But other important contaminants and sources

Ventilation Rate

CO_2 as a tracer gas: ASTM E741 (D6245 for CO_2), ISO 12569

Decay, Constant injection, Constant concentration

Theory and assumptions; Single zone!!!

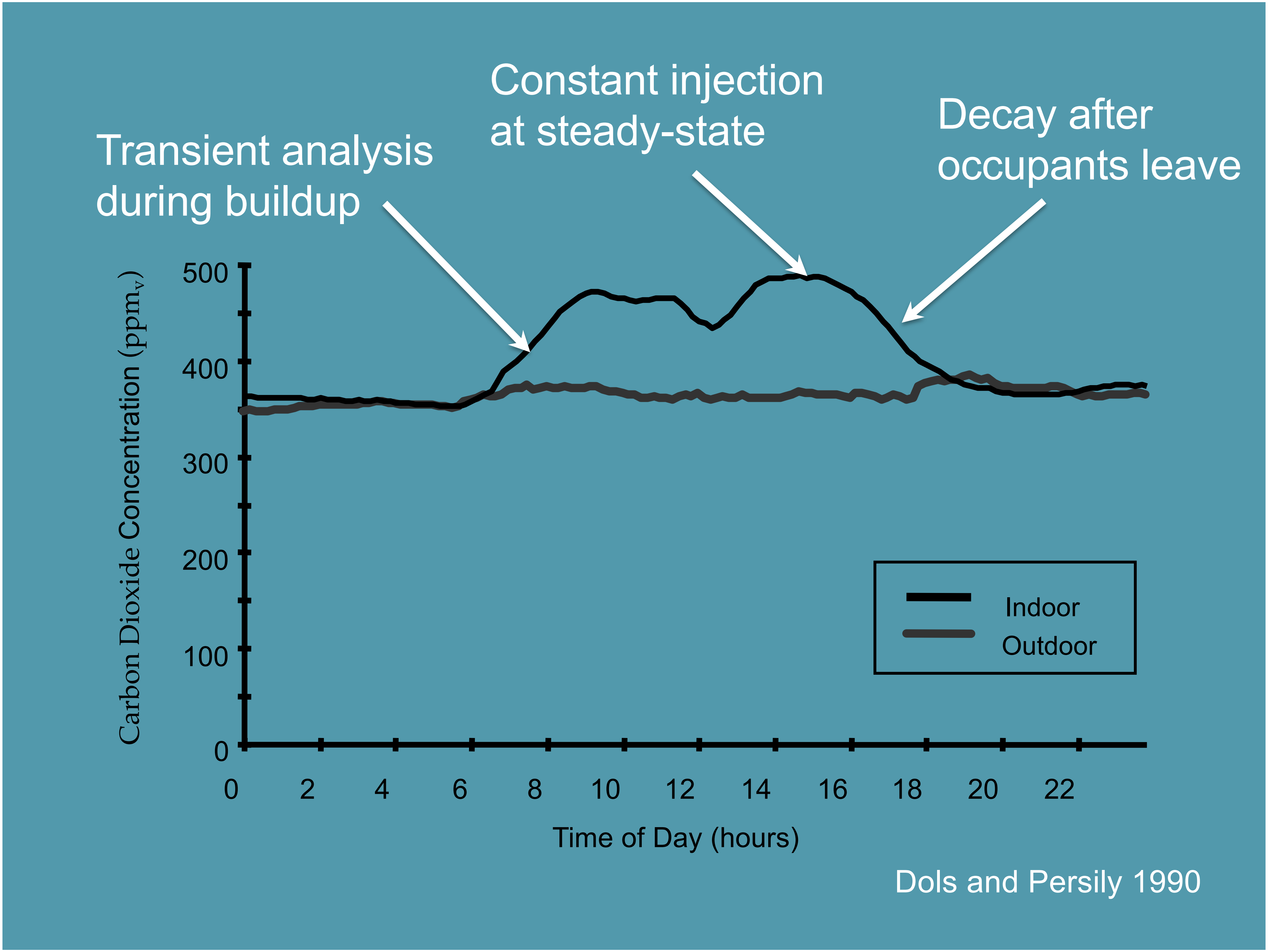
Infection Risk

To verify protective ventilation rate OR Indicator of risk

What is a protective ventilation rate?

Rebreathed air

Fate & transport of CO_2 ≠ F&T of virus-laden aerosol


Transient analysis during buildup
Constant injection at steady-state
Decay after occupants leave
Carbon Dioxide Concentration (ppm$_v$)
500
400
300
200
100
0
0
2
4
6
8
10
12
14
16
18
20
22
Time of Day (hours)
Indoor
Outdoor
Dols and Persily 1990

Using Peak CO_2 to Estimate per Person Outdoor Ventilation Rates

Single-zone constant injection tracer gas method

$$Q_{out} = \frac{G_{CO2}}{(C_{in,Steady-state} - C_{out})}$$

Assumptions: Single-zone, constant air change, CO_2 generation rate constant and known, …

CO_2 generation depends on activity, sex, age, body mass

Estimating before steady-state overestimates air change rate

Uncertainty calculations per ASTM D6245

Thoughts on CO_2 monitoring

Variation happens

Occupancy, activities, ventilation system operation, weather

Measurement

Repeat; Calibration; Sampling location; Relative to outdoors; Relative to time of occupancy; Uncertainty; Repeat

What value: Base on target OA/person or infection risk?

CDC: 800 ppm_v, “potential target benchmark for good ventilation”

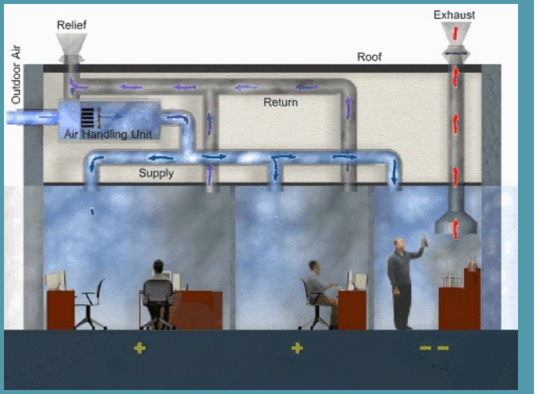
REHVA: 800 ppm_v “indicator of good ventilation and IAQ.”

UK SAGE: Spaces with high aerosol generation, $< 800\ ppm_v$

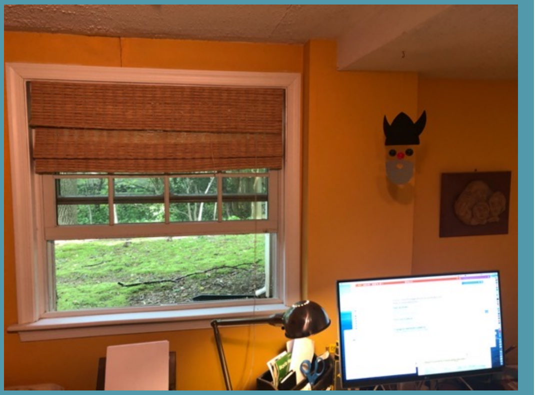
Rationale for values?

More Thoughts on CO_2 monitoring

Make sure ventilation system is operating as intended
Outdoor air, filtration, controls, T & RH, …
Always been a good idea; more so now



Use CO_2 to estimate ventilation rate,
OR
To prioritize for inspection & repair if needed



No OA ventilation system?
Natural ventilation or leakage only
Tracer gas methods can be challenging

Example Calculations

ASHRAE Standard 62.1 rates and default occupancies

Occupants (sex, age, mass, physical activity) to estimate CO_2 generation rate; Ceiling height; C_{out} = 400 ppm_v

Office space

Restaurant

Classroom

Auditorium

	Office	Classroom	Restaurant	Auditorium
Steady-state CO_2, ppm_v				
Baseline (Std 62.1)	1000	1030	1594	2159
50 % occupancy	700	*748*	1058	1280
+50 % ventilation	*800*	*820*	*1196*	*1573*

On-Line Calculator

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

CO2 Metric Analysis Tool

link to documentation of this tool.

Building Type

- (selected) Commercial/Institution
- Residential

Model Type

- (selected) Predefined
- User-Defined

Predefined Commercial Buildings (from ASHRAE Standard 62.1-2016)

Classroom (5-8 y)

Outdoor CO2 Concentration
0 mg/m³

Initial Indoor CO2 Concentration
0 mg/m³

Ceiling Height
3 m

62.1 Ventilation per Person
5 L/s

62.1 Ventilation per Floor Area
0 L/s m²

Occupant Density
25 #/100 m²

Ventilation Rate per Person
7.4 L/s

Time to Metric
2 h

Alternate Ventilation per Person:
5 sL/s

Predefined Occupants

Number of Occupants	Sex	Mass (kg)	Age Group	Activity Level (met)
12	M	23	3 to 9	2
12	F	23	3 to 9	2
1	M	85	30 to 59	3

Copy to User-Defined Model

Get Results

Search on: NIST CO2 tool

Summary

Ventilation important

But won't eliminate risk

Use a layered approach

When monitoring CO_2…

Measure and interpret with care

Measure more than once

Same reference value for all spaces?

More to evaluating ventilation than measuring CO_2

Report: Space & system types, design ventilation rate, occupant density, **time of measurement relative to occupancy,** outdoor concentration, **uncertainty**.

For your reading pleasure

ASTM D6245-2018, Standard Guide for Using Indoor Carbon Dioxide Concentrations to Evaluate Indoor Air Quality and Ventilation. ***In revision.***

Coming soon…

Persily, 2021?, Evaluating Ventilation Performance, Handbook of Indoor Air Quality, Springer Publishing

ASHRAE Position Document on Indoor CO_2

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

Persily, 2015. Challenges in developing ventilation and indoor air quality standards: The story of ASHRAE Standard 62, Building and Environment, 91.

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

Persily,. 2018. Development of an Indoor Carbon Dioxide Metric, *39th AIVC Conference*, Antibes Juan-les-Pins, France, 791-800.

Persily and Polidoro. (2019) Residential Application of an Indoor Carbon Dioxide Metric, *40th AIVC Conference*, Ghent, Belgium, 995-1007.

Persily, 2021. Don’t Blame Standard 62.1 for 1000 ppm CO_2, ASHRAE Journal, 63(2).

Wargocki, 2021. What we know and should know about ventilation, REHVA Journal, 58 (2).