Using CO_2 Monitoring to Manage Ventilation in Buildings

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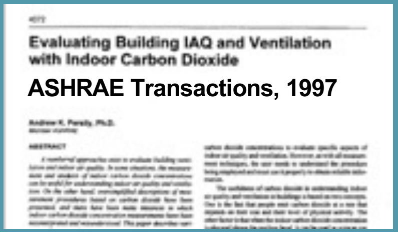
Background

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


Evaluating Building IAQ and Ventilation with Indoor Carbon Dioxide

ASHRAE Transactions, 1997


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

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 receiver

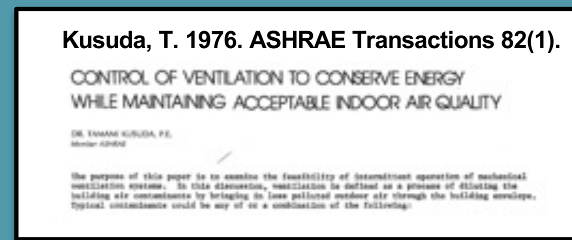
Long Term Indoor CO_2 Monitoring Demand Control Ventilation

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

Short-Term CO_2 Monitoring

IAQ Metric

Ventilation Rate

Infection Risk

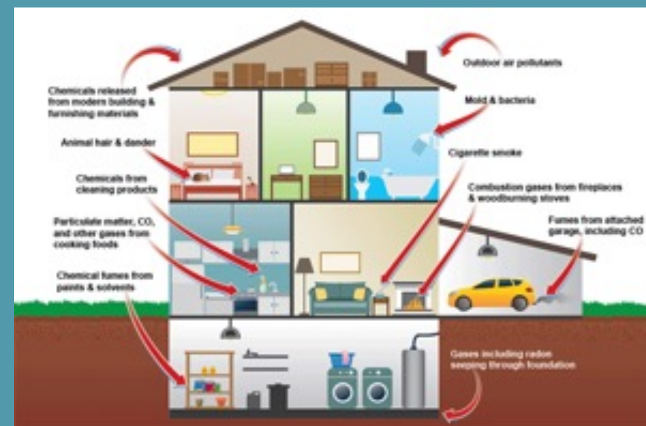
Courtesy of David Meyer,
Shenandoah University

ppm is not an SI unit.
μmol of CO_2/mol of air or μL/L are.
Using ppm_v today.

CO_2 as an IAQ Metric

Maybe for contaminants related to # of occupants & activities

But other important contaminants and sources



CO_2 to Estimate Ventilation Rate

Tracer gas test methods:

- ASTM E741 (D6245 for CO_2), ISO 12569
- *Decay, Constant injection, Constant concentration*

Theory and assumptions; Single zone!!!

BUILDING RESEARCH STATION, GARSTON, NR. WATFORD, HERTS.

THE MEASUREMENT OF THE RATE OF AIR CHANGE

By W. G. MARLEY, M.Sc.

Introduction.

For some considerable time the need has been felt of a simple method of measuring the rate of ventilation. A knowledge of this quantity is valuable in the design of heating systems, but in the majority of instances only a vague estimate of it has hitherto been possible. Occasionally, the air velocity in supply ducts can be measured, but frequently a system of ducts is not employed and the task of determining the rate of air change becomes one of considerable difficulty.

In experiments conducted at the Building Research Station in 1927[1], the ventilation of a room was determined by measurement of the increase in carbon dioxide consequent upon the burning of three standard candles for three hours. A 2.5 litre sample of air was taken by means of rubber hand-bellows, the flask being moved round the room about 3 ft. 6 in. from the floor, and the carbon dioxide was estimated by absorption in barium hydroxide and titration of the excess with oxalic acid. Using this method of measurement the efficacies of an unheated flue and a wall ventilator were compared.

[1] Report of the Building Research Board for the Year 1927, p. 106.

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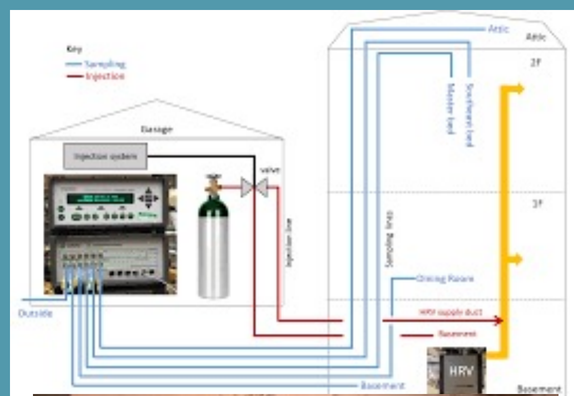
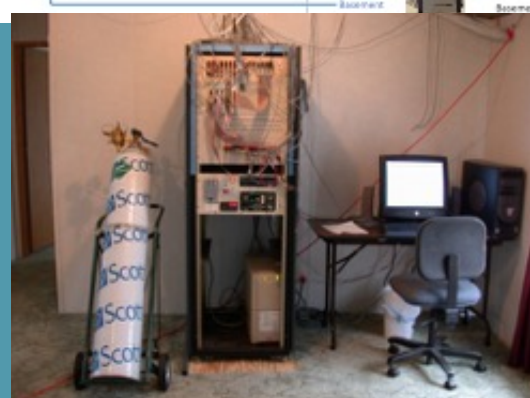
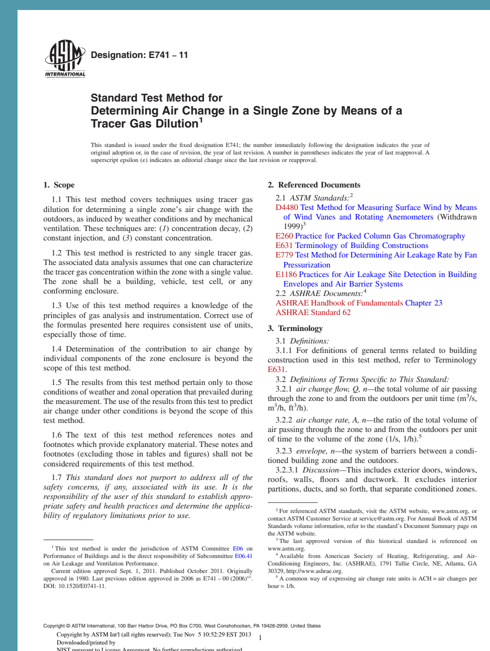






Designation: E741 – 11

Standard Test Method for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution[1]

This standard is issued under the fixed designation E741; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers techniques using tracer gas dilution for determining a single zone's air change with the outdoors, as induced by weather conditions and by mechanical ventilation. These techniques are: (*1*) concentration decay, (*2*) constant injection, and (*3*) constant concentration.

1.2 This test method is restricted to any single tracer gas. The associated data analysis assumes that one can characterize the tracer gas concentration within the zone with a single value. The zone shall be a building, vehicle, test cell, or any conforming enclosure.

1.3 Use of this test method requires a knowledge of the principles of gas analysis and instrumentation. Correct use of the formulas presented here requires consistent use of units, especially those of time.

1.4 Determination of the contribution to air change by individual components of the zone enclosure is beyond the scope of this test method.

1.5 The results from this test method pertain only to those conditions of weather and zonal operation that prevailed during the measurement. The use of the results from this test to predict air change under other conditions is beyond the scope of this test method.

1.6 The text of this test method references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered requirements of this test method.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D4480 Test Method for Measuring Surface Wind by Means of Wind Vanes and Rotating Anemometers (Withdrawn 1999)[3]

E260 Practice for Packed Column Gas Chromatography

E631 Terminology of Building Constructions

E779 Test Method for Determining Air Leakage Rate by Fan Pressurization

E1186 Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems

2.2 *ASHRAE Documents:*[4]

ASHRAE Handbook of Fundamentals Chapter 23

ASHRAE Standard 62

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of general terms related to building construction used in this test method, refer to Terminology E631.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *air change flow, Q, n*—the total volume of air passing through the zone to and from the outdoors per unit time (m^3/s, m^3/h, ft^3/h).

3.2.2 *air change rate, A, n*—the ratio of the total volume of air passing through the zone to and from the outdoors per unit of time to the volume of the zone (1/s, 1/h).[5]

3.2.3 *envelope, n*—the system of barriers between a conditioned building zone and the outdoors.

3.2.3.1 *Discussion*—This includes exterior doors, windows, roofs, walls, floors and ductwork. It excludes interior partitions, ducts, and so forth, that separate conditioned zones.

[1] This test method is under the jurisdiction of ASTM Committee E06 on Performance of Buildings and is the direct responsibility of Subcommittee E06.41 on Air Leakage and Ventilation Performance.

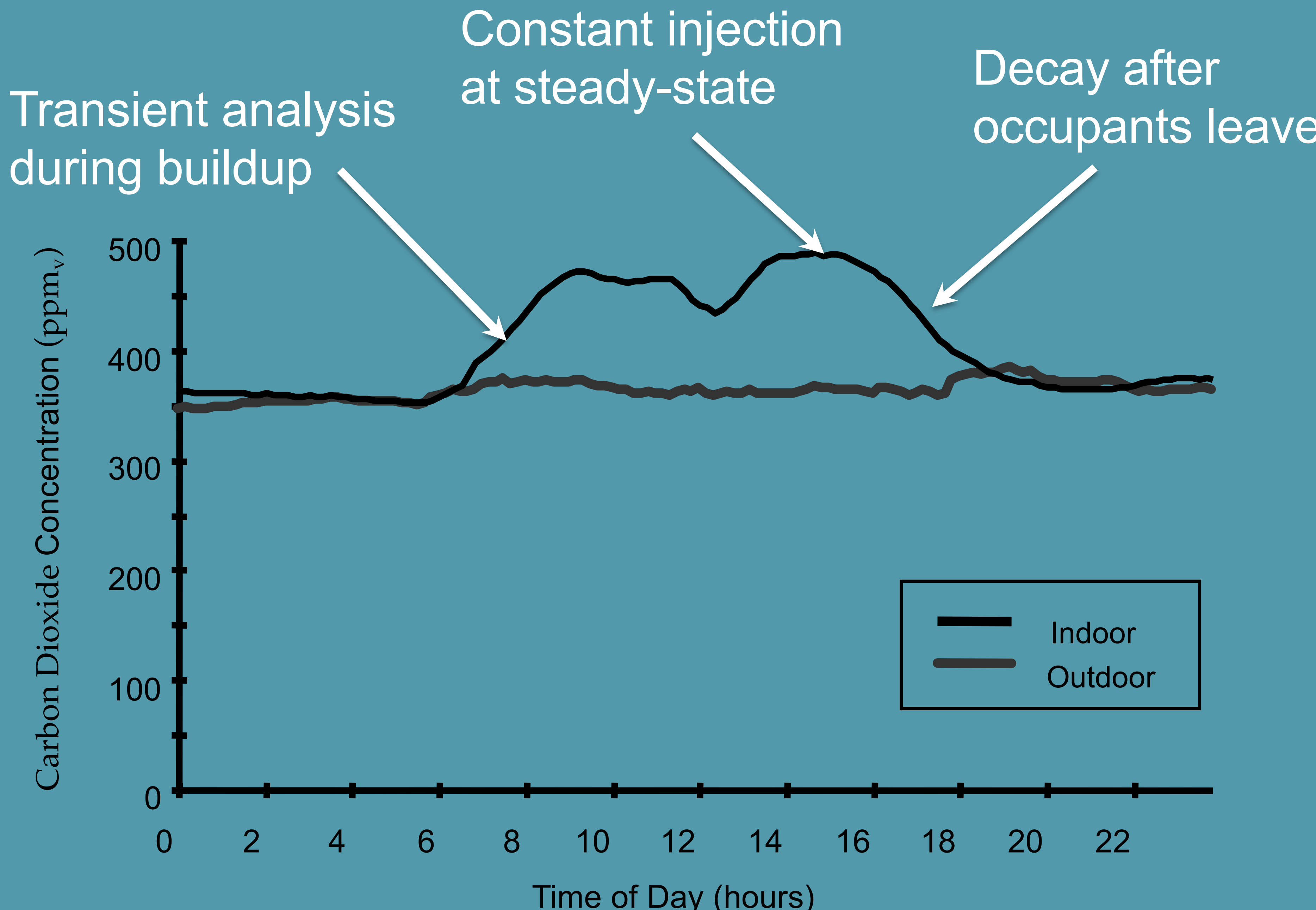
Current edition approved Sept. 1, 2011. Published October 2011. Originally approved in 1980. Last previous edition approved in 2006 as E741 – 00 (2006)$^{\varepsilon 1}$.
DOI: 10.1520/E0741-11.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For Annual Book of ASTM Standards volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

[4] Available from American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE), 1791 Tullie Circle, NE, Atlanta, GA 30329, http://www.ashrae.org.

[5] A common way of expressing air change rate units is ACH = air changes per hour = 1/h.



Persily, A.K. and Dols, W.S. (1990) The Relation of CO2 Concentration to Office Building Ventilation, *Air Change Rate and Airtightness in Buildings, ASTM STP 1067*, 77-92.

Using Peak CO_2 to Estimate per Person Outdoor Ventilation Rates

Single-zone constant injection tracer gas method

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

<u>Assumptions</u>: Single-zone, constant Q_{out}, G_{CO2} constant & known

<u>CO_2 generation</u> depends on activity, sex, age, body mass

<u>Estimating before steady-state</u> overestimates air change rate

<u>Uncertainty calculations</u> per ASTM D6245

Example calculation:
G_{CO2} = 0.0045 L/s; C_{ss} = 1000 ppm_v ; C_{out} = 400 ppm_v
Q_{out} = 7.5 L/s per person

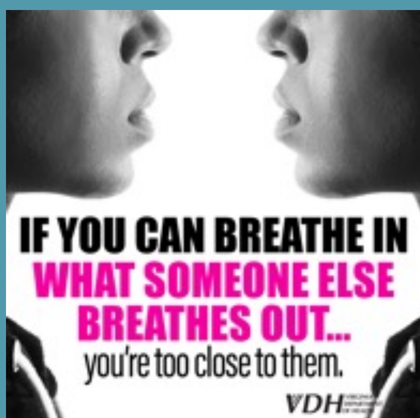
CO_2 as an Indicator of Infection Risk

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




Correlation of Respiratory Aerosols and Metabolic Carbon Dioxide

New studies and insights in real time

E.g., Kappelt, et al. 2021: “by measuring CO2 concentrations, only the number and volume concentrations of released particles can be estimated with reasonable certainty, while the number of suspended RNA copies cannot.”

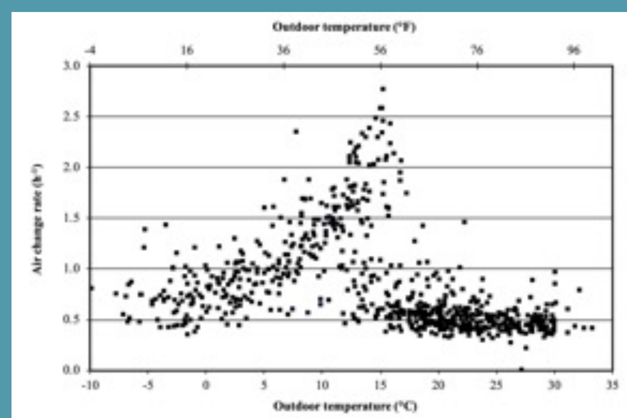
Thoughts on CO_2 monitoring

Variation happens

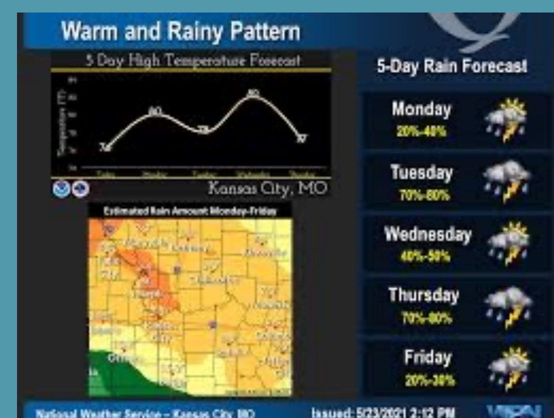
Occupancy, activities, ventilation system operation, weather

Measurement

<u>Repeat</u>; Calibration; Sampling location, duration and timing relative to occupancy; Compare to outdoors; Uncertainty; <u>Repeat</u>



Office building
ventilation rate vs T_{out}



Thoughts on CO_2 monitoring

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

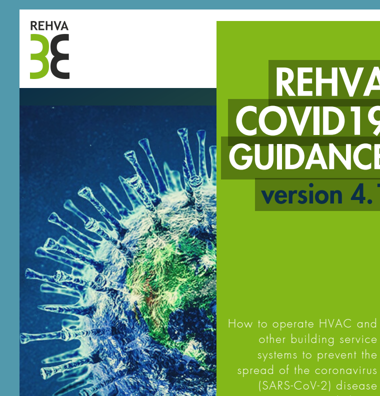
CDC: 800 ppm$_v$, “potential target benchmark for good ventilation”

REHVA: 800 ppm$_v$ “indicator of good ventilation and IAQ.”

UK SAGE: Spaces with high aerosol generation, < 800 ppm$_v$

Rationale for values???

ASHRAE, WHO & others recommend disabling DCV or reducing setpoint to ≈500 ppm$_v$



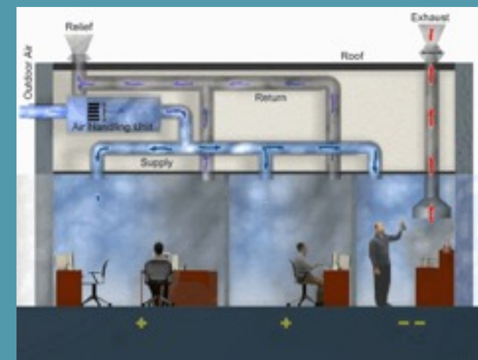
https://www.cdc.gov/coronavirus/2019-ncov/community/ventilation.html
https://www.rehva.eu/fileadmin/user_upload/REHVA_COVID-19_guidance_document_V4.1_15042021.pdf
https://www.gov.uk/government/publications/emg-and-spi-b-application-of-co2-monitoring-as-an-approach-to-managing-ventilation-to-mitigate-sars-cov-2-transmission-27-may-2021

More Thoughts on CO_2 monitoring

Make sure ventilation system is operating as intended

Outdoor air, filtration, controls, T & RH, …

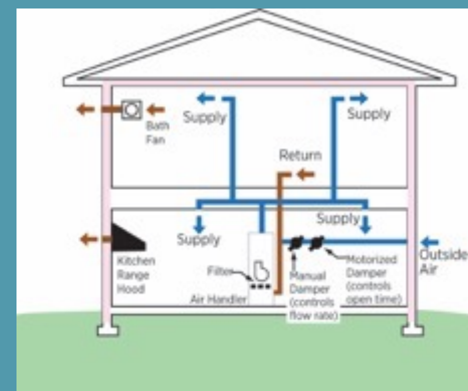
Always been a good idea; more so now



<u>Using CO_2 monitoring</u>

To estimate ventilation rate, OR

To prioritize for inspection & repair



Evaluating Ventilation Performance, Chapter in upcoming Handbook of Indoor Air Quality

<u>Performance issues</u>: System status, Envelope leakage, Ventilation system airflows, Outdoor air change rate, Interzone airflow, Air distribution

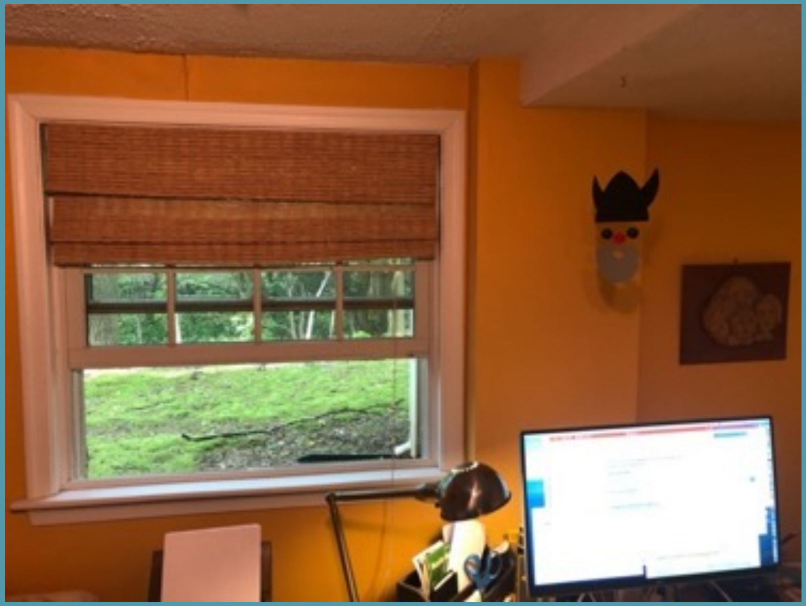
<u>Building and system design information</u> Outdoor air intake rate, controls, …

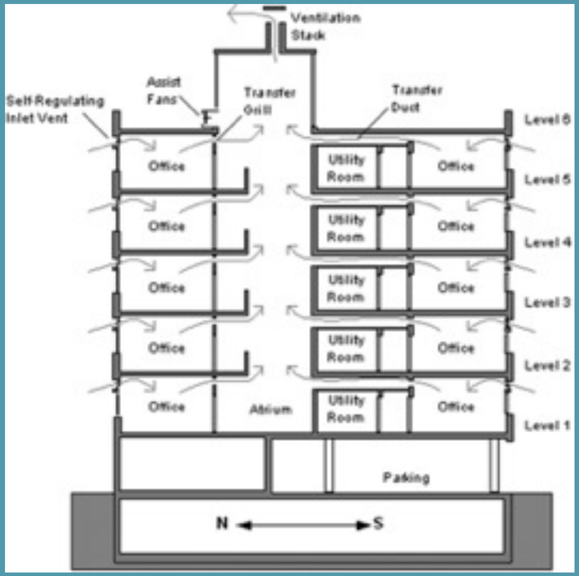
More Thoughts on CO_2 monitoring

No OA ventilation system?

Natural ventilation or leakage only

Tracer gas methods challenging for natural ventilation





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

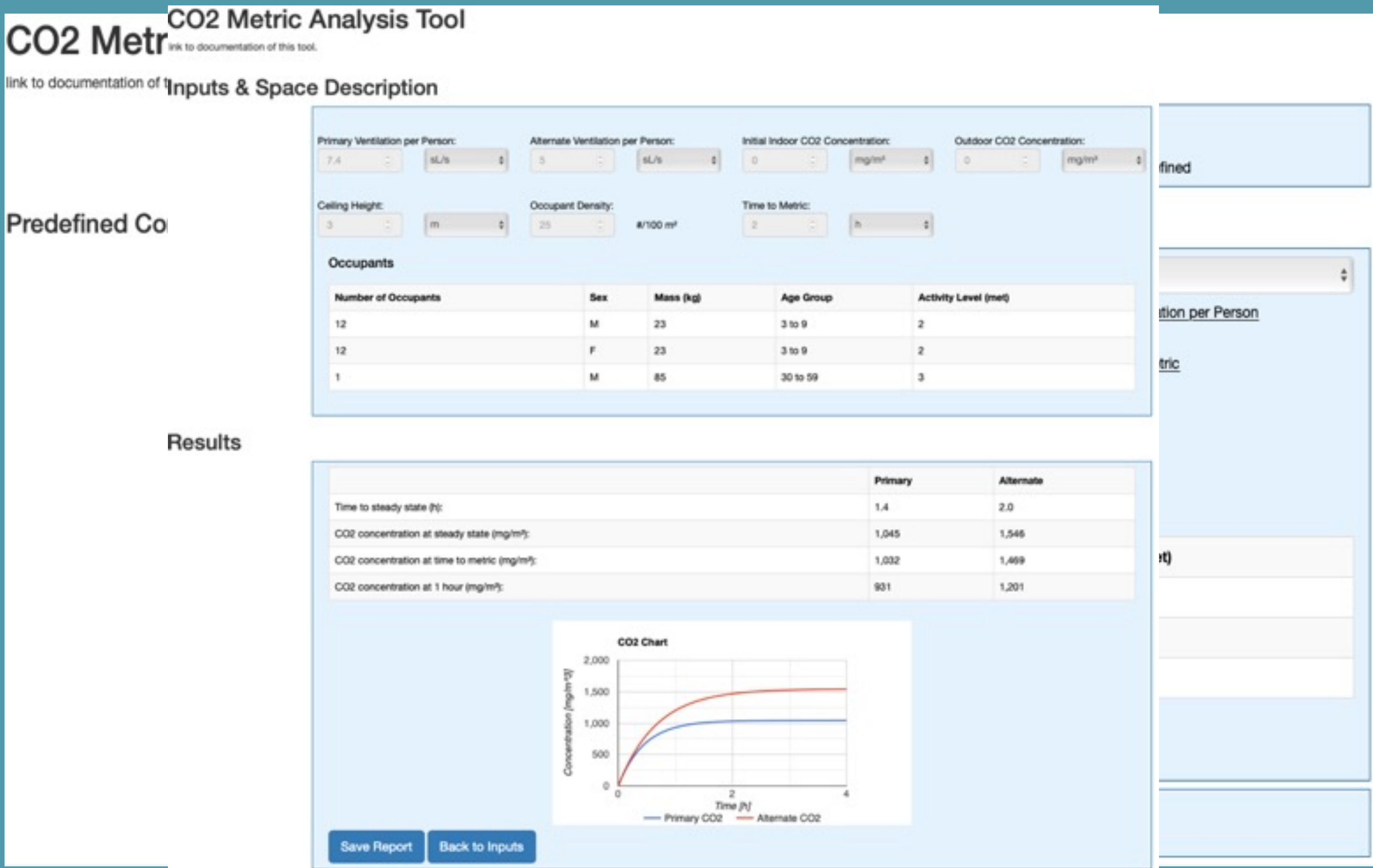
Auditorium

Example Calculations

	Office	Classroom	Restaurant	Auditorium
Baseline ventilation parameters				
L/s per person	8.5	7.4	5.1	2.7
Air changes/h	0.5	2.2	3.2	1.9
Time to 95 % steady-state, h	5.9	1.4	0.9	1.5
Steady-state CO_2, ppm_v				
Baseline (Std 62.1)	999	1031	1533	2150
50 % occupancy	699	*749*	1028	1275
+50 % ventilation	*799*	*821*	*1156*	*1567*
10 L/s per person	909	867	976	873

On-Line Calculator

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



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**.

Reading List

In the works…

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

Persily, 2021?, Evaluating Ventilation Performance, Handbook of Indoor Air Quality, Springer Publishing https://link.springer.com/referencework/10.1007/978-981-10-5155-5

ASHRAE Position Document on Indoor CO_2

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

https://www.cdc.gov/coronavirus/2019-ncov/community/ventilation.html

https://www.rehva.eu/fileadmin/user_upload/REHVA_COVID-19_guidance_document_V4.1_15042021.pdf

https://www.gov.uk/government/publications/emg-and-spi-b-application-of-co2-monitoring-as-an-approach-to-managing-ventilation-to-mitigate-sars-cov-2-transmission-27-may-2021

More Reading

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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).