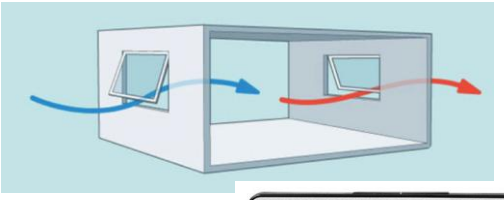
Worldwide CO_2 Guidelines for IAQ: A Review

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

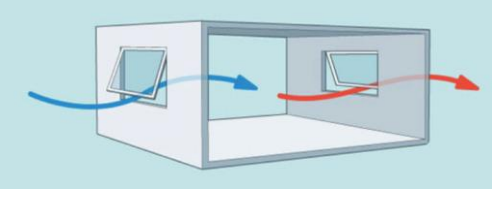
Air Quality Section, California Dept of Public Health
[1] also School of Public Health, UC Berkeley

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, health-based
  - recently, odor-based
- 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

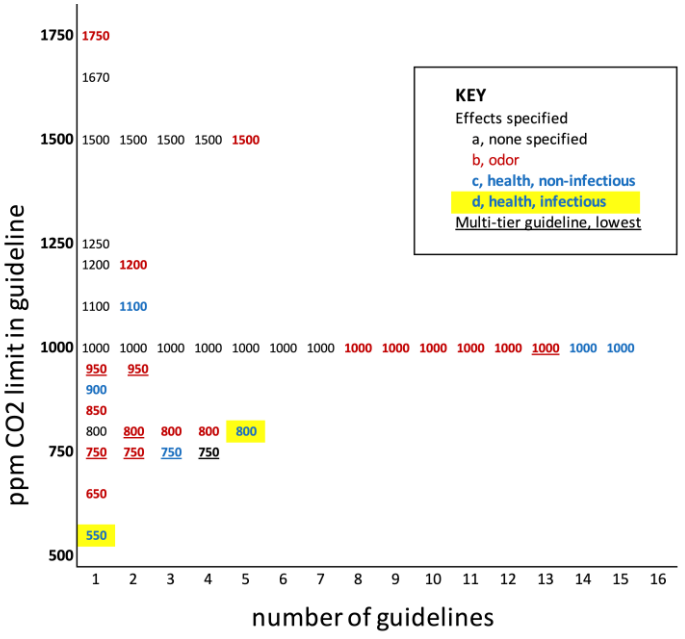
- ISIAQ STC34 database -- international IAQ guidelines*
- + current literature review
- Excluded occupational limits 5,000+ ppm
- 43 CO_2 guidelines, nations/ organizations
- All maximum values
  - one-time ←→ time-averaged
  - single value ←→ multiple tiers
  - absolute indoor ←→ differential (above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

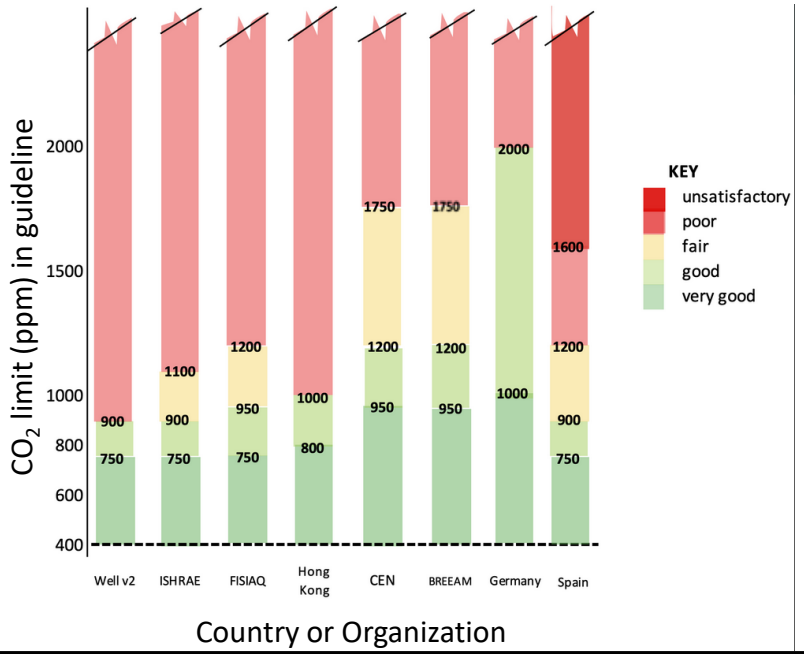


- Multi-tier guidelines: only lowest tier shown, underlined
- "Differential" limits shown here with estimated 400 ppm outdoors added
- Color in plot shows effects to be controlled by limit
- One guideline with 17 values omitted here

5

5

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

6

6

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 <u>averaged CO_2</u> 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.

7

7

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	Limited/ Insufficient	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

8

8

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

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

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

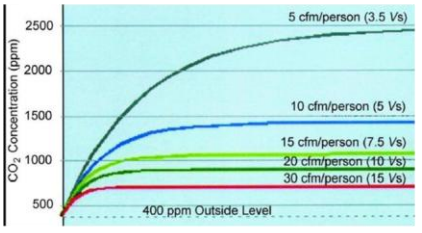
(1) set minimum VR limits
to control risks of indoor long-range transmission of airborne COVID transmission
per model of airborne infection

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

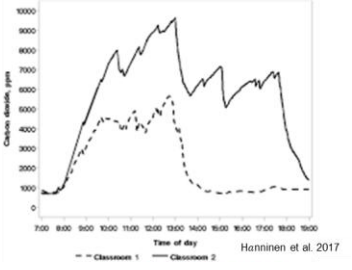
9

9

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

10

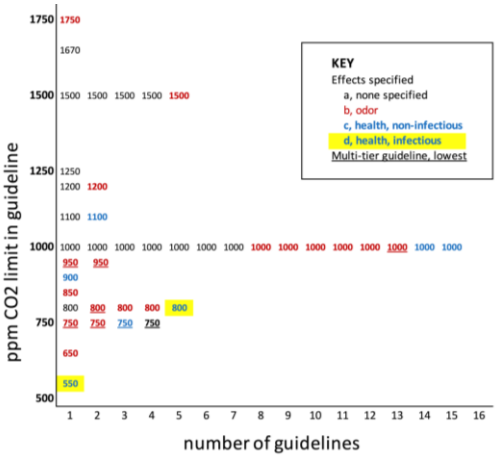
10

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

Questions?



This material now published:
Journal of Exposure Science and Environmental Epidemiology June 2024
Online read-only access at https://rdcu.be/dKJZ1
For pdf, contact mark.mendell@cdph.ca.gov

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

EXTRA SLIDES

13

13

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

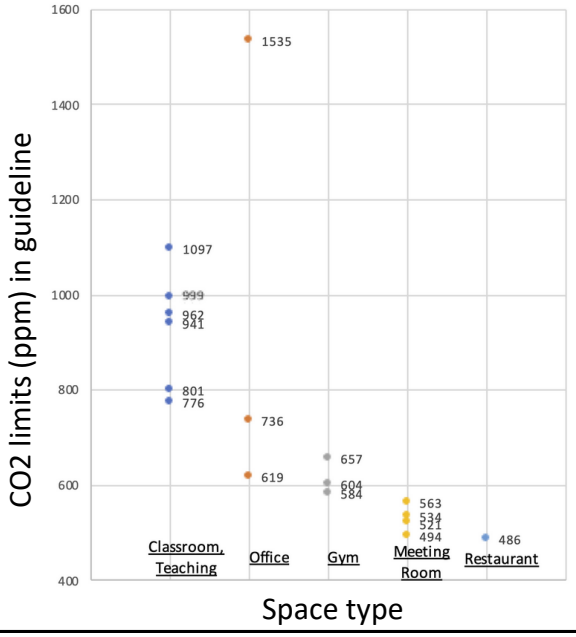
Space Use	Floor Area (m^2)	Room Height (m)	Number of Occupants	Infection-risk-based Indoor CO_2 Concentrations (ppm)
Small classroom	31.6	3.5	13	1097
Classroom	42.5	2.9	25	941
Classroom	56.5	2.9	25	962
reduced occupancy	56.5	2.9	20	999
Teaching space, large	129.5	2.9	50	776
reduced occupancy	129.5	2.9	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

14

14

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.

15

15

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.

16

16