Using CO$_2$ Monitoring to Manage Ventilation in Buildings

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EPA Indoor Air Quality Science Webinar
17 November 2021
Background

CO₂ part of ventilation & IAQ discussions since 17th century
- Impacts on occupants
- Bioeffluent odor perception
- Ventilation rate estimation
- Ventilation control

Misinterpretation of CO₂ for years

More recently: more interest, more measurement, more confusion
CO₂ 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
Short-Term CO₂ Monitoring

IAQ Metric
Ventilation Rate
Infection Risk

ppm is not an SI unit. µmol of CO₂/mol of air or µL/L are. Using ppmᵥ today.

Courtesy of David Meyer, Shenandoah University
CO₂ as an IAQ Metric

Maybe for contaminants related to # of occupants & activities

But other important contaminants and sources
CO₂ to Estimate Ventilation Rate

Tracer gas test methods:
ASTM E741 (D6245 for CO₂), ISO 12569

Decay, Constant injection, Constant concentration

Theory and assumptions; Single zone!!!
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 $Q_{out}$, $G_{CO2}$ constant & known

CO$_2$ generation depends on activity, sex, age, body mass

Estimating before steady-state overestimates air change rate

Uncertainty calculations 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
CO₂ 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 CO₂ ≠ F&T of virus-laden aerosol

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
Repeat; Calibration; Sampling location, duration and timing relative to occupancy; Compare to outdoors; Uncertainty; Repeat

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 $\approx 500$ ppm$_v$

More Thoughts on CO₂ monitoring

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

Using CO₂ monitoring
To estimate ventilation rate, OR
To prioritize for inspection & repair

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

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

*Building and system design information* Outdoor air intake rate, controls, …
More Thoughts on $\text{CO}_2$ 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$_v$
## Example Calculations

<table>
<thead>
<tr>
<th></th>
<th>Office</th>
<th>Classroom</th>
<th>Restaurant</th>
<th>Auditorium</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline ventilation parameters</strong></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>L/s per person</td>
<td>8.5</td>
<td>7.4</td>
<td>5.1</td>
<td>2.7</td>
</tr>
<tr>
<td>Air changes/h</td>
<td>0.5</td>
<td>2.2</td>
<td>3.2</td>
<td>1.9</td>
</tr>
<tr>
<td>Time to 95 % steady-state, h</td>
<td>5.9</td>
<td>1.4</td>
<td>0.9</td>
<td>1.5</td>
</tr>
<tr>
<td><strong>Steady-state CO\textsubscript{2}, ppm\textsubscript{v}</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline (Std 62.1)</td>
<td>999</td>
<td>1031</td>
<td>1533</td>
<td>2150</td>
</tr>
<tr>
<td>50 % occupancy</td>
<td>699</td>
<td>749</td>
<td>1028</td>
<td>1275</td>
</tr>
<tr>
<td>+50 % ventilation</td>
<td>799</td>
<td>821</td>
<td>1156</td>
<td>1567</td>
</tr>
<tr>
<td>10 L/s per person</td>
<td>909</td>
<td>867</td>
<td>976</td>
<td>873</td>
</tr>
</tbody>
</table>
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…
ASHRAE Position Document on Indoor CO₂

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


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