Why Is Measuring Carbon Dioxide Important?

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Why is measuring Carbon Dioxide (CO_2) important?

There are three reasons.

Reason 1) Cognition Improvement – When CO_2 levels increase over the outdoor level of ~ 420 parts per million (ppm), noticeable negative human performance effects occur.

From the widest lens, the Occupational Safety and Health Administration (OHSA) standard is CO_2 levels should be below 5,000 ppm over an 8-hour-time-weighted average (TWA).

Back in the 1960s and 1970s, the US Navy did its own research and claimed that 11,300 ppm of CO_2 was acceptable on submarines.

However, more recent studies have shown complex problem solving and executive functioning get negatively impacted by as little as 640 ppm of CO_2 and the negative effects (response times increase and throughput times decrease) as the CO_2 levels increase.

From 420 ppm to 900 ppm, the decrease in complex cognitive functioning is a linear relationship – meaning more CO_2, even at these low levels, impairs cognitive performance.

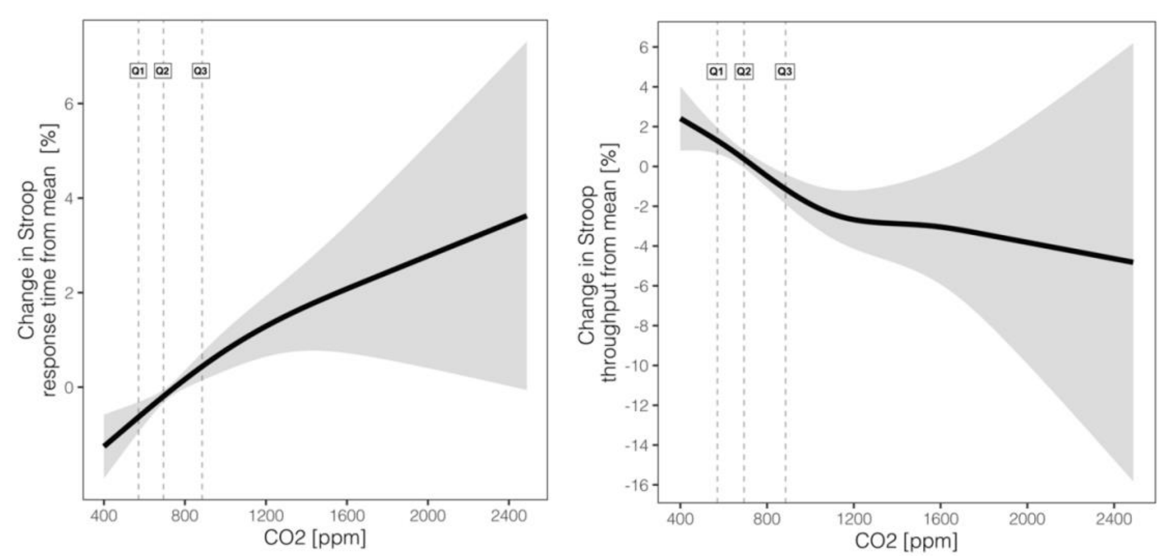


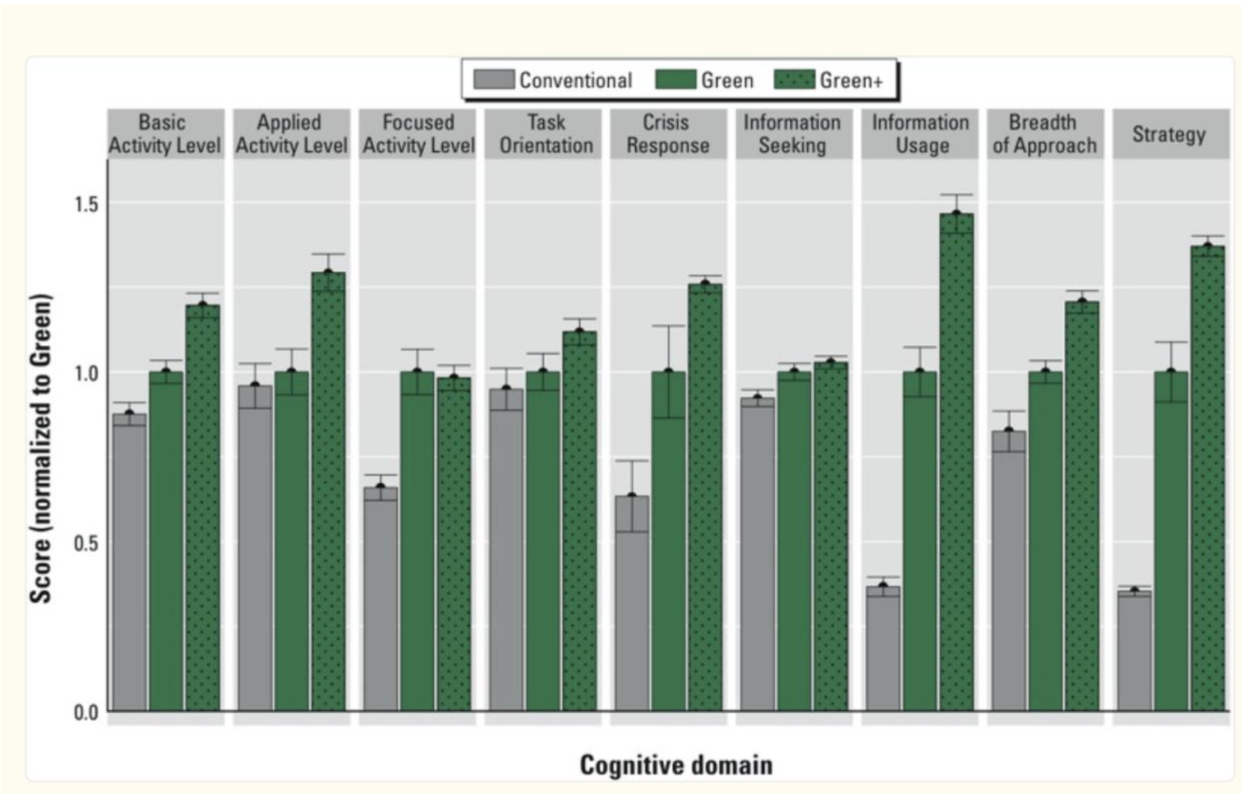
Figure 3. Association between log-transformed Stroop response time and Stroop throughput and CO_2 exposure using natural splines with three degrees of freedom. Grey shading represented the 95% confidence interval. Dashed lines represent the CO_2 quartiles (Q1 = 25%, Q2 = 50%, Q3 = 75%). Adjusted covariates include temperature, age, gender, educational level, job category, workspace type, occupants in the respondents' room, hour, and month.

https://iopscience.iop.org/article/10.1088/1748-9326/ac1bd8/pdf

This next example highlights improved cognitive performance by comparing problem-solving abilities across three different test conditions:

1. standard ASHRAE ventilation rates (gray bar),
2. standard ASHRAE ventilation rates combined with green cleaning methods (green bar), and
3. enhanced ventilation rates aimed at maintaining indoor CO_2 levels around 550 ppm, also paired with green cleaning methods (green-dotted bar).

The results allow us to compare cognitive function under each scenario. Green cleaning methods—which use low-VOC (Volatile Organic Compound) materials and cleaners—led to better cognitive scores than standard ventilation alone. When increased ventilation was added to the green cleaning approach, cognitive performance improved even further. These findings suggest that reducing VOC exposure and indoor CO_2 levels both contribute significantly to enhanced cognitive function.



https://pmc.ncbi.nlm.nih.gov/articles/PMC4892924/

Reason 2) **Cost** - So ideally, every indoor living space should have near outdoor levels of CO_2 (or about 420 ppm). This is easy to do in San Diego, where the weather is almost perfect all year round – just open a window.

But in the Gulf South, with its oppressively humid summers, and the Midwest and Northeastern States, with their cold winters, bringing in air from outside (to dilute the CO_2 concentrations inside) takes energy – a lot of it – to condition that outside air to a comfortable 70°F and 50% relative humidity (RH).

Controlling the amount of outdoor ventilation air that is brought inside using indoor CO_2 levels is the optimal way to ensure proper ventilation levels. Many commercial buildings use this strategy. Most residential buildings – if they have ventilation capabilities – use an ASHRAE-recommended calculation based upon the number of occupants and bedrooms.

One can quickly imagine how using a static ventilation formula for a huge mansion with 2 retired people living in it would be vastly over-ventilated, leading to excess energy consumption required to condition the outside air.

Using indoor CO_2 concentrations is a more direct and improved strategy for controlling ventilation air rates of outdoor air – minimizing cost (by limiting over-ventilation) and maximizing cognitive performance (by ensuring adequate ventilation).

Reason 3) **Health** – It has been a few years since the COVID pandemic ended. We learned some valuable lessons regarding airborne infections and CO_2 levels. CO_2 levels can be used to directly calculate how much air a person indoors is breathing that has been exhaled by another person indoors. Depending on the infectibility of the disease-causing agent, single digit percentages of rebreathed air (from an infected person) can put one at risk for catching the infection.

David Elfstrom, an engineer from Toronto, posted a spreadsheet calculating the percentage of air that one is breathing in that has already been exhaled. The left column is the CO_2 concentration in ppm. The center column is the fraction of air being inhaled that has been exhaled. The column on the right shows how many breaths it would take to breathe in the full exhalation of another person (which is usually around 40,000 ppm of CO_2).

Rebreathed Fraction of Air

https://tinyurl.com/rebreathed-air-fraction maintained by: Twitter:@DavidElfstrom

420 Co = Outdoor Air CO_2 ppm (note Aranet4 meter calibrates to 420 ppm)

38000 Ca = Volume fraction of CO_2 added to exhaled breath (ppm)

Indoor ppm	Fraction	1 in X breaths
500	0.2%	475
600	0.5%	211
700	0.7%	136
800	1.0%	100
900	1.3%	79
1000	1.5%	66
1100	1.8%	56
1200	2.1%	49
1300	2.3%	43
1400	2.6%	39
1500	2.8%	35
1600	3.1%	32
1700	3.4%	30
1800	3.6%	28
1900	3.9%	26
2000	4.2%	24
2200	4.7%	21
2400	5.2%	19
2600	5.7%	17
2800	6.3%	16
3000	6.8%	15
3200	7.3%	14
3400	7.8%	13
3600	8.4%	12
3800	8.9%	11
4000	9.4%	11
4200	9.9%	10
4400	10.5%	10
4600	11.0%	9
4800	11.5%	9
5000	**12.1%**	**8**

⬅ occupational health limit for CO2 exposure (such

Results

Rebreathed fraction

Of the total CO_2 in indoor air, a portion is of human origin, and assuming no other sources, the remainder enters the room with the outdoor air. Thus, if the airspace is well mixed,

$$C_a V_e = (C - C_o)V \qquad (2)$$

where C_a is the volume fraction of CO_2 *added* to exhaled breath during breathing, V is the volume of the shared air space, V_e is the equivalent volume of exhaled breath contained in indoor air (m^3), C is the volume fraction of CO_2 in indoor air, and C_o is the volume fraction of CO_2 in outdoor air.

The volume fraction of CO_2 added to exhaled breath and the rate of breathing remain essentially constant during short-duration exposures to inspired CO_2 concentrations up to approximately 15,000 p.p.m. (Kellogg, 1964; Schaefer et al., 1963). At low levels of oxygen consumption, such as office work, the CO_2 production rate and breathing rate are approximately 0.30 l/min and 8.0 l/min, respectively, giving a C_a of 0.038.

Solving Equation 2 for V_e/V gives

$$f = \frac{V_e}{V} = \frac{C - C_o}{C_a} \qquad (3)$$

where f is equivalent to the fraction of indoor air that is exhaled breath, which is also the rebreathed fraction. Thus, if the indoor CO_2 concentration is 700 p.p.m. above the outdoor level, which according to the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE, 1999a) is the maximum CO_2 concentration providing air quality that will be satisfactory to a majority of people 'with respect to human bioeffluents (body odor)', then an inhaled breath would contain 1.8% exhaled breath. Equation 3 is valid whether or not steady-state conditions have been reached.

For the total exposure period t, the time-weighted average fraction of indoor air that is exhaled breath ($\bar{f}$) can then be computed easily by integrating f over time and dividing by the elapsed time.

https://docs.google.com/spreadsheets/d/1AjFzhqM_NILYvZjgE8n0CvGZzYh04JpF_DO0phrOcFw/edit?gid=0#gid=0

In sum, measuring indoor CO_2 levels are essential for optimizing cognitive performance and health to ensure enough outside ventilation air is provided but not too much where the extra costs to condition the air are wasted due to minimal benefits. Measuring CO_2 provides direct feedback on the occupancy levels compared to the ventilation rate indoors.