Squirrel In Hell

2017-03-21

Effects of carbon dioxide on health and cognition

Summary

- Really high concentrations of CO_2 (30,000 - 40,000 ppm) produce obvious and terribly bad physiological effects.
- CO_2 levels even in poorly ventilated buildings rarely exceed 3,000 - 5,000 ppm.
- The evidence about those levels of CO_2 directly affecting cognition remains inconclusive.
- However, CO_2 levels are roughly indicative of overall air quality, which seems to affect both health and perceived comfort.
- CO_2 levels below 600 - 800 ppm will generally correspond to very good quality ventilation, however the measurements are highly local and will depend on air flow in the room and the location of the measuring device (and whether someone is breathing on it just to see what happens).
- Overall, a CO_2 meter might serve as a fun reminder and proxy for checking ventilation quality, but the exact values reported by it probably should not be treated too seriously.

Quotations

A Review of Cognitive and Behavioral Effects of Increased Carbon Dioxide Exposure in Humans (2016; NASA)

> *Existing research has reliably demonstrated the respiratory and cardiovascular effects of carbon dioxide (CO_2) inhalation at moderately increased levels, with documented physiological changes to heart rate, blood pressure, tissue pH, and blood solubility (for a review of the human health risks of acute elevated CO_2 exposure, see Rice, 2004). Studies of indoor air quality have linked increased levels of ambient CO_2 with physiological symptoms such as headache, fatigue, and sore throat (Apte et al., 2000; Seppanen et al., 1999; Wargocki et al., 2000).*

> *CO_2 is also a potent vasodilator. As CO_2 levels rise to 3% (23 mm Hg), exercise tolerance decreases, while heart rate, blood pressure, and resting energy expenditures increase (Cooper, 1970). Early symptoms of exposure include air hunger and increased respiration. Dizziness, headaches, and shortness of breath are also common. Exposure to higher CO_2 concentrations may result in confusion, heart palpitations, sweating, chest pain, anxiety, and panic attacks (Maresh, 1997; Beck, 1999; Woods, 1988). At levels as high as 10% (76 mm Hg) inhaled CO_2, severe dyspnea, vomiting, disorientation, and hypertension will develop, with prolonged exposure resulting in seizures and the eventual loss of consciousness (Cooper, 1970).*

> *This assessment of existing research into the psychomotor, cognitive, and sleep effects of elevated CO_2 exposure revealed conflicting, often contradictory findings. The majority of studies demonstrated no significant cognitive effects, although some results suggest mild*

> *impairments of psychomotor coordination, memory, and concentration. Additionally, some findings demonstrated no sleep impairments, while others showed disruptions of circadian functioning, hypervigilance, or changes in sleep architecture.*

> *Additionally, this survey highlights the fact that the majority of existing studies focus solely on the physiological mechanisms (e.g., headaches, heightened heart rate) by which increased CO_2 exposure may impact cognition, but fail to consider the possibility that observed performance changes may in fact be attributable to changes in brain or muscle pO_2, which covaries with pCO_2 in a way that may not be consistent across trials and individuals. A thorough examination, therefore, of the fluctuation of pO_2 as inspired CO_2 is manipulated remains critical if the impacts of elevated CO_2 exposure are to be decoupled from other physiological changes.*

Real-time monitoring of personal exposures to carbon dioxide (2016)

> *Adverse health and well-being outcomes associated with elevated indoor CO_2 levels are based on CO_2 as a proxy, although some emerging evidence suggests CO_2 itself may impact human cognition.*

> *Participants carried a CO_2 monitor continuously for 7-day periods recording their exposure levels at 1-min intervals.*

> *Approximately half of the participants slept in bedrooms employing ductless split air-conditioners (group "AC"); half slept in bedrooms naturally ventilated through operable windows (group "NV").*

> *Mean daily integrated exposures for group AC were statistically higher than for group NV: 22,800 ppm h/d vs. 16,000 ppm h/d ($p < 0.005$). Exposure events associated with potential adverse cognitive implications (duration > 2.5 h, average CO_2 mixing ratio > 1000 ppm) occurred, on average, at frequencies of 0.5 /d across all participants, 0.6 /d for AC participants and 0.2 /d for NV participants. The majority of such events occurred in the home (86%), followed by work (9%) and transit (3%).*

Human responses to carbon dioxide, a follow-up study at recommended exposure limits in non-industrial environments (2016)

> *The outdoor air supply rate was set high enough in a low-emission stainless-steel climate chamber to create a reference condition with CO_2 at 500 ppm when subjects were present, and chemically pure CO_2 was added to the supply air to create an exposure condition with CO_2 at 5000 ppm (the measured exposure level was ca. 4900 ppm). Ten healthy college-age students were exposed twice to each of the two conditions for 2.5 h in a design balanced for order of presentation. The raised CO_2 concentration had no effect on perceived air quality or physiological responses except for end-tidal CO_2 ($ETCO_2$), which increased more (to 5.3 kPa) than it was in the reference condition (5.1 kPa). Other results indicate additionally that a 2.5-h exposure to CO_2 up to 5000 ppm did not increase intensity of health symptoms reported by healthy young individuals and their performance of simple or moderately difficult cognitive tests and some tasks resembling office work.*

Associations of Cognitive Function Scores with Carbon Dioxide, Ventilation, and Volatile Organic Compound Exposures in Office Workers: A Controlled Exposure Study of Green and Conventional Office Environments (2016)

> *Twenty-four participants spent 6 full work days (0900–1700 hours) in an environmentally controlled office space, blinded to test conditions. On different days, they were exposed to IEQ conditions representative of Conventional [high concentrations of volatile organic compounds (VOCs)] and Green (low concentrations of VOCs) office buildings in the United*

> *States. Additional conditions simulated a Green building with a high outdoor air ventilation rate (labeled Green+) and artificially elevated carbon dioxide (CO_2) levels independent of ventilation.*

> *On average, cognitive scores were 61% higher on the Green building day and 101% higher on the two Green+ building days than on the Conventional building day ($p < 0.0001$). VOCs and CO_2 were independently associated with cognitive scores.*

Is CO_2 an Indoor Pollutant? Direct Effects of Low-to-Moderate CO_2 Concentrations on Human Decision-Making Performance (2012)

> *Twenty-two participants were exposed to CO_2 at 600, 1,000, and 2,500 ppm in an office-like chamber, in six groups. Each group was exposed to these conditions in three 2.5-hr sessions, all on 1 day, with exposure order balanced across groups. At 600 ppm, CO_2 came from outdoor air and participants' respiration. Higher concentrations were achieved by injecting ultrapure CO_2. Ventilation rate and temperature were constant. Under each condition, participants completed a computer-based test of decision-making performance as well as questionnaires on health symptoms and perceived air quality. Participants and the person administering the decision-making test were blinded to CO_2 level. Data were analyzed with analysis of variance models.*

> *Relative to 600 ppm, at 1,000 ppm CO_2, moderate and statistically significant decrements occurred in six of nine scales of decision-making performance. At 2,500 ppm, large and statistically significant reductions occurred in seven scales of decision-making performance (raw score ratios, 0.06–0.56), but performance on the focused activity scale increased.*

Association of Ventilation Rates and CO 2 Concentrations with Health and Other Responses in Commercial and Institutional Buildings (1999; review study based on 40 other studies, around 60,000 participants in total)

> *Many investigations of the association of indoor car- bon dioxide concentrations with health and perceived air quality (PAQ) have been reported. At the concen- tration range encountered in normal indoor environ- ments (350–2,500 ppm), CO 2 is not thought to be a di- rect cause of health effects (ACGIH, 1991). However, because occupants are the dominant indoor source of CO 2 , the increase in indoor CO 2 concentration above the outdoor concentration (approximately 350 ppm) is considered a good surrogate for the indoor concen- trations of bioeffluents (e.g., body odors). Additionally, other indoor pollutants may be generated and vary in rough proportion to occupant-generated CO 2 ; for ex- ample, emissions from office equipment.*

> *Results of the studies on the association of CO 2 concen- trations with health and PAQ outcomes generally sup- port the findings of an association of ventilation rates with outcomes; however, a larger proportion of the CO 2 studies, compared to ventilation rate studies, failed to find a significant association of CO 2 with health or perceived air quality outcomes; this was par- ticularly true among the findings reported in peer-re- viewed articles. We suspect that the less consistent findings of the CO 2 studies are due to the temporal variation in indoor CO 2 concentrations. CO 2 concen- trations vary each day with time elapsed after the start of occupancy, even when the rate of outside air supply is stable. The timing of CO 2 measurements, and the CO 2 metrics used in the analyses (e.g., peak value, measured range), varied among the studies; thus, the measured CO 2 concentrations reflect the measurement time as well as the rate of air supply per occupant. More consistent results would be expected if all studies used either the peak or time-average indoor carbon dioxide concentration.*

> *The sampling strategy for CO 2 is extremely important. The indoor CO 2 concentration will generally be spa- tially non-uniform and measurement protocols should be designed to determine the average CO 2 concen- tration in the breathing zone or in the exhaust air streams. Precautions are necessary to avoid measure- ments in air directly exhaled by building occupants. The CO 2 concentration is seldom at steady state in real buildings because of variations in occupancy and ven- tilation rates.*

> *In addition to minimum ventilation rate standards, some guidelines and standards list a maximum accept- able indoor carbon dioxide concentration, typically 800 ppm or 1,000 ppm. These two concentrations corre- spond to outdoor ventilation rates of 11.6 and 8.0 Ls a1 per person with sedentary activity (ASTM D 6245-98) at steady state when the concentration of carbon diox- ide in outdoor air is 350 ppm.*

> *Almost all the studies included in this review found that ventilation rates below 10 L/s per person were associated with a significantly worse prevalence or value of one or more health or perceived air quality outcomes. Most of these studies have been conducted in office buildings. Available studies further show that increases in ventilation rates above 10 L/s per person, up to approximately 20 L/s per person, are sometimes associated with a significant decrease in the prevalence of SBS symptoms or with improvements in perceived air quality. Data from multiple studies also indicate a dose-response relationship between ventilation rates and health and perceived air quality outcomes, up to approximately 25 Ls a1 per person; however, available data are not sufficient to quantify an average dose-re- sponse relationship. The less consistent findings for re- lationships in the range above 10 Ls a1 per person are compatible with the prediction that benefits per unit increase in ventilation would be likely to diminish at higher ventilation rates and, thus, be more difficult to detect epidemiologically.*

> *Based on these results, we conclude that in office buildings or similar spaces constructed using current building practices, increases in ventilation rate in the range between 0 and 10 Ls a1 per person will, on aver- age, significantly reduce occupant symptoms and im- prove perceived air quality.*

European Collaborative Action on Urban Air, Indoor Environment and Human Exposure: ECA 11: Guidelines for ventilation requirements in buildings (1992)

> *At the low concentrations typically occuring indoors CO_2 is harmless and it is not perceived by humans.*

> *Although CO_2, is a good indicator of pollution caused by sedentary human beings, it is often a poor general indicator of perceived air quality. It does not acknowledge the many perceivable pollution sources not producing CO_2 and certainly not the non-perceivable hazardous air pollutants such as carbon monoxide and radon.*

> *Humans perceive the air by two senses. The olfactory sense is situated in the nasal cavity and is sensitive to several hundred thousand odorants in the air. The general chemical sense is situated all over the mucous membranes in the nose and the eyes and is sensitive to a similarly large number of irritants in the air. It is the combined response of these two senses that determines whether the air is perceived fresh and pleasant or stale, stuffy and irritating.*

> *Radon is a radioactive gas which occurs in the indoor air. It increases the risk of lung cancer. Risk estimates for radon are given in "Air Quality Guidelines for Europe" (2) published by the World Health Organization (see Annex C). The major source of indoor radon is usually soil gas under the building. Radon occurs in high concentrations in soil gas with large variations due to local geology. Soil gas with radon may enter a building by*

> *infiltration through cracks and other openings in floors and walls separating the building from the soil.*

Minnesota Department of Health (website)

> *Carbon dioxide is often measured in indoor environments to quickly but indirectly assess approximately how much outdoor air is entering a room in relation to the number of occupants.*

> *Outdoor "fresh" air ventilation is important because it can dilute contaminants that are produced in the indoor environment, such as odors released from people and contaminants released from the building, equipment, furnishings, and people's activities. Adequate ventilation can limit the build up of these contaminants. It is these other contaminants and not usually* CO_2 *that may lead to indoor air quality problems, such as discomfort, odors "stuffiness" and possibly health symptoms.*

> *These rates of ventilation should keep carbon dioxide concentrations below 1000 ppm and create indoor air quality conditions that are acceptable to most individuals.*

> *What levels of* CO_2 *are considered safe? Carbon dioxide is not generally found at hazardous levels in indoor environments. The MNDOLI has set workplace safety standards of 10,000 ppm for an 8-hour period and 30,000 ppm for a 15 minute period. This means the average concentration over an 8-hour period should not exceed 10,000 ppm and the average concentration over a 15 minute period should not exceed 30,000 ppm. It is unusual to find such continuously high levels indoors and extremely rare in non-industrial workplaces. These standards were developed for healthy working adults and may not be appropriate for sensitive populations, such as children and the elderly. MDH is not aware of lower standards developed for the general public that would be protective of sensitive individuals.*

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