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Impact of Indoor Air Quality in human health

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Indoor environmental quality (IEQ) concerns the environment existing inside a building and it depends by various factors like thermal and hygrometric comfort, lighting, acoustic and indoor air quality (IAQ). IAQ is the final effect of the presence of air pollutants and of the existing ventilation which is able to dilute them. An incontestable evidence links poor IAQ and harmful health effects inducing respiratory and cardiopulmonary pathologies (Yang et al. 2009). The measure of carbon dioxide (CO_2) concentration level can be used as an indicator of the quality of IAQ (Schibuola and Tambani 2020).

As people spend more time indoors, it is important to identify the relationship between indoor air quality and building occupants' health. An example of this are students who spend a significant part of their school time inside classrooms characterized by higher occupancy density and most of the cases, poorly ventilated. Daisey et al. (2003) reviewed over 300 articles that have examined a wide range of CO_2 concentrations in schools and verified that with a CO_2 concentration over 1,500 ppm, occupants were negatively affected. In addition, in the case of young students, the exposure to contaminants is by far more critical for children as they inhale more air per unit of body weight and present higher resting metabolic rates if compared to adults (Annesi-Maesano et al. 2003). These larger specific doses involve their less able to deal with toxic chemicals (Bates 1995).

The effects on human health of exposure to CO_2 concentration have been widely studied under different parameters and different duration exposure (Table 1). These effects can be classified as physical, psychological, and physiological, and are often interrelated (Shriram et al. 2019).

On the one hand, several studies have reported that the physical effects of exposure to higher CO_2 concentration are respiratory problems and Sick Building Syndrome (SBS) (Seppanen et al. 1999, Apte et al. 2000). None of the SBS symptoms such as headache, fatigue, depression, difficulty in concentration, and eye irritation increased with reduced CO_2 concentration. Exposure to CO_2 concentration greater than 1000 ppm showed reduced attendance in schools (Muscatiello et al. 2015) and increased symptoms of headache, fatigue, and difficulty in concentration (Shendell et al. 2004).

And Daisey et al. (2003) verified symptoms of dizziness or fatigue at high CO_2 concentrations by analysing the status of occupants at CO_2 concentration levels between 1,500 ppm and 4,000 ppm. Nevertheless, respiratory symptoms including breathing difficulties, sneezing, cough, and shortness of breath were reported to be higher at a CO_2 concentration of 800 ppm, and the American Society of Heating, Refrigerating, and Air- Conditioning Engineers' (ASHRAE) threshold standard limit of CO_2 is 1000 ppm (Tsai et al. 2012).

There are many ways to measure the physiological response, but several studies focused on blood pressure (BP) in the study of the physiological response to indoor environmental quality changes (Zhang et al. 2016, Kajtár and Herczeg 2012). There was a change in BP in the physiological response due to the CO_2 concentration. Zhang et al. (2016) found that systolic blood pressure (SBP) and diastolic blood pressure (DBP) increases when CO_2 concentration is high. Kajtar and Herczeg (2012) showed that high CO_2 concentration levels increased the subjects' DBP.

On the other hand, the psychological effect of exposure to CO_2 was established by the reduced decision-making performance of the occupants (as can be seen in table 1). The physiological measurements conducted at elevated CO_2 concentration with bioeffluents reported a higher CO_2 concentration in tissues, variation in heart rate, and increased blood circulation (Vehvilainen et al. 2016, Zhang et al. 2016, Zhang et al. 2017). Another way to measure the psychological response due to indoor air pollutants is by indoor air quality (IAQ) satisfaction, a verbal scale determined by a questionnaire survey. Thus, Mui and Wong (2007) surveyed the IAQ satisfactions of 396 workstation offices and showed that 70–80% of the occupants were satisfied with CO_2 concentrations of 1,020 ppm to 1,080 ppm

Table 1. Summary of literature studies on exposure to CO_2 concentration (Shriram et al. 2019)

Author	CO2 concentration (ppm)	Duration of exposure (hours)	Parameters studied	Remarks
Exposure to pure CO_2				
Kajtar, and Herczeg (2012)	3000	3.5	Reading text and error detection. Heart rate, blood pressure	Percentage of error detection reduced by 5%, Heart beat rate reduced by 4 times and blood pressure increases by 5 times
Satish et al. (2012)	600, 1000, 2500	2.5	Cognitive and behaviour responses	A reduced performance of 15% (1000 ppm) and 74% (2500 ppm) when compared with 600 ppm
Allen et al. (2016)	550, 945, 1400	1.5	Cognitive performance test	15% (945 ppm) reduced cognitive performance and 50% (1400 ppm) when compared with 550 ppm
Zhang et al. (2016)	500, 5000	2.5	Office work tasks, subjective rating, and physiological responses	Reduced performance but not statistically significant. No significant variation with perceived air quality and health symptoms
Zhang et al. (2017)	500, 1000, 3000	4	Physiological responses and cognitive performance	Increase in end tidal CO_2 and decreased heart rate and no other significant variation in physiological response
Exposure to CO_2 concentrations with bioeffluents				
Maddalena et al. (2015)	900, 1800	4	Perceived air quality, SBS and decision making performance	No effect on perceived air quality and SBS was observed. However, a negative effect on decision making performance was observed
Vehvilainen et al. (2016)	900, 2700	4	Blood CO_2 content, oxygen saturation, skin temperature and salivary stress hormones	18% increase of blood pCO_2, variation in heart rate and increases in peripheral blood circulation by 3 times
Zhang et al. (2017)	500, 1000, 3000	4	Physiological responses and cognitive performancesalivary stress hormones	End tidal CO_2 increased by 3–4mm Hg and significant variation in physiological reposes. Reduction in cognitive performance was reported.
Maula et al. (2016)	540, 2260	4	Cognitive performance	Increase in perceived fatigue and reduced performance was observed. No health symptoms were reported.

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