INDOOR AIR QUALITY
PERFORMANCE
Research Brief

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Figure 1: Occupant concentration and cognitive performance have been shown to be negatively affected by poor indoor air quality.

Source: https://nearsay.com/c/508013/470466/how-does-proper-ventilation-impact-the-workplace

Keywords:

volatile organic compounds (VOCs), CO_2, ventilation rates, cognitive function, productivity, learning, decision-making

CONTENT OVERVIEW

IAQ + PERFORMANCE SUMMARY

Studies have shown that VOCs, CO2, and human bioeffluents are common harmful pollutants that effect human productivity and are often found at high levels indoors (Satish 2012, Allen 2016, Zhang 2017). Reducing these indoor air contaminants with by providing adequate levels of outdoor air through improved ventilation has been shown to increase mental cognition and productivity in offices (Allen 2016) and schools (Fisk 2017) in several academic studies.

I. Performance in Offices

Cognitive function is a driver of real-world productivity in office workers (Allen et al. 2016), furthermore, it encompasses the quality of real-time decision-making and problem-solving (Azuma et al. 2018). Standards for ventilation have been largely based on human comfort with indicators such as bioeffluents, body odor, and satisfaction (ASTM-D6245). More recent research shows that other indicators like CO2 have an influence on human performance at thresholds lower than those that were developed as acceptable standards based on human comfort (Allen 2016).

Low ventilation rates are associated with low cognitive performance and are indicated by the presence of pollutants such as CO2 (Maddalena et al. 2015). A study by Seppanen et al. found that work performance, indicated by speed and accuracy of typical office tasks, increased at a rate of 0.8% with every 10 cfm/person increase in ventilation between 14 to 30 cfm/person, but the benefit of increased ventilation was not as great over 30 cfm/person (Seppanen 2005).

Another study by Allen et al. comparing cognitive performance of office workers in variously ventilated spaces similarly found that increased outdoor ventilation, lower CO2 concentrations, and lower total volatile organic compounds (TVOCs) concentrations improves indoor air quality and significantly improves productivity. Overall, a 21% decrease in typical participant cognitive score across nine cognitive function domains was seen with 400 ppm increases in CO2 concentrations, and an 18% increase in scores was associated with a 20-cfm increase in outdoor air per person (Allen 2016). The study used a validated, computer-based cognitive test to assess office worker performance. CO2 concentration had a major impact on cognitive function scores (Allen 2016). To contextualize this study, background outdoor CO2 concentrations are typically 350-400 ppm (ESRL 2020). ASHRAE Standard 62.1 suggests an airflow rate of 20 cfm/person, which corresponds to a CO2 concentration of 945 ppm, commonly stated as 1,000 ppm (ASTM-D6245). This standard is commonly required by local building codes that use ASHRAE standards (Allen 2016). In Allen's study, changes in CO2 concentrations from 550 ppm to 945 resulted in a 15% reduction in cognitive test scores. Changes in concentrations from 550 to 1400 ppm, resulted in 50% decreases in cognitive scores. (Allen 2016). An earlier study by Satish et al. found similar effects of CO2 concentrations on decision-making performance using the same computer-based test. In this study, scores in seven of nine cognitive function domains decreased by 11-23% when the CO2 concentration increased from 600ppm to 1,000ppm (Satish 2012).

Researchers have found that CO2 by itself does not cause any health or behavior impacts. Rather, it is an indicator of low outdoor air ventilation rates and thus increased presence of additional pollutants such as TVOCs and the production of human bioeffluents, which have a negative impact on cognitive performance (Zhang et al. 2016; Zhang et al. 2017; Maula et al. 2017).

Performance in Offices (cont.)

Table 1: Health and performance impacts of increased CO2 concentrations. While physiological health impacts are seen above 1000ppm, this table contextualizes both productivity impacts at lower CO2 concentrations and physiological impacts of CO2 at higher concentrations. This table is based on various sources as noted.

CO2 Concentration (ppm)	Associated Health and Productivity Impacts
350 - 400	Background (normal) outdoor air level (ESRL)
500	Lower level tested by Allen et al 2016 (Allen 2016)
< 600	Rare IAQ complaints (Wallingford 1986)
600-800	Occasional IAQ complaints (Wallingford 1986)
945	Cognitive function scores were 15% lower compared to 550 ppm per Allen et al. 2016 (Allen 2016)
1,000	ASHRAE 62.1 suggested maximum concentration (ASHRAE 62.1)
800 - 1,000	IAQ complaints more prevalent (Wallingford 1986)
> 1,000	Widespread IAQ complaints (Wallingford 1986)
1,400	Cognitive function scores were 50% lower compared to 550 ppm per Allen et al. 2016 (Allen 2016)
1,000 - 2,000	Level associated with complaints of drowsiness and poor air (WDHS)
3,000	Level associated with occupant dissatisfaction, exhaustion (Kajtar 2011)
2,000 - 5,000	Level associated with headaches, sleepiness, and stagnant, stale, stuffy air. Poor concentration, loss of attention, increased heart rate and slight nausea may also be present (WDHS, Vehviläinen et al. 2016)
5,000	This indicates unusual air conditions where high levels of other gases could also be present. Toxicity or oxygen deprivation could occur. This is the permissible exposure limit for daily workplace exposures (WDHS)
40,000	This level is immediately harmful due to oxygen deprivation (WDHS)

Performance in Offices (cont.)

The cognitive function tests by Allen et al. also provided evidence of impacts on decision-making performance due to TVOC concentrations. Keeping other variables constant, on average, scores in the various cognitive function domains were 60% higher in "green" building conditions with low TVOCs around 50µg/m3 as compared to "conventional" office environments with high TVOCs around 550µg/m3 (Allen 2016).

II. Performance in Schools

In the United States, indoor carbon dioxide concentrations tend to be much higher in school classrooms than in office buildings. Low ventilation rates with high CO2 concentration are widely found in many mechanically ventilated schools, and increasing ventilation rates impose energy cost and increased size of HVAC systems. (Fisk 2017). Findings on the impact of CO2 concentrations above 600 ppm on cognitive functions (Allen 2016, Satish 2012) are particularly concerning since many spaces far exceed the 1,000ppm standard. For example, 66% of 120 classrooms in Texas (Corsi et al. 2002) and 45% of 435 classrooms in Washington and Idaho (Shendell et al. 2004) were found to be above this 1,000ppm threshold, it was reported that elevated CO2 concentrations were associated with an increase in student absences (Shendell et al. 2004). Another study found that a 17% increase of CO2 concentration lead to a 16% reduction in performance, as measured by math and code tests (Dorizas 2015). Fisk's research shows that students perform better academically in classrooms with higher ventilation rates, which are associated with lower levels of CO2 (Fisk 2017). Teachers, students, and school staff can by negatively affected by poor indoor air quality leading to common associated health problems like coughs, eye irritation, headaches, allergic reactions, aggravate asthma or other respiratory illnesses (EPA). According to the Asthma and Allergy Foundation of America, nearly 1 in 12 school-aged children has asthma, which is the leading cause of school absenteeism due to chronic illness (AAFA, EPA).

III. Reduced Absenteeism

Enhanced ventilation in buildings can improve performance of workers by 8% by reducing absenteeism and improving health overall (MacNaughton 2015). Healthier buildings reduce sick time and increase productivity (Miller 2009). Effective ventilation and the absence of volatile organic compounds leads to happier, healthier workers. Additional information regarding absenteeism due to the adverse health implications of indoor air quality can be found in the IAQ Physiological Health Research Brief.

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