INDOOR AIR QUALITY
PHYSICAL HEALTH
Research Brief

PARTNERSHIP INITIATIVE
INTEGRATED DESIGN LAB
at the Center for Integrated Design

Figure 1: Indoor building environments have a direct effect on occupant health. Poor air quality can cause a range of temporary building related health symptoms, commonly referred to as to as Sick Building Syndrome symptoms, as well as long term health effects.

Source: https://majesticfacility.com/the-sick-building-syndrome/

Keywords:

volatile organic compounds (VOCs), indoor allergens, sick building syndrome (SBS), asthma, respiratory health, bioeffluents

CONTENT OVERVIEW

IAQ + PHYSICAL HEALTH SUMMARY

Considering humans spend nearly 90% of their lives indoors, the potential impact of indoor air quality within homes, schools, offices or other building environments on human health is important to consider (EPA ROE). Poor indoor air quality can lead to illness, causing medical expenses and absenteeism from work and school. Diluting indoor pollutants through effective ventilation can reduce the effects of pollutants on occupant's health.

I. Indoor Pollutants

Indoor air pollutants can be classified as volatile organic compounds (VOCs), particulate matter, infectious agents, allergens and gases. (Gerardi 2010). High levels of these indoor pollutants are associated with health effects, especially for people with existent asthma or other respiratory problems (MacNaughton 2015).

Volatile Organic Compounds (VOCs)
VOCs are known indoor irritants which often have unpleasant odors and have been linked to fatigue, difficulty concentrating, respiratory problems, and cancer (Gerardi 2010, Bernstein 2008, Fisk 1997). Chemical VOCs such as Formaldehyde are predominantly emitted by office furniture, cabinetry, carpet tile, vinyl wall coverings, paints, and adhesives (Bernstein 2008). A review by Bernstein et al. discusses that the primary adverse health associations with VOCs have been symptoms of mucous membrane irritation and systemic effects such as fatigue and difficulty concentrating, and that occupants almost always complain at high levels above 3000µg/m3. Microbial VOCs can be released from mold or mildew caused by moisture accumulation and have been associated with adverse health effects such as eye, nose and throat irritation, coughing, wheezing, fatigue, headache, dizziness, and nausea (Bernstein 2008).

Allergens
Non-mold allergens (dust, pet and rodent dander, cockroach antigens, foods) and mold allergens both cause adverse health effects when present indoors. The smaller size of non-mold allergens can penetrate deeper into the lungs causing respiratory aggravation (Gerardi 2010). Unwanted water and moisture indoors can cause favorable conditions for mold growth (Cedeno-Laurent et al. 2018), which has been attributed as a main source of building-related Illnesses (OSHA). In a meta-analysis of studies related to occupant health in schools or day care centers with dampness or mold, Fisk et al. drew associations to moderate increases in health risks for cough (32%) and wheezing (68%), and small increases for nasal symptoms (20%) when dampness or mold was observed (Fisk 2019).

Particulate Matter (PM)
Particulate matter is notable for the small sizes of airborne particulates that can carry absorbed toxins deep into the lung, causing respiratory implications including aggravation of existing bronchitis, asthma, and allergies. Sources include diesel engines, heating appliances, road dust, construction debris, and consumer products (Gerardi 2010).

Gasesv
Nitrogen dioxide (NO2) is an indoor pollutant that is produced by human activity and is typically generated by heating and cooking appliances. Nitrogen dioxide can cause serious damage to the respiratory tract and exacerbate asthma (Gerardi, 2010). Carbon Monoxide is a colorless, odorless, nonirritating gas that can be produced by heating appliances, causing fatigue, headaches, dyspnea, loss of consciousness and death (Gerardi, 2010).

Carbon dioxide (CO2) is produced at a rate of 35,000 – 50,000 ppm per breath, which is 100 times higher than the concentration of typical outdoor air (WSU Energy Program Report 2013). For this reason, CO2 can be used as an indicator of building ventilation rates, as indoor CO2 will rise substantially beyond outdoor levels in an occupied building if ventilation rates are low. CO2 is also an indicator of accumulation of indoor pollutants such as VOCs and particulates (Vehviläinen et al. 2016, Allen 2016, Maddalena et al. 2015). CO2 has been linked to decreased cognitive performance

Indoor Pollutants (cont)

at levels below 1000 ppm (Allen 2016) and increased rates of Sick Building Syndrome symptoms beginning at 1000ppm and above, shown in Table 1 (Vehvilainen 2016, Apte 2000, Wallingford 1986). Higher CO2 concentrations ranging from 2,000 – 4,000 ppm cause elevated concentrations of pCO2 in human tissues, changes in heart rate variation and increase peripheral blood circulation leading to symptoms of headaches, sleepiness, and changes in body temperature (Vehviläinen et al. 2016). Air quality has been shown to be noticeably unpleasant and make people more exhausted when CO2 concentrations are beyond 3,000 ppm (Kajtar 2011). Impacts of CO2 below 1000ppm have been shown to impact cognitive performance, as discussed in the IAQ Productivity brief.

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)

Indoor Pollutants (cont).

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)

II. Sick Building Syndrome (SBS)

Sick Building Syndrome (SBS) is a common acute condition triggered by indoor pollutants with symptoms ranging from irritation of sinuses, dull headache, rash, and fatigue (Gerardi 2010, Kajtar 2011, Cedeno-Laurent et al. 2018). The primary factors affecting SBS related symptoms are outdoor ventilation rates, temperature, humidity, dust, and the microbial content of the air (Burge 2004). Burge surmises in a literature review that adjusting a single factor may not result in an immediate treatment for symptoms, but that the factors may work in association with one another. SBS symptoms subside when exposure to indoor irritant ends (Burge 2004). Evidence suggests low ventilation rates are associated with respiratory health effects, such as mucosal and allergy symptoms and can trigger additional respiratory problems in adults and children (Fisk 2017). Increase in ventilation rates in office settings has shown to decrease SBS symptoms (Heerwagen 2000, Apte 2000, Shan 2016).

III. Asthma

Asthma is an ailment associated with poor indoor air quality and disproportionately impacts low-income and racial minority children (Gauderman 2005). In a Center for Disease Control study, the economic burden of asthma was estimated to be more than $80 billion per year (Nurmagambetov 2018). A major factor in the development and exacerbation of asthma is exposure to indoor allergens and irritants such as dust, particulates, mold and moisture, with as much at 40% of the excess asthma in minority children attributed to exposure to indoor allergens (Lanphear 2001). The Seattle Housing Authority, an entity that provides low income housing in Seattle, implemented the Breath Easy Program in 2003 in an effort to reduce asthma and other ailments associated with poor indoor air quality. Breathe Easy homes are new and renovated housing projects that improve indoor air quality through enhancing exterior envelope, replacing off-gassing indoor materials, and installing energy recovery ventilators with continuous fresh air supply (Takaro 2011). A study found that Breath Easy homes reduced asthma related clinical visits from 62% to 21% and nearly eliminated exposure to mold, rodents, and moisture (Takaro 2011).

IV. Ventilation + IAQ

Bringing outdoor air into a building has the potential to significantly reduce the adverse effects of indoor air pollutants by reducing their concentration in indoor air (Gerardi 2010). While high ventilation rates above code minimums have been shown to improve air quality and health outcomes (Fisk 2017, Tarantini 2017), many buildings do not ventilate according to minimum ASHRAE standards (Mendell 2013, Allen 2016). Despite the health implications of indoor air contaminants, ASHRAE designates required ventilation rates based on perception of indoor air quality rather than relative risk of exposure (Lin 2014). The ASHRAE Standard 62.1 per person ventilation rates are based on bioeffluent concentration with which 80% or more of the occupants express satisfaction with air quality (ANSI/

Ventilation + IAQ (cont)

ASHRAE 62.1-2019). Many studies have shown benefits in health and performance when increasing ventilation rates beyond ASHRAE standards (Mendell 2013, Allen 2016). An earlier study by Mendell indicated that ventilation rates 6-17cfm/person above the 20cfm/person guidance for offices at the time was effective in reducing building-related health symptoms, but further benefits were not evident from higher ventilation rates, suggesting that an upper threshold might exist (Mendell 2005).

V. Ventilation + Spread of Airborne Infectious Disease

Multiple studies have indicated that increasing ventilation rates with outdoor air reduces the spread of airborne infectious disease by diluting bacterial and viral load in indoor air (Seppannen 1999, Li 2007). Recirculating inside air and low outside air ventilation rates can aide in the transmission of infectious diseases (Wargocki 2002). This benefit is realized only if the outdoor air brought into the building does not contain high concentrations of common outdoor pollutants such as particulate matter, ozone, and nitrogen oxides. These outdoor pollutants are associated with pediatric asthma, pulmonary inflammation, and decreased lung function and can enter buildings in high levels (Laumbach 2010, Roy 2011). MERV 13 filters are highly effective in filtering particulate matter and airborne bacteria and viruses, and can reduce these indoor pollutants by up to 95%. A recent paper echoes these findings (Bahnfleth et al. 2020). To prevent the spread of viruses such as SARS-CoV-2, Bahnfleth suggests building engineering control methods should be employed, including increased existing ventilation rates/outdoor air exchange rates, enhanced filtration and disinfection, and avoiding air-recirculation within the ventilation system when able (Bahnfleth et al. 2020). These mitigation strategies are detailed in ASHRAE guidelines for responding to SARS-CoV-2/COVID-19 (ASHRAE).

A literature review performed by Seppanen et al. identified three studies investigating the prevalence of respiratory illness in relation to ventilation rates (Seppanen 1999). The studies took place in military barracks, a jail, and a nursing home, and evaluated ventilation rate changes between 2.5 versus 20 cfm per person, 8 versus 26 cfm per person, and 4 versus 8 cfm per person respectively. In all three studies, lower ventilation rates yielded an increase in the rate of illness, ranging from 50% to 370%. Another literature review of indoor airflow and transmission rates of infectious diseases performed by a panel of medical experts and building scientists concluded that the spread of infectious diseases, such as measles, tuberculosis, chickenpox, influenza, smallpox, and SARS, increases with decreased ventilation (Li 2007). This panel was not able to provide conclusive recommendations on ventilation rates based on the findings of available studies, but an inverse relationship between infection rate and ventilation rate was observed.

VI. Ventilation + Absenteeism

Increasing ventilation rates has also been shown to decrease absenteeism in school and office settings. A study of 162 classrooms in 28 Californian schools in three school districts found that all school districts had median ventilation rates lower than the 7.1 l/s per person standard in California (Mendell 2013). Increasing classroom ventilation rates to the California standard in these classrooms was shown to decrease illness related absence by 3.4%. Another study found that doubling of ventilation rate in an office space from 25 to 50 cfm per person led to a 35% decrease in short term absence (Milton 2000). These results echo other studies that increased ventilation rates greatly benefit occupant health and reduce sickness related absence in work and school settings (Mendell 2005, Wyon 2004, Wargocki 2000, Fisk 2017, Allen 2016).

Ventilation + Absenteeism (cont.)

A LEED Gold certified office refurbishment for 150 employees that improved indoor air quality through enhanced outdoor air ventilation, continuous monitoring of CO2, and avoiding VOC emitting materials saw an annual savings of $85,000 per year due to a 44% reduction in absenteeism (World GBC 2018). An internal survey of employees at the company revealed the reduction in absenteeism largely due to a 64% reduction in reported allergy problems and 68% reduction in respiratory problems (Laski 2018).

VII. Ventilation + Energy + Diminishing Returns for IAQ

While higher ventilation rates may improve health and productivity, increasing ventilation rates may impose energy costs and increase HVAC systems (Fisk 2017). It is important to note that there is likely a rate of diminishing returns for increasing ventilation rates and IAQ, and more outdoor air is not necessarily better. For example, one study did not find a difference in the rate of absence when comparing ventilation rates between 34 and 90 cfm/person (Myatt 2002). A recent study by the California Energy Commission (CEC) was conducted to determine the effectiveness of air change rates per hour in hospital settings as indicated by contaminant levels of CO2 and particulate concentrations. Testing various ventilation rates from 0 to 12 ACH, the study found that rates up to 2 ACH were effective in reducing CO2 and particulate concentrations in patient rooms, but there were diminishing rates of return for increasing rates above 2 ACH. In administrative areas, diminishing rates of return were observed above 0.5 ACH.

It is important to recognize that there are buildings that are currently under ventilated, and would benefit from increased ventilation. On the other hand, it is also important to acknowledge that some buildings are receiving adequate ventilation, and increasing the ventilation rate would not necessarily yield higher indoor air quality, yet would represent significant energy and cost implications. For example, current national standards for hospitals call for 4 ACH in patient rooms, and the CEC's study suggests that increasing ventilation beyond that minimum standard does not positively impact IAQ, however, it would mean significantly increased energy use and costs associated with a higher ventilation rate (Barolin 2020).

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