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Indoor air pollution, occupant health, and building system controls—a COVID-19 perspective

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12.1 Introduction: indoor air pollution and its ongoing significance

The World Health Organization’s (WHO’s) statistics reveal an estimated 7 million casualties worldwide annually due to air pollution taking into account the combined effect of ambient (outdoor) and household (indoor) pollution, with 90% of people breathing air exceeding the WHO guideline limits (WHO, 2021). Climate change has also led to deterioration in global air quality levels, posing a challenge in itself. The recent occurrences of heatwaves in the North-western United States to floods and landslides on the Western coast of India all point toward climate change happening at an alarming pace. National Climate Assessment states that “increased ground-level ozone and particulate matter levels are the direct impacts of climate change.” This can directly affect human health by creating problems like decreased lung performance, asthma, and other cardiovascular and respiratory diseases (US CDC, 2016). Mitigating ambient pollution levels is a long continuing process involving global policies to reduce air pollution, carbon dioxide reduction, etc., offering a “win-win” strategy for both climate and health (WHO, 2021). Indoor air pollution, on the other hand, can be controlled and effectively managed considering the scale and complexity involved. The quality of indoor air is also crucial, considering that 90% of the time is being spent by humans living indoors, mostly at their homes or workplaces (Leech et al., 2002). The WHO states that “an alarming 3.8 million casualties worldwide annually occurs due to the direct...
impacts of indoor air pollution,” leading to disease and premature deaths in poor income countries (WHO, 2021). Also, the current global COVID-19 pandemic has confined us to our homes and indoor environments, with “work from home” being adopted as the new normal. Therefore it becomes important to ensure good quality indoor air in our homes and workplaces. Also, once the COVID-19 restrictions ease and people start returning to indoor public places such as offices, schools, restaurants, and shopping malls, it becomes important that the air quality in these places is evaluated and well taken care of.

Major super spreading events or outbreaks of COVID-19 take place in indoor environments (Althouse et al., 2020) (nightclubs, homeless shelters, meat processing plants, gyms, restaurants, etc.), with the most popular being the Skagit County choir outbreak, wherein a 2.5-hour-long choir practice session attended by 61 people, including a symptomatic index patient, led to 32 confirmed cases, 20 probable secondary cases, 3 critically hospitalized cases, and 2 death cases, accounting an infection rate of an alarming 87%! Studies have found that the SARS-CoV-2 virus (the coronavirus disease-causing pathogen) is also spread airborne in the form of exhaled respiratory droplets (Kumar and Morawska, 2019). Compared to outdoor air, these droplets have higher stability in indoor environments (Kumar and Morawska, 2019); and significantly high concentrations of indoor air pollutants can aid in COVID-19 transmission (Li et al., 2020; Sloan Brittain, Wood, and Kumar, 2020) via the coalescence effect (Setti et al., 2020a).

Therefore reducing indoor pollution levels can ensure better infection control in the event of future virus outbreaks. With viruses constantly changing through mutation and newer virus variants expected to occur in the future (CDC, 2021), managing indoor air pollution levels therefore becomes more important. In this chapter we will briefly review indoor air pollution and its sources, its impact on occupant health, and the role of building system controls in mitigating indoor air pollution. Also, note that most of the discussions here have been made from the recent COVID-19 point of view, considering its ongoing significance.

### 12.2 Indoor air pollution sources and occupant health

Indoor air pollution refers to the significantly high concentrations of physical, chemical, and biological contaminants in the indoor air and their negative impact on the human body (OECD, 2021). These include harmful gases, VOCs (volatile organic compounds), aerosols or PM (particulate matter), inorganic compounds, and
radioactive materials. The main factors affecting the concentration of these pollutants and hence the IAQ (indoor air quality) are (1) ambient air quality and climatic conditions; (2) daily human activities; and (3) building materials, appliances, and furniture (Marč et al., 2018).

Outdoor air can enter and leave a building through infiltration (through small openings and cracks), natural ventilation (large openings like doors, windows), and mechanical ventilation (fans, air handling systems) (EPA, 2021a). Therefore the quality of ambient (outdoor) air directly affects the IAQ. If the outdoor air pollutant concentration is high, they can get transferred indoors via infiltration, ventilation, etc., making the IAQ poor. A recent study (Ogen, 2020) has found that regions with the highest ambient NO₂ concentrations reported the largest COVID-19 fatality cases, suggesting that high concentrations of tropospheric harmful gases (NO₂, SO₂, etc.) can directly affect the lungs/immune system, making people more susceptible to SARS-CoV-2 or related viruses in future. Another metaanalytic study (Pope et al., 2020) gave crucial evidence of increased air pollution association (and most significantly PM₂.₅ levels, i.e., particulate matter with a width of 2.5 microns or less) with cardiovascular- and respiratory-related morbidities. In yet another time-series study (Li et al., 2020) the researchers found a positive correlation between ambient pollutant concentrations of NO₂, PM₂.₅, and CO and COVID-19 occurrence rates. All these cases reflect the enormity of outdoor pollutant concentrations and their impact on human health.

Additionally, climatic conditions of the place also influence the level of air pollution. The main meteorological parameters affecting air pollution are (1) temperature, (2) atmospheric stability, (3) wind direction and speed, and (4) mixing height. The main factor affecting the dilution of pollutants is atmospheric stability (AIR-EIA, 2021). The capacity of the atmosphere in resisting/aiding vertical mixing and thus turbulence is called stability (AIR-EIA, 2021). An unstable atmosphere aids in better dilution and vice versa (AIR-EIA, 2021). Therefore high-pressure systems like anticyclones, long winter nights, cloudless clear skies, and still air increase the atmospheric stability, leading to poor dispersion of pollutants and hence higher ambient pollutant concentrations, whereas low-pressure unstable atmospheric conditions like cyclones and winds increase pollutant dispersion and lower pollutant concentrations. Pollution levels and virus transmission rates are also affected by meteorological parameters like atmospheric temperature and humidity. Low relative humidity (RH) can help in increasing the evaporation rate from exhaled respiratory droplets (Sloan Brittain, Wood, and Kumar, 2020). This leads to the suspension of smaller droplets in the air for a significantly longer duration, aiding in virus spread (Sloan Brittain, Wood, and Kumar, 2020; Wolkoff, 2018).
High humidity levels also aid in virus spread, when the virus clings on to the moisture particles. A recent study (Li et al., 2020) found that temperature was found inversely correlated with COVID-19 incidence rates, that is, a higher ambient temperature corresponding to lower incidence rates and vice versa. The atmosphere is highly dynamic and unstable, so small changes in meteorological conditions and seasonal changes can impact the level of outdoor pollutants and consequently the indoor pollution levels. Since outdoor air mixes with the indoor air via infiltration/ventilation, care must be given on how well this air is treated as it enters indoors. This is discussed in the subsequent sections.

Human activities in buildings also affect the level of indoor air pollutants. These include cooking, combustion burning, tobacco smoking, incense burning, use of detergents, deodorants, solvents, and cleaning products. Humans’ activities also lead to microorganisms formation, like mold, fungus, and bacteria, as well as attract insects, such as dust mites and roaches (Van Tran, Park, and Lee, 2020). CO₂, SO₂, CO, NO₂, and PM are the primary emissions associated with combustion burning and cooking activities (Van Tran, Park, and Lee, 2020). Additionally, the cooking method, type of fuel, food, and oils used for cooking also impact the emission levels of PM (Apte, 2016). Among all types of emissions, PM is considered to be the most dangerous, as previous researchers have found key epidemiological evidence suggesting long-term PM exposure leads to increased mortality risks (Pope et al., 2020). According to US Environmental Protection Agency (EPA), “particulate matter is a combination of solid particles (e.g., dirt, dust, smoke, or other visible particles) or liquid droplets in the air” (US EPA, 2021b). These particles are sometimes referred to as aerosols and appear in solid, fluid, or suspended states (Gaddi and Capello, 2020). PM includes PM₁₀, which are minute particles with diameters of 10 micrometers or less, and PM₂.₅, which are finer particles with diameters of 2.5 micrometers or less (US EPA, 2021b). The significantly small size of PM poses an added menace to human health as it can penetrate into small respiratory airways, reaching the alveoli directly (Van Tran, Park, and Lee, 2020; Miller, 2012). An important aspect to be discussed here is the coalescence phenomenon, wherein airborne viruses can create clusters with the PM suspended in the atmosphere (Setti et al., 2020a). This reduces the diffusion coefficient and enhances its residence time and abundance in the atmosphere (Setti et al., 2020a). Thus PM can act as a carrier for airborne viruses like SARS-CoV-2. Recently a study (Setti et al., 2020b) found the first evidence of SARS-CoV-2 RNA present in airborne PM, thereby justifying the virus-carrying nature of PM. Normal human activities like walking, use of furniture, and other indoor objects can resuspend house dust.
contributing to 25% of the indoor PM concentration (Van Tran, Park, and Lee, 2020).

Smoking is another important source of indoor PM$_{2.5}$, increasing the indoor PM concentrations from around 25 to 45 μg/m$^3$ (Van Tran, Park, and Lee, 2020). The particles emitted during smoking settle on the room ceiling, floor, indoor furniture, etc., and remain suspended in the household air (Apte, 2016), posing an additional risk. Cooking and cigarette smoking together form the largest source of indoor air PM (Van Tran, Park, and Lee, 2020). Other sociocultural practices like the burning of incense sticks, oil-lit lamps, candles, and mosquito repellents in indoor environments also contribute to indoor PM, facilitating the spread of virus droplets (Amoatey et al., 2020).

Building materials, appliances, and indoor furnishings also contribute to indoor air pollution, mainly toward VOC emission. VOCs are primarily gases containing a range of chemicals emitted from liquids or solids (Van Tran, Park, and Lee, 2020). Common building materials, such as polyvinyl chloride (PVC)-based materials, carpets, adhesives, paints, sealants, and particle boards, can release toxic organic compounds (Van Tran, Park, and Lee, 2020). Additionally, electronic equipment like computers, tablets, photocopy machines, printers, and other office equipment emit ozone (O$_3$) and other volatile compounds (Van Tran, Park, and Lee, 2020). Paints and varnishes, insulation materials, and adhesives used in particulate board furniture also emit a significant amount of VOCs (Apte, 2016). Air fresheners, laundry products, cleaning products, detergents, deodorants, perfumes, etc., are other sources of VOC emission (Apte, 2016). Long-term exposure to VOCs is associated with harmful health risks to humans, potentially cancerous in nature. Other indoor pollutants usually found in small concentrations and posing a significant threat to human health are toxic heavy metals (lead, cadmium, chromium, etc.), radioactive gases like radon, organic and inorganic pesticides, and biological pollutants, most of which are carcinogenic in nature.

Just like outdoor air, indoor air is also dynamic, with a wide array of factors affecting its quality, from day-to-day activities like cooking and cleaning to sociocultural activities like incense/candle burning. Digitalization in homes and the use of hi-tech gadgets also have their fair share of contribution to indoor air pollution. In reality, however, indoor air and outdoor air are not two separate entities and are constantly engaging with each other via ventilation and infiltration. Additionally, the design, operation, and maintenance of ventilation systems also have a significant impact on IAQ (Van Tran, Park, and Lee, 2020). Therefore it becomes important to understand the role of building ventilation systems in affecting IAQ.
**12.3 Building ventilation systems and challenges**

Ventilation is the means to introduce fresh quality air into a space and extract stale, polluted, or odorous air out of the space (Passe and Battaglia, 2015). It is a widely implemented engineering strategy for the dilution and removal of airborne contaminants and is closely related to IAQ (Megahed and Ghoneim, 2021). Requirements for ventilation are twofold: health and comfort (ISO 17772-1:2017). Its main benefits are: (1) removing odor, VOCs, humidity, carbon dioxide, and PM; (2) removing heat through temperature-/wind-driven pressure differences (or a combination of both); (3) cooling down building skin/fabric overnight by removing heat from the thermal mass; and (4) increasing airspeed, which increases human thermal comfort perception (Passe and Battaglia, 2015).

Ventilation in a building/space can be attained by natural and/or mechanical means (ISO 17772-1:2017). Natural ventilation is achieved by air movement via naturally occurring winds (Passe and Battaglia, 2021) (caused by hydrostatic pressure differences or density pressure differences), whereas mechanical ventilation uses mechanical devices like fans and air terminal devices to supply and extract air (ISO 17772-1:2017). In this system ventilation air is typically provided by a heating, ventilating, and air conditioning (HVAC) system. A hybrid ventilation system combines both natural and mechanical modes of ventilation. Different ventilation systems bring different air distribution patterns and efficiencies (Sun and Zhai, 2020; Anand, 2022). Although natural ventilation systems may well be adopted by the occupants due to their free availability, they are insufficient in some buildings/climates (Van Tran, Park, and Lee, 2020). Nowadays, mechanical ventilation systems like air conditioners and fans are commonly used in buildings, which significantly increase energy consumption (Van Tran, Park, and Lee, 2020; Anand, 2019). Because energy consumption in buildings has become a global concern, demand-controlled ventilation (DCV) systems are nowadays being widely used. This system minimizes the ingress of outdoor air and encourages indoor air recirculation during periods of partial occupancy, minimizing the energy needed to maintain a comfortable indoor temperature (Sloan Brittain, Wood, and Kumar, 2020). Although air recirculation is ideal as a measure for energy saving, it can transport airborne pollutants (including contagious viruses) from one location to another, potentially increasing the risk of airborne viral infection (Morawska, 2020). Thus a contradiction appears between energy efficiency and its ensuing impact on IAQ standards (Sloan Brittain, Wood, and Kumar, 2020).

Furthermore, healthy IAQ strategies are not planned out during the design stage of a project. Rather, complicated HVAC systems are
commonly added in the latter stages and sometimes postoccupancy to control the characteristics of indoor air, prioritizing thermal comfort over occupant’s health (Sloan Brittain, Wood, and Kumar, 2020). Even in hospital buildings with adequate mechanical ventilation provisions for patient management and infection control, there are reported events of nosocomial outbreaks/hospital-acquired infections (HAIs) (Satheesan and Mui, 2020). This is because of a defective ventilation system, wherein air is getting circulated from the patient areas to circulation areas, as a result of which airborne viruses also get transferred, leading to possible nosocomial outbreaks (Satheesan and Mui, 2020). In a recent study (Chia et al., 2020) performed air sampling in 3 AIIRs (airborne infection isolation rooms) of a general ward in a hospital and detected SARS-CoV-2 PCR-positive particles of sizes greater than 4 μm and between 1 and 4 μm in two rooms, despite these rooms having a good ventilation rate of 12 air changes per hour. The situation can become unfavorable in public buildings and other shared spaces, such as institutions, offices, libraries, restaurants, and public transport (AIR-EIA, 2021; Althouse et al., 2020; Amoatey et al., 2020; Apte & Salvi, 2016; CDC, 2021; Chia et al., 2020; Cummings & Waring, 2020; Ding et al., 2020; Gaddi & Capello, 2020; González-Martin et al., 2021; ISO 17772-1:2017; Kumar & Morawska, 2019; Leech et al., 2002; Li et al., 2020; Li et al., 2021; Marc et al., 2018; Masson-Delmotte et al., 2021; Megahed & Ghoneim, 2021; Miller et al., 2012; Morawska et al., 2020; OECD, 2021; Ogen, 2020; Passe & Battaglia, 2015; Pope et al., 2020; Saini et al., 2021; Satheesan et al., 2020; Setti et al., 2020; Setti et al., 2020; Sloan Brittain et al., 2020; STANDARDS et al., 2016; Sun & Zhai, 2020; US EPA, 2021; US EPA, 2021; Van Tran et al., 2020; WHO, 2021; Wolkoff, 2018), where the ventilation is achieved by split air conditioning units or fans or by simply relying on doors and windows (Morawska, 2020). The ventilation rates in these building typologies are significantly lower than in hospitals for various reasons, including limiting airflows for energy and cost savings (Morawska, 2020). Limiting outdoor airflow was responsible for another such COVID-19 outbreak in an air-conditioned restaurant, wherein one index patient infected 10 others. In that study conducted by Li et al. (2021), using warm tracer gas and CFD (computational fluid dynamics) simulation to predict how the respiratory droplets exhaled by an index case flows through the restaurant air, it was found that a “contaminated recirculation bubble” was created due to a high concentration of exhaled droplet nuclei, further aggravated by the lack of outdoor air supply. Both the hospital ward case and the restaurant case clearly show the connection between various ventilation systems and the spread of infectious pathogens in indoor environments. With newer variants of Covid-19 being prevalent and other novel viruses expected to emerge in the future, it therefore becomes important to revisit and
modify the current ventilation design strategies (Satheesan and Mui, 2020).

The existing ventilation standards and indicators also have their limitations. ANSI/ASHRAE Standards 62.1 and 62.2, RHEVA, Bureau of Indian Standards, etc., are some of the accepted standards for ventilation and IAQ. These standards specify minimum ventilation rates, air distribution effectiveness, ACH (air change per hour), and other measures to define and maintain acceptable IAQ. However, they give only thumb rule numbers for maintaining an ideal IAQ and can sometimes under-/overpredict the actual ventilation needed. For example, it is usually presumed that an ACH increase would reduce the infection risk and vice versa, but previous researchers have found that the risk of pathogen exposure could increase with an increased ventilation rate under certain circumstances (Satheesan and Mui, 2020). Also, these standards do not give an accurate prediction of airflow distribution, which is crucial in determining the transport route of bioaerosols and hence in the dilution of indoor air pollutants. The effective minimum ventilation rate for avoiding airborne transmission/infection control also remains unknown (Li et al., 2021). Obstructions to the airflow pattern like indoor furniture, curtains, and partitions create eddies (Satheesan and Mui, 2020), affecting the airflow distribution and are unaddressed by these standards. Therefore airflow pattern prediction becomes more crucial than the building ventilation rates/ACHs, etc., recommended by the standards.

In spite of modern buildings being equipped with advanced ventilation arrangements, there are still lesser options for the circulation of fresh air (Saini, Dutta, and Marques, 2021). The situation becomes even worse for people like migrant workers and refugees living in fragile conditions (Saini, Dutta, and Marques, 2021) with poorly ventilated spaces where cooking and living usually happen in the same room itself. Poorly ventilated toilets can also result in fecal-derived aerosols (Ding et al., 2020) getting circulated back indoors and affecting IAQ. Building occupants are usually not able to judge the quality of the air they are breathing. Sudden changes in the ambient pollution levels due to open burning, vehicular emissions, industrial activities, etc., also affect the IAQ and increase infection risk. For all these reasons, it becomes important to incorporate additional building engineering controls to control, monitor, and ensure good IAQ.

### 12.4 Building engineering controls: an opportunity for future

The following section is a brief compilation of various recommendations by international bodies like World Health Organization (WHO), The American Society of Heating, Refrigerating and
Air-Conditioning Engineers (ASHRAE), and The Federation of European Heating, Ventilation and Air Conditioning associations (RHEVA) and other researchers (González-Martín et al., 2021; Megahed and Ghoneim, 2021; Saini, Dutta, and Marques, 2021; Sloan Brittain, Wood, and Kumar, 2020) with respect to building engineering controls and their role in mitigating indoor air pollution and infection spread.

### 12.5 Improving ventilation systems

Outdoor ventilation rate, efficiency, and flow distribution are the main parameters affecting the concentration of indoor air pollutants and virus-laden microdroplets in the air. The basic idea is to increase the ventilation rates as far as possible, due to which the indoor pollutant concentrations decrease by dilution. In naturally ventilated buildings ventilation rates can be increased by increasing door/window openings and thereby increasing the outdoor airflow rate. In mechanically ventilated buildings ventilation rates can be increased by bringing systemic modifications to the HVAC design and operation (Morawska, 2020).

Air recirculation should ideally be avoided to prevent the recirculation of virus-laden particles within the indoor environment (Morawska, 2020). Central AHUs (air handling units) should mostly be operated at 100% outdoor air for both single-zone and multi-zone occupancy types, and ideally, recirculation is being avoided (Morawska, 2020). Opening outdoor dampers and closing the recirculation dampers can help in achieving this. In systems where it is not possible the Outdoor Air (OA) supply level should be maximized and supplemented with filtering devices or ultraviolet germicidal irradiation (UVGI) systems to remove or deactivate potential viral contamination from the recirculated air (Morawska, 2020). When directional airflow is not required due to infection risk, spatial air mixing without causing strong air currents is recommended (ASHRAE, 2020). Smaller rooms can make use of portable air-cleaning devices to achieve better control. The use of split air-conditioning units should be supplemented with additional outdoor ventilation by regular or periodic opening/closing of building fenestration systems.

Building ventilation/HVAC engineers can also make effective use of CFD and tracer gas/smoke test experiments to determine the overall airflow and bioaerosol distribution in the existing ventilation system and identify problematic areas like recirculation/stagnant zones and modify the system using additional fans/filters/inlets or mechanical equipment. Additional exhaust fans can also be installed in high-occupancy/more polluting spaces. Ideally, this is a better approach. The use of BIM (building information modeling) and CFD can also be
employed by architects to make predictive models on airflow simulation, bridging the knowledge gap on pollutant/airborne virus transmissions in the built environments and the performance of ventilation systems (Megahed and Ghoneim, 2021).

### 12.6 Filtration technology

Under situations when ambient pollution levels are high and provision of natural ventilation becomes challenging, incoming polluted outdoor air can be filtered using carefully designed HEPA (high-efficiency particulate air) filters to remove outdoor pollutants and viral particles. Most important among them are PM$_{2.5}$ and NO$_2$, which are understood to strongly promote COVID-19 transmission, as seen in earlier studies (Sloan Brittain, Wood, and Kumar, 2020; Li et al., 2020). Mechanical filtration captures pollutants by forcefully circulating the polluted outdoor air through a fibrous material (Johannes et al. 2021). Electronic filtration, adsorption filtration, UV photolysis, photocatalytic oxidation (PCO), plasma, and member separation are other important filtration methods. The type of technology used depends on the nature and type of pollutants that are to be filtered, capital, and maintenance costs (Johannes et al., 2021). Since mechanical filtration requires energy and maintenance demands, natural and organic air filtration systems that are plant-/algae-based are presently being explored (Johannes et al., 2021; Megahed and Ghoneim, 2021).

Biological purification methods are based on the action of natural living systems like microorganisms, plants, and biotechnology to eliminate or transform the gas pollutants. Bioscrubber, biotrickling filter, capillary bioreactor, membrane bioreactor, and microalgae reactor are other air purification biotechnologies (Johannes et al. 2021). The only concern while using plant-based biofilters is increased RH, spores, and bioparticles emission (Cummings and Waring, 2020). Hybrid systems that integrate biotechnology and physical-chemical or mechanical filtration means can offer a better solution.

### 12.7 IAQ monitoring

As described earlier, the ambient pollution level is an important factor affecting the quality of indoor air. Therefore regular monitoring of air pollution levels is critical, especially in areas having low air quality. In highly polluted areas measures to incorporate ambient pollution monitoring sensors can be incorporated at a city/regional level. Similarly, real-time indoor IAQ monitoring sensors can also aid in giving the occupants an idea about the quality of indoor air and give them alarms/notifications indicating potential hazards. Real-time
ACH, O₂, CO₂, PM₁₀, and PM₂.₅ monitoring and alarming systems can be installed in critical areas of indoor homes and public spaces. Building owners/facility managers can also use new technologies that employ artificial intelligence (AI) and data science like, for example, IoT (Internet of Things), WSNs (wireless sensor networks), ML (machine learning), and FL (fuzzy logic) to make smart prediction systems for real-time control and management (Saini, Dutta, and Marques, 2021). This forms the basis of smart home technology and building automation in the future (Van Tran, Park, and Lee, 2020). The main challenge in using these monitoring systems lies in the cost, reliability, and feasibility of sensing technology (Saini, Dutta, and Marques, 2021). In this current pandemic scenario IAQ monitoring systems can be used as a supplementary instrument to ensure the quality of building ventilation systems.

12.8 Conclusion

To begin with, viral transmission via small airborne microdroplets (also commonly referred to as “aerosols”) in the context of the ongoing COVID-19 pandemic has brought a renewed focus to air pollutants (especially PM) and their role in infection spread. Global pollution levels are constantly increasing as a result of human activities and their consequential impact on the environment, resulting in what is today popularly known as “climate change.” The United Nation’s IPCC (Intergovernmental Panel on Climate Change) declared a “code red for humanity” in its recent report (Masson-Delmotte et al., 2021), giving a glimpse of the world’s uncertain future. According to the report (Masson-Delmotte et al., 2021), human activities have unequivocally been the principal driver of climate change. These actions include the burning of fossil fuels for energy and transport, emissions from agriculture and waste, and energy profiles of buildings. Manmade emissions of greenhouse gases (GHGs), led by carbon dioxide, methane, and nitrous oxide, are altering the climate system, raising average surface temperatures globally. A warmer world is expected to bring extreme implications for human health and ecosystem survival. As earth’s climate warms, long-dormant bacteria and viruses, trapped in ice and permafrost for centuries, are springing back to life (BBC Earth, 2017). The recent COVID-19 pandemic clearly depicts how fragile our ecosystem is and how unprepared we are in protecting ourselves from biopollutants.

So the main question is, how can we be better prepared during events of future virus outbreaks? As the earth’s temperature rises, demand for air conditioning units is also increasing with added energy concerns. Modern HVAC systems encourage air recirculation and demand well-insulated spaces, minimizing outdoor fresh air intake,
leading to poor ventilation and increased infection spread. Under such situations, most international bodies like WHO and ASHRAE are encouraging increased outdoor air supply to dilute indoor air pollutants. However, this is not a one-step solution to combat indoor air pollution. For example, in extreme climates like cold or hot climates, it is not practically possible to bring outdoor air as it can compromise thermal comfort. Before COVID-19, the main focus was on achieving comfort and energy savings at the expense of IAQ. Now priority has to be given to IAQ equally, if not more. Alternatively, when IAQ is given priority, comfort conditions can get compromised. Therefore a balance between the two is ideal and this becomes a challenging aspect for architects/engineers. In this context the use of building engineering controls in the form of sensors and alarms supplemented with air filtration systems can help improve indoor air to some extent. Air quality monitoring and predictive modeling via WSNs, ML, AI, and FL are all emerging concepts that could be worked out simultaneously with CFD and BIM modeling to better manage the buildings in the future. Infection control becomes a newer challenge for existing buildings and future buildings and it should involve collaborative efforts of microbiologists, IAQ scientists, HVAC engineers, and architects.

To conclude, man’s fight against airborne infections involves a greater fight against air pollution. Global ambient emissions have to be brought down and policymakers and governments worldwide should adopt stringent measures and collectively work toward achieving net-zero emissions by 2050. Indoor pollution levels, on the other hand, can be better managed by improving ventilation design and incorporating other building engineering controls and systemic modifications. The greater challenge would be for the disadvantaged sections of the society, who themselves are living in places with a poor air quality index. For them to incorporate such building engineering controls is challenging due to cost, maintenance, and energy concerns. Governments should therefore step up and ensure the “right to clean air for all” as a part of town/city planning strategies involving measures to continuously monitor and improve the ambient air quality at a local, regional, national, and international level. Decisive leadership and collaborative efforts of all stakeholders can therefore help lower the pollutant levels and consequentially control future virus outbreaks.

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Non-Print Items

Abstract

The recent COVID-19 pandemic has taken a serious toll on humanity and mankind, affecting every section of society. Scientists are still trying to find out the possible transmission routes of this deadly virus, with airborne routes cited by many as a possible route of infection spread. Because airborne aerosols, dust particles, and other indoor pollutants aid in virus transmission, it becomes important to assess their roles in affecting human health. The study therefore tries to review indoor air pollution and its sources, how it impacts human health, and the role of built components and technological systems in combating indoor air pollution and in the process control infection spread also. Most of the studies have found out that there exists a need to accurately determine the airflow distribution pattern rather than relying on generic ventilation standards like ventilation rates, air change rates, and CO₂ levels. Although increasing outdoor airflow rates and avoiding air recirculation are some of the suggestions given to control indoor pollution levels and infection spread, it can become challenging in areas with high ambient pollution levels. This signifies the need to incorporate additional engineering controls, sensing technologies, artificial intelligence tools, and predictive modeling methods to combat the health hazards of indoor air pollution and potential novel viruses that can emerge in the future.

Keywords
IAQ, COVID-19; Infection spread; Air pollution; Ventilation controls; Predictive modeling; Occupant health