Biological Air Quality Considerations for Non-Healthcare, As Built Environments

Authors:

Paul Meechan, PhD, Mark Hernandez, PhD, Patty Olinger, JM, RBP, Mark Zarzeczny,

Dr. Stefan Wagener, Dr. Wayne Thomann, Raj Gupta, Dr. Murray Cohen

Affiliation: GBAC, Global Biorisk Advisory Council

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Abstract

The importance of good air quality in buildings has been brought into sharp focus as we continue to try and mitigate the spread of the SARS-CoV-2 virus. When a virus or other infectious agent is transmitted through tiny droplets and aerosols, it is said to be an airborne disease. SARS-CoV-2, influenza, chicken pox, and measles are all examples of airborne diseases. This paper will address several options for improving the quality of indoor air in non-healthcare settings such as schools, restaurants, and gyms, the implementation of which will make these facilities safer not only during a pandemic, but also after the current crisis is behind us.

Introduction

Air quality has become a focus of cleaning considerations since the SARS-CoV-2 virus pandemic started. This document is designed to provide measures a facility and those involved in cleaning facilities ought to take into consideration to control the spread of infectious agents within their facilities, with a particular concern for those spread through airborne routes. These considerations are for as built environments (schools, gyms, restaurants, convention centers) and do not pertain to healthcare or similar facilities with specific needs, such as patient isolation areas.

Assess the Risk of Airborne Disease

In any situation, assessment of risk is the first critical step. For this work, the key steps are to:

a) Determine the infectious agent (bacterium, virus, fungi) you need to prevent or eliminate.
b) Determine if the agent poses airborne risk.
c) Select mitigations if needed.

It may not always be possible to identify the specific agent you need to inactivate or kill. During the SARS-CoV-2 pandemic, the agent is known, as it is for flu (influenza) season. However, there are a number of other agents that can cause outbreaks of illness (such as norovirus or methicillin-resistant Staphylococcus aureus, or MRSA) that do not necessarily have a typical or predictable season during which it is most prevalent. Knowing the infectious agent will be helpful in determining mitigations.

For the information in this document, whether or not the infectious agent is an airborne risk is also important. For agents such as SARS-CoV-2 and flu, droplets and aerosols are important transmission pathways, while agents such as MRSA are not spread in this way (CDC, 2021; Public Health Agency of Canada [PHAC], 2011; PHAC, 2012). Although some of the measures in the following section would be helpful in both instances, they were compiled with the intent of addressing the need to break the airborne chain of transmission of infectious agents. Additional or different measures would be required to address the transmission of non-airborne agents.

Risk Mitigation

Once you have identified the agent as airborne transmissible, you need to consider the risk mitigations, or how you will reduce the risk to those working in or visiting your facility. The risk can never become zero, so the goal is to reduce the risk to a safe enough level for your workers and visitors to feel safe in your environment.

Reducing the risk is what is known as risk mitigation, or the steps or actions to be taken to eliminate the source of the infectious agent, prevent its spread, or remove it once it has spread. Although source elimination is the most effective, it may not be possible. Therefore, the following measures should be considered as overlapping, re-enforcing, and complementary mitigation actions.

Elimination at Source

The first mitigation should be an attempt at source control or keeping the infectious material out of the building. Two options for this have been used during the COVID-19 pandemic, with varying degrees of success. The first option is to identify those individuals who are infectious through passive or active screening prior to entry. An example of passive screening is asking employees or visitors to a facility to self-screen for known symptoms before entering the building. Active screening includes measures such as temperature checks or the requirement for a negative test before entering. The risk here is that there may be a significant number of infectious individuals who are not symptomatic, or that the test taken produced an inaccurate result.

The alternative, and potentially complementary, mitigation is to provide controls to keep potentially infectious outside air from entering the building, either through directional airflow out of the building or filtering the supply air. For viral agents such as SARS-CoV-2 or influenza, this may not be useful, as the air in the outdoor environment is usually not heavily contaminated with either virus.

Re-entrainment Mitigations

The second mitigation to be considered should be re-entrainment mitigations; that is cleaning and disinfecting to prevent the infectious agent from being moved from a settled surface back into the air or picked up on surfaces by uninfected workers or visitors. Specific, high-touch point cleaning and disinfecting on a schedule, dictated by both the type of agent (e.g., how long it survives on a surface), and how many people will touch the surface in a given amount of time (e.g., more people touching a surface will require more frequent cleaning/disinfecting).

Note that cleaning itself is not sufficient, as a cleaning solution may not actually destroy the infectious agent and may simply spread it across a surface. The cleaning/disinfecting solution must be one that is capable of working against the infectious agent you are concerned about. Your risk assessment may have indicated the type of agent you need to kill or inactivate, but if it is not possible to make that determination, a disinfectant that can kill Mycobacterium tuberculosis and non-enveloped viruses (such as norovirus), or one that is considered capable of inactivating "emerging viral pathogens" (see the EPA website for US guidance) would provide adequate disinfection for most non-healthcare settings.

The same guidance would follow for floor or surface cleaning and disinfection, with the additional guidance that the risk assessment needs to consider the risk posed by aerosols that may be generated by the cleaning equipment itself, and whether the disinfectant works quickly enough to prevent any equipment from spreading the agent through such aerosol generation. The equipment might need to have air driven through the cleaning/disinfecting system and exhausted through a HEPA filter to trap any liberated agents.

HVAC Mitigations

A well-functioning HVAC system reduces the risk of airborne infectious aerosol exposure. The American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) recommends certain low-cost measures that all building owners and operators should consider improving the effectiveness of their respective HVAC systems (ASHRAE, *Ashrae Epidemic Task Force* 2021).

First, the operator should ensure the HVAC system provides the minimum levels of outside air prescribed by codes and standards. Fresh air dilutes the concentration of contaminants thereby reducing the risk of infection. Secondly, air filters that achieve MERV-13 or better are recommended to improve further the air quality. Third, the air in a space should be flushed between occupied periods. ASHRAE recommends the flush time to equal "three air changes of equivalent clean air supply (ASHRAE, *Ashrae Epidemic Task Force* 2021)."

System commissioning is another relatively low-cost action to ensure the HVAC system functions properly. An HVAC system, like a car, contains many moving and inter-related components that work together. An annual tune-up is recommended to ensure controls and sequence of operations are accurate and maintain the correct temperature, humidity, outside air, and pressurization settings. A complete list of ASHRAE's core recommendations is available at the following link: ASHRAE Epidemic Task Force Core Recommendations.

In addition to these core recommendations, the following HVAC mitigation measures can further improve the indoor air quality of a building:

i. Filtration (MERV)

- Advantages: Increase in filtration (MERV value) increases the removal of particles, including those containing pathogens, including SARS CoV-2
- Disadvantages: Additional energy required to overcome resistance by higher MERV value filters, faster loading of filter (ASHRAE, 2021)

ii. Physical disinfectants (UV)

- Advantages: Mature technology used to reduce pathogens, especially useful for TB areas.
- Disadvantages: Hazardous if persons exposed to UV; only functions in line of sight; quickly degraded by dust or dirt on lamps.

iii. Electronic air cleaning

- Advantages: established technology.
- Disadvantages: ongoing maintenance required; capital cost to implement in HVAC system.

iv. Chemical Disinfectants (ozone, propylene glycol)

- Advantages: effective at concentrations below regulatory concerns.
- Disadvantages: may be banned in some locations; may create hazardous byproducts.

v. Point source mitigations (room air disinfection)

- Advantages: modular; easily implemented, no HVAC renovations required
- Disadvantages: only functional within local area, may not protect staff at short range

vi. Staffing changes (heat load/cooling/ACH); multiple shifts (e.g., 7AM-11PM)

- Advantages: easier to implement than capital changes to HVAC; more flexible than HVAC modifications.
- Disadvantages: possible loss of interaction between staff if staffing numbers limited; additional energy costs for additional shifts.

The following HVAC maintenance functions are recommended for source removal and air conveyance cleaning according to ACR, the NADCA Standard 2021 edition (NADCA, 2021).

i. Cleaning of the HVAC system consisting of mechanical agitation and negative air for extraction. Cleaning of the air conveyance system in any facility should be at the forefront of any remediation project.
ii. Cleaning of Coils is necessary to have sufficient airflow. All coils including evaporator and reheat coils must be thoroughly cleaned and inspected.
iii. All exhaust systems must be cleaned and in proper working condition to have proper air exchanges.
iv. Proper filtration and attention to system requirements is a must. Many systems are not designed for HEPA filtration or high MERV ratings and will not function properly if retrofit with increased MERV rating and utilized incorrectly. A clean air conveyance system will assist in

air exchanges of clean air and is the lungs of the facility. Whatever is happening in the facility is happening in the air conveyance systems. Cleaning and disinfection of the system is a required before the introduction of UV lighting, filters, or any other equipment. These mitigation tactics are important and may be necessary but must be implemented after source removal of all contaminants is complete.

Other Mitigations

There are additional mitigations that are not necessarily physical but may add important layers of protection. The first is the use of occupant behaviors. For example, if windows or doors can be propped opened, someone in the facility needs to have sufficient knowledge of airflow to assess whether allowing or limiting the access and flow of outdoor air provides an advantage to preventing or eliminating a specific infectious agent.

The culture of a facility can be a significant determinant towards whether a program to drive down the amount of an infectious agent is successful. For example, do the staff keep their areas clean, and can they be engaged to help clean their own high touchpoint areas? Are they watching out for each other and making sure they stay home if ill? As we have seen with COVID, adherence to vaccination recommendations, mask wearing, and social distancing is a cultural phenomenon and needs to be considered if such controls will be implemented again in the future.

Finally, someone in the facility needs to be setting the standards and direction for the custodial duties, including how often items such as high touchpoint cleaning/disinfecting will be performed. Implementing these directions may be performed by facility staff or contract cleaning companies and there needs to be an agreement as to the frequency of the duties and, if split between contractors and staff, who is responsible for which duties and who supplies any materials and chemicals required to accomplish each task.

Monitoring

Instrumentation for the direct, real-time characterization of airborne particulate matter (PM) within the built environment has matured rapidly over the last decade. This includes, but is not limited to, the reporting of particle size distributions in respirable size ranges, as well the fractions thereof that are of are comprised of primary biological materials (PM_{bio}). This type of instrumentation was originally developed for atmospheric science and military applications, and relies on high throughput, laser optical particle counters. A new generation of optical particle recognition equipment incorporates UV lamps that not only count and size airborne PM, but also grossly categorize biological origins of some particles based on fluorescence signatures (Huffman et al., 2019) Many of these PM monitors estimate mass in size ranges that are relevant to the regulatory sector ($PM\text{-}_{10}$, $PM\text{-}_{2.5}$ and PM_1) using density correlations.

Reliable PM monitors are now available from many commercial vendors that are often paired with gas sensors to observe carbon dioxide levels (CO_2) and volatile organic carbon (VOC) levels (Demanega et al., 2021). Taken together, these gas and PM measurements can be used to assess occupant exposures and ventilation performance in real-time, with a high degree of confidence, provided the following conditions are met:

i. Monitors are strategically placed for composite measurement near "return" air flow.
ii. Air in the occupied space is maintained in a well-mixed condition.
iii. Monitors are routinely and appropriately calibrated and maintained.
iv. Near field influences (e.g., heaters, occupants, high-velocity air fans) are avoided.
v. Sampling frequency is maximized in context of air exchange rate.

Sensor networks can report their data across secure cellular, Wi-Fi or satellite IoT platforms to popular database formats for near real-time analysis of selected indoor air quality indicators and/or archived with occupancy information as well as architectural metadata, including building materials, room configurations, and maintenance activities.

Cleaning and Disinfection Indicators

Cleaning and disinfection are distinct from each other, in that cleaning refers to the association of broad range of undesired inorganic and organic contamination of surfaces and indoor air, whereas disinfection refers solely to the viability and/or infectious potential of microorganisms. Indeed, the deposition and resuspension of PM in the built environment links the biological considerations for cleaning and disinfecting indoor surfaces to indoor air, and vice-versa. Practical definitions for disinfection require that surfaces or air need to be relatively clean prior to disinfection, because of the interferences contamination present to disinfectants effectively inactivating their microbial targets. Both physical (e.g., UV light) and chemical disinfectants (e.g., peroxides, surfactants) can be effective for indoor air and surface applications; however, the associated occupant exposures to cleaners, UV, and any other disinfectant must be considered before, during and after cleaning/disinfection practice. The US Environmental Protection Agency (USEPA) curates a comprehensive database of cleaning and/or disinfecting chemicals approved for indoor use) against microbiological agents, while National Institute for Occupational Safety and Health (NIOSH) provides guidance regarding personal exposure limits to many of these commonly used chemicals (USEPA, 2021; US OSHA, 2021). All EPA approved cleaners and disinfectants, whether they are applied to surfaces, indoor air, or both, have prescribed application protocols that depend on direct contact and sufficient (minimum) contact time.

Performance indicators can be applied to assess the impact of cleaning and ventilation interventions toward lowering occupant exposures to airborne and surface contaminants. For airborne agents, concomitant composite measurements of PM and ventilation rate can be juxtaposed to occupancy conditions pre- and post-intervention (e.g., HVAC cleaning, increased outdoor air fractions and/or filtration improvements). Airborne PM levels, and accepted tracers for ventilation rate (usually CO_2), can be normalized by occupancy patterns to assess the effect of interventions on airborne PM exposure in respirable size ranges. (Batterman, 2017).

Similarly, cleaning indicators have been used to assess the impacts of cleaning interventions on surface-borne microbes. This is most often executed with routine ATP surveys of microbial activity on candidate surfaces that serve as sentinels as high-touch surfaces in any given facility (e.g., student desks or escalator handrails) (Sanna et al., 2018).

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