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A Data-driven Indoor Air Quality Framework for Post-COVID-19 Workplace Re-entry: Summary for Policymakers

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Date of Issue: 08 June 2020

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How to cite this document
Rastogi, P., Sobek, O.N., Jephson, G., Allison, J. 2020. A Data-driven Indoor Air Quality Framework for Post-COVID-19 Workplace Re-entry: Summary for Policymakers. Glasgow, UK. Version 1.2, 01 June 2020

An Introduction

It is virtually certain that social interaction and accessing public places poses a serious risk of viral transmission between infected persons and others.

The pandemic has had a major short-term impact on workplaces, as people work from home or are unable to work. However, the COVID-19 virus will continue to impact workplaces even as lockdowns ease, since new measures to protect workers' health must be implemented. The health-promoting aspects of buildings have always been important to our long- and short-term health, wellbeing, comfort, and productivity. The pandemic has sharpened minds to the immediate and catastrophic impacts of building design and operation on disease transmission.

Prevailing government guidance on prevention and public health reflects the risk of viral transmission via different routes (Figure 1).[1,2] The upshot is that buildings need to operate assuming aerosol transmission is a sufficiently serious risk. Our recommended approach involves four key features and is based on the Hierarchy of Controls approach.[3]

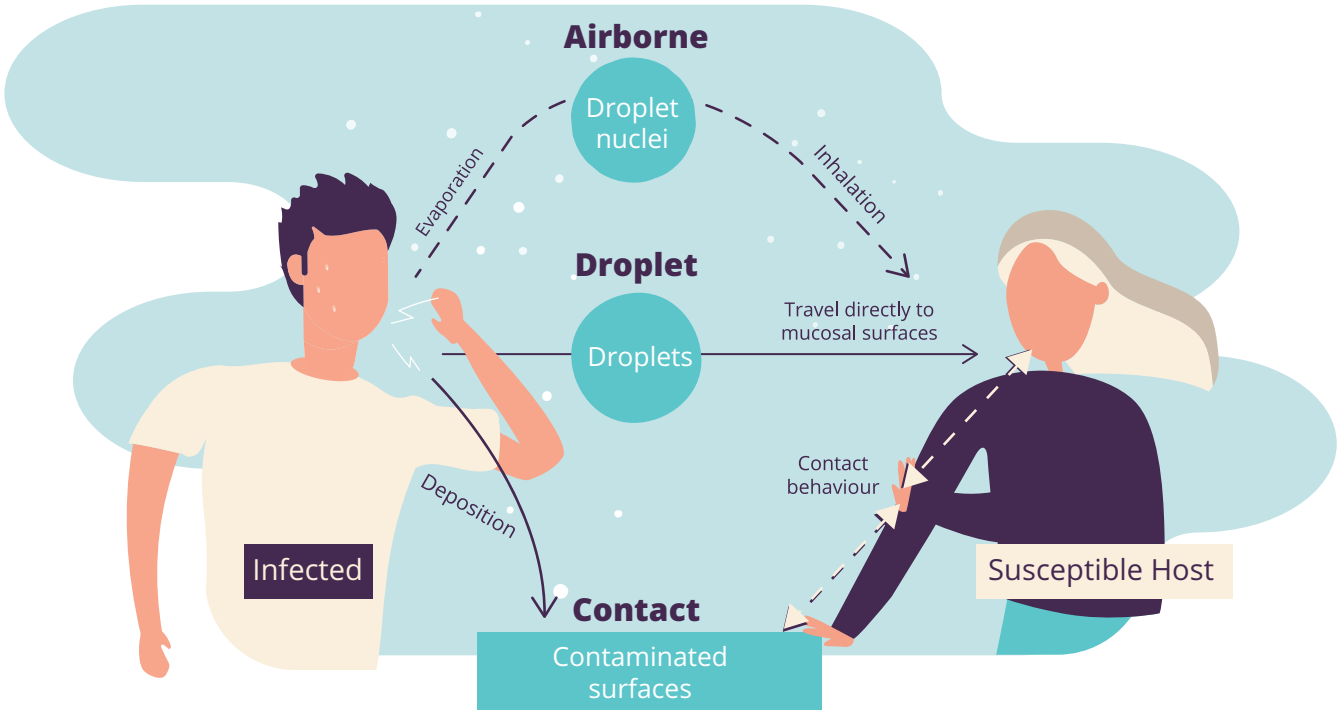

Figure 1: The three primary routes for infectious transmission during social interaction.

Back to Work Protocol: Key Features

A back to work protocol is a plan for re-populating buildings such as offices that were temporarily emptied due to the ongoing restrictions on travel and public interaction.

This protocol presented here is specifically about building operation. It can help building managers reduce risk by following established frameworks and guidelines. A protocol is only as good as its implementation, which is why this one explicitly includes measurement of outcomes for verification and iterative improvement. This process will be iterative, and no single action alone will be enough.

Key Features

1. **Implement engineering and administrative controls**

   Taking actions to manage risk through building operation, such as those recommended by professional societies.[4–6]

2. **Measure and verify outcomes**

   Most actions recommended for healthy building operation have measurable outcomes, either directly (e.g., temperature) or through proxies (e.g., CO_2 for ventilation). Measuring the outcomes of these actions using sensors and inspections/surveys translates engineering intent into operational reality.

3. **Inform and engage occupants**

   Push notifications and feedback or surveys can be used to both inform occupants about policies and actions and encourage them to participate in building operation. Occupants often have the best understanding of how policies are working and how hazards are developing or being controlled.[7]

4. **Review and improve**

   No plan survives first contact with implementation. Reviewing the plan based on the results of measurements and surveys will help to ensure that unintended consequences are minimised, and improvements implemented rapidly.

Engineering Controls

Engineering Controls are changes to the operation of building systems recommended by various professional organisations and government bodies.[4–6,8] These actions can be implemented by facility managers and engineers, and potentially reported using arbnco's award-winning ubiquitous sensing systems to mechanisms such as the Arc Re-entry tool set from USGBC.[9]

Table 1: Engineering controls for buildings: actions, measurable outcomes, and potential (unintended) consequences.

Action	Measurable Outcomes	Potential Consequences
General Ventilation		
• Increase outdoor ventilation • Increase window ventilation • No recirculation	✓ Lower CO_2 ✓ Lower VOC	x Increased outdoor PM ingress x Increased energy use x Uncomfortable air speeds
Air Treatment/ Filtration		
• Improve HVAC filtration to MERV-13 or better • Upper-room or in-duct Ultraviolet Germicidal Irradiation (UVGI)[5]	✓ Lower PM	x Energy penalty x Higher Ozone levels
Local Air Treatment		
• Portable room cleaners	✓ Lower VOC ✓ Lower PM	x Possibly ineffective for reducing viral load
Source Control/ Elimination		
• Toilet exhaust / extract / ventilation • Toilet operation and flushing	✓ Lower VOC ✓ Lower RH in toilets / bathrooms	x Energy penalty x Noise
General IEQ		
• Maintain appropriate temperature and humidity	✓ Temperature ✓ RH	x Energy penalty

Administrative Controls

Administrative Controls are changes to building operation recommended by various professional organisations and government bodies.[1,2,5,6,8,10–12] While Engineering Controls primarily deal with the operation of building systems, these actions and policies are implemented by individuals and facility managers. These can be potentially reported through mechanisms such as the Arc Re-entry tool set from USGBC.[9]

Table 2: Administrative controls for buildings: actions, measurable outcomes, and potential (unintended) consequences.

Action	Measurable Outcomes	Potential Consequences
Enhanced Disinfection		
• Enhanced cleaning schedules • Access to alcohol-based disinfection • Access to hand washing	✓ Surveys of occupants asking about disinfection	x Increased VOC x Increased Formaldehyde
Physical distancing		
• Work-from-home and staggered occupancy • Deliberate distancing – separation of desks, physical barriers, etc. • Guidelines on social interaction • Statistical assessment of occupancy through measurement	✓ Uptake, reactions, and compliance ✓ Lower space utilisation ✓ Spatially-resolved occupancy over time ✓ Dwell times / interaction times	x Compliance fatigue x Lower space efficiency x Resistance to occupancy measurement
Behavioural		
• 'Cough hygiene' • Face masks • Hand washing • Avoidance of overcrowding	✓ Effectiveness of communication ✓ Uptake and response	x Compliance fatigue
Access Control		
• Access control to prevent overcrowding • Body surface temperature measurement to control entry of symptomatic individuals	✓ Visitor and entry logging ✓ Body surface temperature readings	x Crowding at entrance x Resistance to invasiveness of body temperature measurement

Measure and Verify

A protocol is only as good as its implementation, which is why we explicitly include measurement and verification.

Most actions recommended for healthy building operation have measurable outcomes, either directly (e.g., temperature) or through proxies (e.g., CO_2 for ventilation), as discussed in tables 1 and 2. Measuring the outcomes of these actions using sensors and inspections/surveys translates engineering intent into operational reality. This also forms the basis for the new Arc Re-entry tools[9], which can be used to benchmark performance and compliance using the thresholds given in Table 3. In addition, arbnco is in the process of rolling out new metrics to encourage the spatial and temporal coverage of measurements, which will enable the benchmarking and comparison of diverse measurement practices. The arbn well standard sensor network covers most areas of regular occupancy.[13] The arbn well Best Practice Guide outlines two levels of sensor spatial coverage: minimum and optimum.

The optimum sensor layout should be sufficient under most conditions to evaluate the intended measurable outcomes and many unintended potential consequences. The standard arbn well sensor network includes continuous, distributed measurement of CO_2, VOC, PM, Temperature, and Humidity. The system's capabilities will be extended by 2021 to include gaseous pollutants such as Ozone, Formaldehyde, etc. and statistical (de-personalised) occupancy measurement.

Since pathogen transmission considerations have been exacerbated by the current pandemic, we recommend additional measurement points in vulnerable places and potential sources such as toilets and elevators. Since the best protection in these places is adequate ventilation/exhaust[4–6], a simple CO_2 measurement will suffice for general prevention.

Table 3: Thresholds for measurable outcomes to demonstrate good (green) and acceptable (amber) performance in Arc Re-entry tools.[9] These thresholds represent a higher standard of performance than the state of the art. They are subject to further review and adjustment based on sensor uncertainty.

Parameter	Investigate	Low Acceptable	Good	High Acceptable	Investigate	Units	Source
CO_2	350	350	350-750	700-1000	> 1000	ppm	CIBSE Guide A 2018 (Table 4.5), LEED v4.1 O+M Beta Guide
RH	<30	30-40	40-60	60-70	>70	%	CIBSE Guide A 2018
TVOC*[1]	<0	n/a	0-175	175-200	<200	µg/m^3	RESET v2 2018
PM1	<0	n/a	0-12	12-15	<15	µg/m^3	TBD
PM2.5	<0	n/a	0-12	12-15	<15	µg/m^3	WELL v2 2020, Optimisation 1
PM10	<0	n/a	0-30	30-35	<35	µg/m^3	WELL v2 2020, Optimisation 1

*[1] *TVOC measurements in ppb will be converted to µg/m^3 using a conversion factor of 3.767, based on the molecular weight of toluene.*

Inform and Engage Occupants

Push notifications and feedback or surveys through the arbn well system can be used to inform occupants about policies and actions and encourage them to participate in building operation. Occupants often have the best understanding of how policies are working and how hazards are developing or being controlled.[7] The arbn well system is built to be human-centric, and the new Arc Re-entry tools[9] emphasise occupant engagement as well.

Review and Improve

The process of adapting workplaces to reopen safely will be iterative, and no single action alone will be enough nor perfect upon first implementation. Examining the outcomes of engineering and administrative controls through physical measurement and occupant engagement should determine which actions work and which do not. Plans and guidance that adapt to the evidence are more reliable than those that remain rigid.

As the properties of COVID-19 are better known, the guidance will change. Much of the guidance here is based on the understanding of previous epidemics such as SARS, MERS, and H1N1. Some solutions and actions mentioned here will also have to be modified once more is known about how the virus infectivity and routes change over time.

While the workforce begins to recover from COVID-19, effective planning is vital to ensuring a safe transition back to work for employees.

Adhering to professionally recommended controls for building operation, both through building engineering and management, allows businesses to better control potential infection risks. By then verifying and examining the measurable outcomes of these recommendations, such as temperature, CO_2, and occupancy, through sensors, building and facilities managers can better implement and adjust the proposed controls. Through feedback, surveys, or push notifications, employers can continuously remind occupants of policies and have them contribute to strategy adoption and implementation.

Reviewing the plan based on the results of measurements and surveys will ultimately help ensure that unintended consequences are minimised, and improvements implemented rapidly, towards the creation of healthy indoor environments that suppress the transmission of viruses such as COVID-19.

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