Reboot Readiness: A Primer on How to Design for Contagions

HKS

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A Primer on How to Design for Contagions

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2020 The Year of COVID-19

In December 2019, Wuhan, China became ground zero for a global pandemic that in the first few months of 2020 has brought the global economy, and life as we once knew it, to a halt. Almost every country has dealt with it, and continues to deal with it, in slightly different ways, while being united in a need to contain and mitigate the emerging infectious disease known as COVID-19.

As we return to spaces left void by the emergence of COVID-19, it will be essential to understand how the events of the last several months have reshaped not only our social fabric but also the environments where we work, live, play, and receive care. Much like the sustainability movement, which enlighten us to concepts such as “global warming” and “carbon footprint,” the insurgence of the novel respiratory virus COVID-19 has increased public awareness of the need for prevention and control strategies to reduce the global threat of contagion. With this awareness, a newfound sense of social responsibility and connectedness has emerged that will likely influence how users will interact with the built environment for decades.

Recovery will Demand Resilience

Like dealing with climate change, we will need near-term (Day 0, 1), mid-term (Day X), and long-term (Day XX) recovery plans that have clear and actionable goals. Yet, these plans must also be nimble enough to accommodate rapidly emerging new knowledge. When developing a recovery plan, we must consider not only the moment of re-entry but also strategically plan for future disruptions.

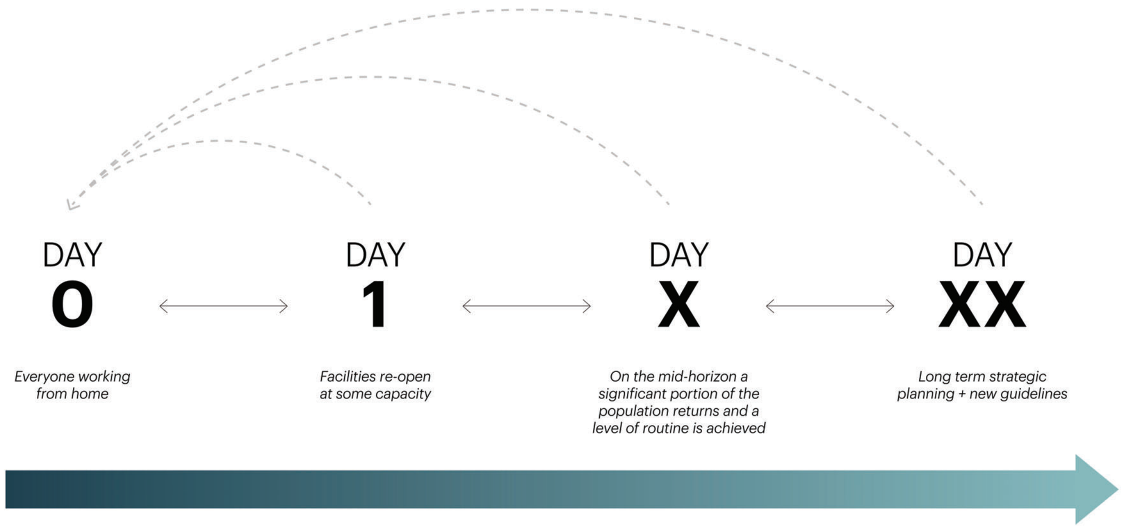

Figure 1—Reentry Timeline

As we move toward the recovery of our economies, communities, workforce, and educational and health care delivery systems, we must understand that this current challenge demands new approaches to protecting the health and well-being of all individuals.

This brief provides an overview of the science that defines our current understanding about how a contagion spreads and outlines actionable principles to implement in our built environments to support the recovery process today and be contagion-ready now and in the future.

Introducing the Pathogenic Virus

Pathogens refer to a broad range of microorganisms that cause infection or disease. Pathogens vary in structural composition and complexity and come in a multitude of shapes and sizes.[1,2,3] Two of the most common types of pathogens are viruses and bacteria. While both viruses and bacteria can cause infections with similar symptoms, there are fundamental differences between their structural make up, the way in which they reproduce, and how they respond to medications. Bacteria are single cell microorganisms that reproduce on themselves, and infections that are caused by bacteria can often be treated with antibiotics. [4] However, bacteria are also able to employ different strategies such as spontaneous mutation or horizontal transfer to change their structural make up that allow them to become impervious to antibiotics, making the bacteria antibiotic resistant and rendering the antibiotic useless in the treatment of the infection.[5]

Viruses, on the other hand, consist of genetic material such as DNA or RNA that is encapsulated by a protein coat and are much smaller in size than bacteria. Viruses require a host to live in and replicate, and do not respond to antibiotic treatments.[4] Pathogenic viruses can infect and replicate within human cells and cause diseases. The continuous emergence and re-emergence of pathogenic viruses has become a major threat to public health.[6]

The most recent coronavirus, known as COVID-19, is a highly pathogenic virus that is made of RNA and has club-like extensions protruding from its protein coat.[7] These extensions infect the host by causing adhesions in the host's cells. Due to its highly pathogenic nature, COVID-19 can quickly spread and is resistant to any known antiviral medications.[7] The science on how the virus spreads is evolving but the official position as of today is a primarily person to person spread via droplets (causing the 6′ social distance rule), and secondarily through surfaces. Airborne transmission via droplet nuclei in the meanwhile has become a growing concern. Recent research suggests that COVID respiratory droplets of all sizes (droplets and droplet nuclei) can travel up to 27′ (between 7-8 m) when expelled through sneezing or coughing.[8,9] While vaccines are being developed at record speed, it's important to be aware that a second wave of infections may happen, and if it does, it may look different.

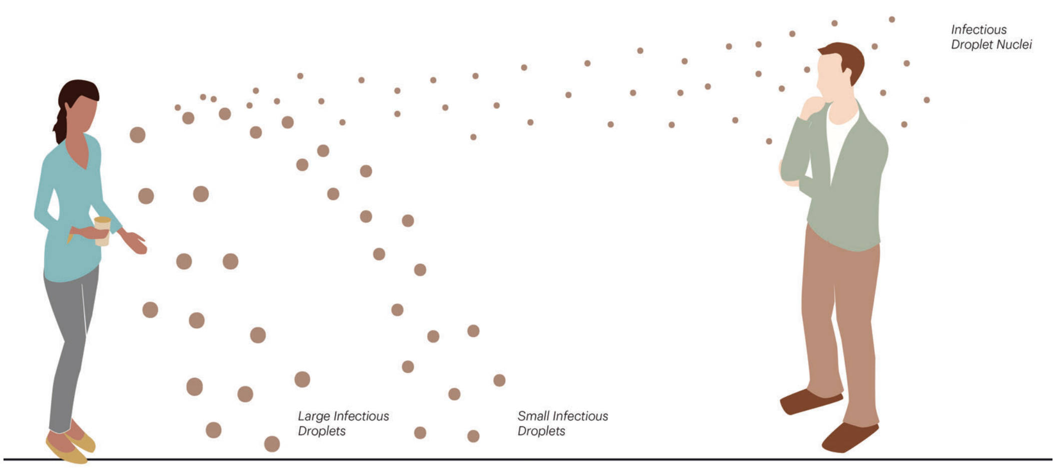

Figure 2—Spread of virus via person to person transmission of large and small infectious respiratory droplets (droplet and droplet nuclei)

1 **Agent**
The chain begins with an infectious agent such as a virus or bacteria.

2 **Reservoir**
Transmission occurs when the infectious agent leaves its environment where it normally lives. Reservoirs can include people, animals, or environmental conditions such as water, soil, or plants. Human reservoirs can act as either asymptomatic or passive carriers that exhibit no symptoms of the infection or as a symptomatic carrier that shows infectious symptoms.

3 **Portal of Exit**
The portal of exit is the pathway in which the infectious agent takes to leave the host, and is usually near the site where the infectious agent is localized.

4 **Modes of Transmission**
The infectious agent must be carried by some mode of transmission to an appropriate portal of entry of a susceptible host. Modes of transmission can occur either through direct or indirect means. Direct modes of transmission include person-to-person contact or contact between person-to-environment (water, surfaces, or plants). Droplet spread is also another mode of direct transmission. Indirect transmission can occur through airborne transmission of droplet nuclei, fomites and vectors. Fomites are inanimate objects such as surfaces, textiles, and instruments, while vectors are organisms such as flies or mosquitos that may carry an infectious agent.

5 **Portal of Entry**
The portal of entry refers to the way in which the infectious agent enters its new host. Often the point of entry for the new host is the same as the original host's portal of exit. For example, the entry point and portal of exit for COVID-19 is the respiratory tract.

6 **Susceptible Host**
A susceptible host is required to complete the chain of transmission. A host's susceptibility is dependent on many factors including whether the host has underlying medical conditions or intrinsic factors that suppress their ability to resist infection.

Figure 3—Chain of Transmission

How Can We Break the Transmission Chain?

Understanding the foundations of how a virus spreads is important. Viral infections occur when pathogens successfully progress through six vital links in what is known as the chain of transmission.[10] Breaking any one of the links in the chain of transmission will stop the virus from spreading and is an essential component to ensuring containment. As such, each link in the chain provides a unique opportunity to leverage an innovative approach to containing contagions by holistically targeting all components of the work system.[1]

The built environment can play an important role in stopping the transmission of pathogens. Yet, it is often an underutilized strategy within the overall work system. Our environments are full of surfaces, instruments, equipment, and textiles that can act as fomites.[7, 11] As we navigate through our built environments, we leave traces. Traces are the viral particles individuals leave behind on the surfaces they come into direct or indirect contact with.[7] These surfaces can become a pathway for pathogen exchange, acting as a reservoir for viral transmission.[11] The traces that are left behind on surfaces can be redistributed within the environment due to changes in natural and mechanical airflow and human movement, potentially increasing the number of surfaces containing the pathogen. In the case of COVID-19 the fundamental risk is from person-to-person spread of droplets. However, as we walk through interior environments there is direct or indirect contact with surfaces where viral particles may be deposited or resuspended due to natural airflow patterns, mechanical airflow patterns, or other sources of turbulence in the indoor environment such as foot fall, walking, and thermal plumes from warm human bodies. Because of the potential of the built environment to become a reservoir for the virus it is important to understand, and minimize, the viral traces we leave behind.

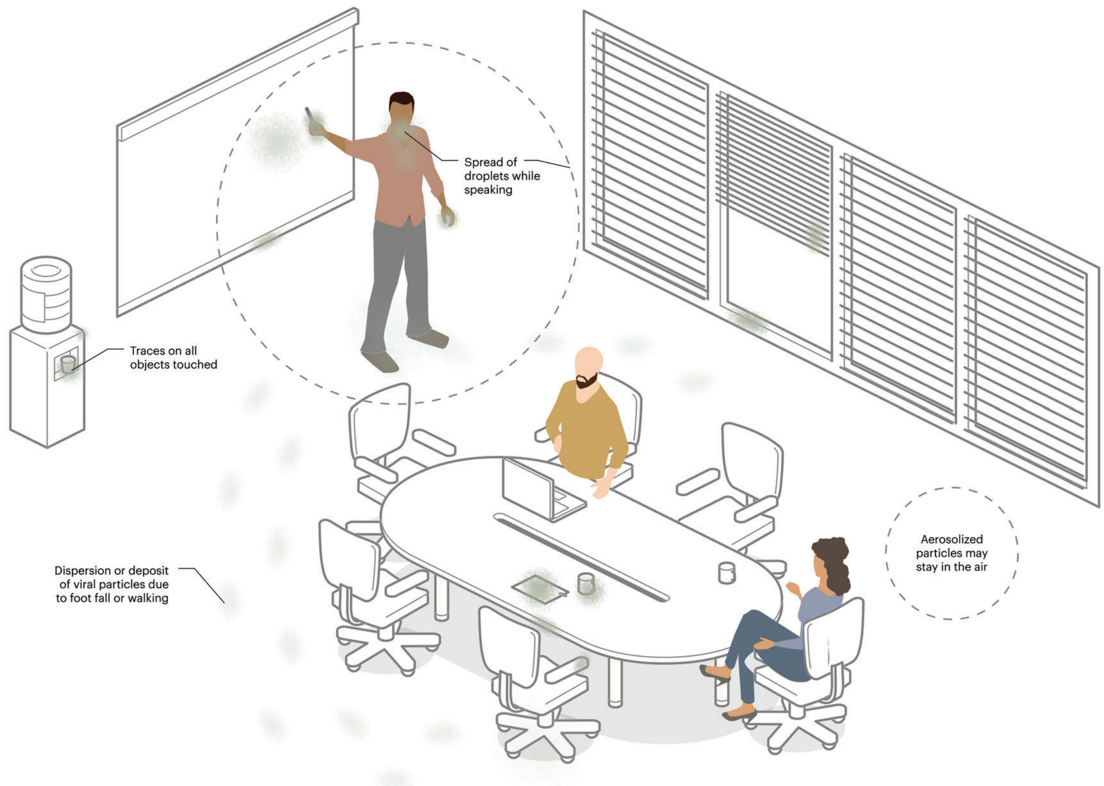

Figure 4—Traces in the Built Environment
Adapted from: https://msystems.asm.org/content/5/2/e00245-20

Additionally, the innate property of surface materials can mediate the length of time in which pathogens are able to remain infectious on a surface, making some surfaces more prone to viral transmission for a longer duration of time than others. [12] Appendix 1 illustrates how long different commonly touched surfaces in an office can retain infectious viral material, potentially becoming a source of contagion for a typical office employee throughout the course of their day. With contaminated surfaces remaining infectious from a few hours up to several days, it is important to institute frequent and routine cleaning protocols that occur throughout the day to help minimize contagion spread. Equally important is the design of the air flow within indoor environments addressed in Appendix 2. Both are key components of reducing the spread of contagions.

Basic Principles for Recovery & Resilience

To break the transmission chain the built environment must be addressed within a systems approach. We propose a nested system approach that individual organizations can deploy. First at the level of policies and protocols (operational), next at the built environment scale (building), and finally, at the level of personal agency (individual). These three scales must work in parallel, to contain and mitigate the spread, managed by an eco-system of digital and material technology, and precise and positive communications, to achieve not just physical, but psychological safety as well.

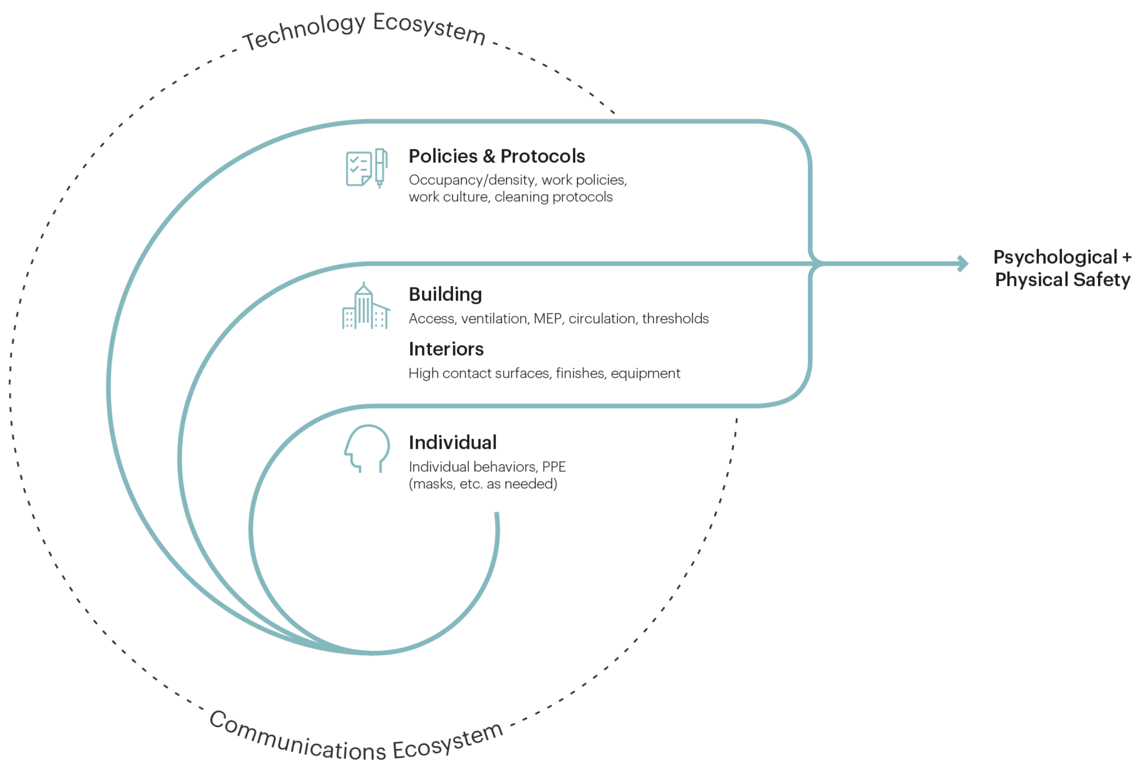

Figure 5—Transmission Prevention Nested Systems Approach

1. **Organizational Policies and Protocols**
   Polices and protocols that contain the reservoir, manage and trace the path from it, limit the mode of transmission and path of entry, and protect susceptible hosts are important components in containing pathogenic viruses. Policies should be flexible enough to account for global infrastructure and cultural differences, regional needs such as commuting, as well as personal needs that place vulnerable individuals at greater risk such as individuals with compromised immune systems or additional medical conditions that can make the individual more susceptible to becoming infected. In simple terms we need policies and protocols that *limit exposure to carriers, rapidly isolate those who may be exposed, and protect those who are vulnerable*.

   1. Limit the risk by only having people congregate/ travel as needed
   2. Space out seating plans to allow for recommended distances (6′ as per CDC and 3′ as per WHO)
   3. Establish policies for limiting the max occupancy in shared areas, especially with vertical circulation systems such as elevators
   4. Improve sanitation & cleaning protocols
   5. Provide staff education regarding implementation of new policies and protocols
   6. Actively promote psychological safety and mental health programs
   7. Assess sick and other leave policies as well as visitation policies

2. **Building Systems & Interiors**
   The built environment is the second line of defense and a critical one since many infectious diseases are spread in interior environments. It is important to carefully assess the health of our buildings and develop strategies that prevent infection and promote human health.

   1. Optimize density and decompress spaces to enable distancing
   2. Control Access
      i. Control access and invest in thresholds that can be used for screening
      ii. Identify paths of travel for both staff and visitors
      iii. Identify isolation areas for further assessment to contain spread early

3. Manage Circulation & Flow

i. Widen circulation pathways to allow social distancing
ii. Reduce cross-traffic by implementing unidirectional flows
iii. Plan for optimized flow of people and resources with special consideration for separation of clean and dirty items (e.g. linen and trash)
iv. Utilize on-stage, off-stage mechanisms to separate back of the house and front of the house mechanisms
v. Consider stairs options in addition to elevators

4. Enhance MEP

i. Optimize airflow distribution to maintain an effective dilution ventilation
ii. Increase outdoor ventilation where possible
iii. Avoid recirculation of indoor air
iv. Provide enhanced mechanical filtration
v. Provide appropriate humidity levels

Detailed Guidelines are available here. See summary in Appendix 2

5. Provide Access to Fresh Air and Sunlight

In general sufficient air circulation can disperse concentrated payload of droplets- fresh air and natural ventilation can help provided the external air quality is optimum

6. Minimize need for contact with high-touch surfaces and use design cues to promote safe behavior at critical points of decision

i. Reduce number of high touch surfaces
ii. Implement processes or technologies for touchless check-in and check-outs
iii. Reduce number of shared surfaces/ equipment/ products
iv. Use contactless systems for entry/exit where possible
v. Use foot operated systems vs. hand operated systems where possible
vi. Use empathetic and attractive signage at key points of decisions to promote safe behaviors

7. Maximize Cleanability
    i. Reduce clutter
    ii. Reduce seams
    iii. Reduce hard to reach or clean surfaces
    iv. Choose (and clean) surfaces based on virus transmission rates

3. **Individual Level Protection**

   In a resilient approach, individuals are the last line of defense - and they must be protected both physically and psychologically. Along with handwashing and hand-sanitization, the importance of facemask use for all individuals when indoors is an essential component to mitigating viral spread. Facemasks can effectively help limit viral spread by both reducing the velocity and distance traveled of expired aerosols that may contain the virus and providing a barrier to aerosolized particles from entering into a new host. [8]

   In combination with appropriate procedures for putting on and taking off facemasks and following other public health control measures such as social distancing, handwashing, and routinely cleaning surfaces the use of facemasks can provide increased physical and psychological safety for both self and others. [13] For psychological safety it is important to engage individuals and empower them to take care of both their own health and the health of people around them.

   1. Wash hands
   2. Wear masks while indoors until a significant change such as a vaccine or reduction in incidence rates
   3. Follow personal hygiene protocols and stay home when sick
   4. Be respectful and emotionally sensitive to others
   5. Go outside and get fresh air as much as possible
   6. Maintain physical distance of 6′ at all times in public or workplaces
   7. Maintain social connections while remaining at safe physical distance (by leveraging open spaces and digital communication)

The table below summarizes these deployable actions, across a variety of scales, that must be deployed in parallel to contain and mitigate spread.

ORGANIZATIONAL POLICY + PROTOCOL	BUILDING SYSTEMS + INTERIORS	INDIVIDUAL BEHAVIOR
+ Limit the risk by only having people congregate/travel as needed + Space out occupancy protocols for recommended distances (6′ as per CDC and 3′ as per WHO) + Establish policies for limiting the max occupancy in shared areas, especially with vertical circulation systems such as elevators + Improve sanitation & cleaning protocols + Provide staff education regarding implementation of new policies and protocols + Actively promote psychological safety and mental health programs + Assess sick and other leave policies as well as visitation policies	+ Optimize density and decompress spaces to enable distancing + Control access, establish thresholds and define isolation areas + Manage circulation & flow, and minimize cross-traffic + Enhance MEP systems, by improving air circulation, filtration and humidity levels + Provide access to fresh air and sunlight + Reduce need for contact with high-touch surfaces by leveraging contactless technology, and use design cues to promote safe behavior at critical points of decision + Maximize cleanability by reducing clutter on hortizontal surfaces, minimizing seams and crevices, and using cleanable surfaces and materials	+ Wash hands + Wear masks while indoors until a significant change such as a vaccine or reduction in indidence rates + Follow personal hygiene protocols and stay home when sick + Be respectful and emotionally sensitive to others + Go outside and get fresh air as much as possible + Maintain a physical distance of 6′ at all times in public or workplaces + Maintain social connections while remaining at safe physical distance (by leveraging open spaces and digital communications)

Figure 6—Summary of deployable strategies to contain and mitigate spread

Precautionary Principle

The science around emerging infectious diseases is evolving. While the data is still being collected, vaccines have not been found, and treatment protocols are developing, many theories and predictions will emerge. This will be the case for new technologies and products on the market. Many of these may provide seemingly quick solutions to a contagion, while compromising other key stakeholders like people, the environment, and the planet.

It is important that in an emerging field, decisions are made cautiously. The precautionary principle is a strategy for approaching issues of potential harm when extensive scientific knowledge on the matter is lacking. It emphasizes caution, pausing and review before leaping into new innovations that may prove disastrous.[14]

Pandemic Preparedness Needs Pandemic Resilience

We have been battling a lethal virus that is difficult to detect because of a lack of preparedness and knowledge. However, preparing for any kind of contagion in a preventive way that promotes physical as well as psychological safety can give us a certain resilience to combat the next wave of this pandemic, or a completely new one. Just like natural disasters caused by climate change, contagions have become an increasing threat because of a fundamental tear in our public health infrastructure. This will fundamentally change the way we work, live, play and heal. This ever-present threat of contagion that has already radically changed and continues to transform how we interact with each other, is also an opportunity to re-imagine our buildings, our cities, and our societies.

Additional Information

Critical Resources

CDC

https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/social-distancing.html

OSHA Return to Work Policies

https://www.osha.gov/Publications/OSHA3990.pdf

NIOSH Work Policies

https://www.cdc.gov/niosh/topics/ptd/

Relative Humidity:

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6364647/

ASHRAE Position Document on Infectious Aerosols (Page 10 has a summary of items for consideration):

https://www.ashrae.org/file%20library/about/position%20documents/pd_infectiousaerosols_2020.pdf

ASHRAE Environmental Health Committee (EHC) Emerging Issue Brief: Pandemic COVID-19 and Airborne Transmission:

https://www.ashrae.org/file%20library/technical%20resources/covid-19/eiband-airbornetransmission.pdf

High Touch Hospital Surfaces:

https://www.cidrap.umn.edu/news-perspective/2020/04/study-finds-evidence-covid-19-air-hospital-surfaces

Healthy Buildings

https://forhealth.org/

https://covid-19.forhealth.org/

Date Completed

June 2nd 2020

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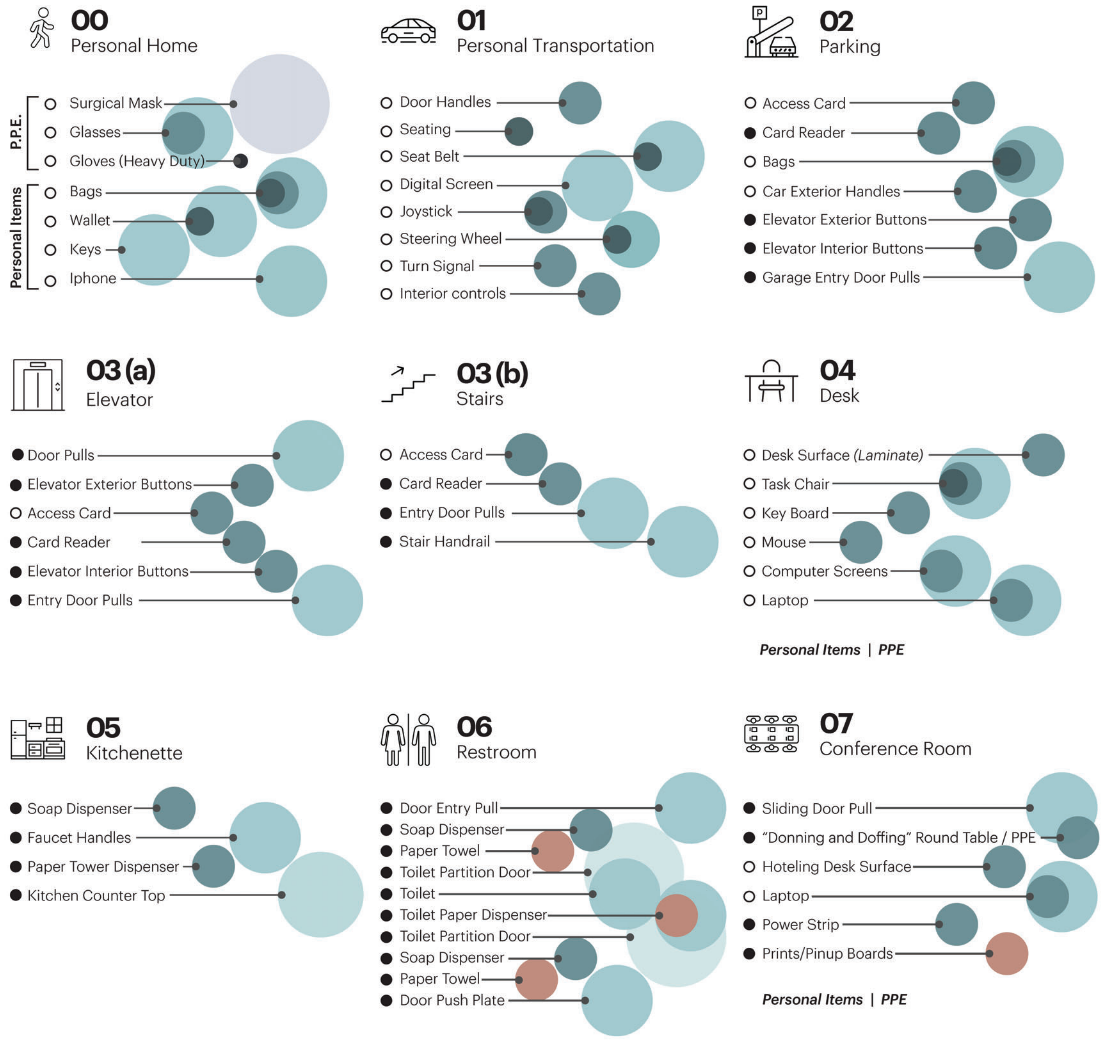
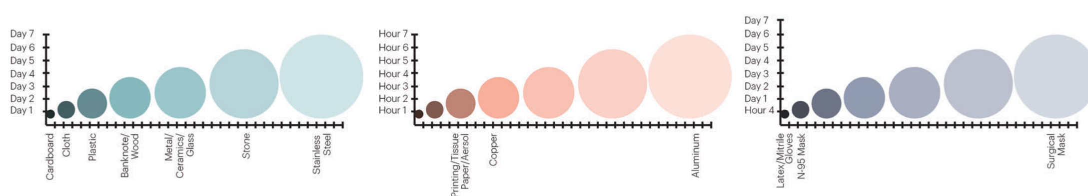
Appendix 1



COVID-19 LIFESPAN ON SURFACES



LEGEND

- ● Shared Surface
- ○ Private Surface

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Tracing Contact Journey

Recent evidence suggests that COVID-19 can remain viable and infectious on plastic for up to 72 hours and on stainless steel for up to 48 hours, while COVID-19 was found to remain viable on cardboard for 24 hours and on copper for up to 4 hours. [11] Appendix 1 illustrates how long different commonly touched surfaces in an office can retain infectious viral material.

Appendix 2

HVAC Operational Opportunities and Challenges

Changes to building operations, including the operation of HVAC systems can reduce airborne exposures to viruses. However, basic principles of social distancing, surface cleaning and disinfection, handwashing and other strategies of good hygiene are far more important than anything related to the HVAC system. Because small particles remain airborne for some period of time, the design and operation of HVAC systems that move air can affect disease transmission. Consider the following HVAC Operational Opportunities and Challenges when returning to work.

- Increase outdoor air ventilation while minimizing occupant density; with a lower population in the building effective dilution ventilation per person increases. Disable demand-controlled ventilation (DCV) if applicable.
- Keep airside systems running longer (24/7 if possible) or at the very least increase the preconditioning period in the morning and extend the afterhours runtime to further improve dilution.
- Avoid recirculation. Open minimum outdoor air dampers to 100% if possible, in mild weather seasons (be cautious in extreme weather, it will impact thermal comfort).
- Upgrade air filtration to MERV-13 or the highest compatible with the existing filter rack while sealing edges of the filter to limit bypass. Fans must be able to accommodate greater static pressure drop with increase in infiltration performance.
- UVGI (ultraviolet germicidal irradiation) lights are commonly used in HVAC applications. However, in-stream tubes, as an additional intervention, can help to destroy contaminants at low velocities to encourage a higher effectiveness (higher dosage and kill rate). This will require a well-engineered UV system retrofit integration. Occupants must be protected from UV light leakage (radiation) to ensure safe system operation.
- Higher relative humidity is known to reduce infection rates (it provides an air transmission barrier, prevents propagation). If humidity control is viable, consider replacing the humidity sensor in the air-side system first (these sensors are prone to failure and are hardly replaced, O&M issue) and verify dewpoint constraints during critical design days (prevent condensation) before increasing humidity levels.
- Operable windows can be very effective in providing an increase in ventilation rates if the building can maintain external static pressure while continuing to serve

other conditioned zones. Contact sensors at operable windows may be necessary to modulate fan spends and close off dampers. Even with the right controls in place, the effective number of annual hours within typical thermal comfort ranges are limited when using both dry-bulb and relative humidity constraints. Consider relaxing workplace dress policies to account for higher dry-bulb temperatures and relative humidity while maintaining within ASHRAE Adaptive Comfort limits (increases passive ventilation potential). Outside air quality should be monitored to ensure other pollutants (carbon monoxide and particulate matter) or irritants (seasonal allergic rhinitis) do not degrade desired indoor air quality levels.

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