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# Reimagining Construction and Renovation of Health Care Facilities During Emergence from a Pandemic



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## KEYWORDS

- COVID-19 pandemic • Construction • Renovation • Health care facilities
- Risk assessment • Aspergillosis • Waterborne and airborne pathogen
- Health care design

## KEY POINTS

- The coronavirus disease 2019 (COVID-19) pandemic response has had a tremendous impact on society and delivery of health care around the world. Learnings during response have rapidly increased the use of remote communication strategies such as telehealth and challenged long-standing concepts of airborne transmission.
- Outbreaks of disease are associated with construction and renovation when planning and risk mitigation is ignored or not effective.
- The infection control risk assessment (ICRA) and mitigation recommendations are essential components of infection prevention and patient safety programs.
- Infection preventionists/health care epidemiologists need to be aware and have access to guidelines for design and construction of health care facilities as well as new investigations of interventions to prevent transmission from the environment of care.
- Policies and procedures that address ICRA and the newly adapted water ICRA, safe work practices, training, monitoring, contingencies, and authority should be optimized.

## INTRODUCTION

As this article was being published it coincided with the approximate 1-year anniversary of declaration of the coronavirus disease 2019 (COVID-19) pandemic emergency in the United States.<sup>1</sup> Its cause, severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2), has and continues to have dramatic and long-lasting impact on the lives of all people around the world.<sup>2</sup> According to Dr Keith Wiloo, Henry Putnam University Professor of History and Public Affairs at Princeton,

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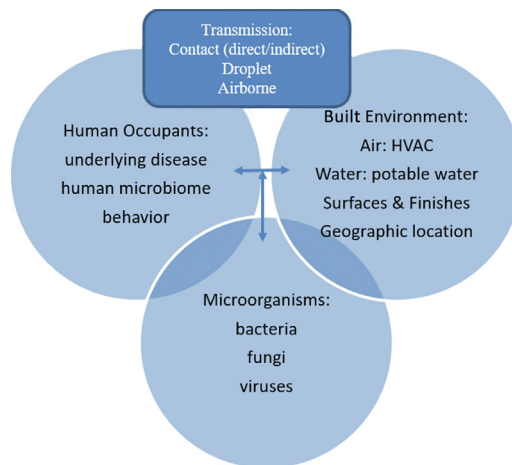
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*This pandemic is right up there as a world-changing event. It has already had a profound impact on society, on basic questions like the nature of our social interactions. It's already shaped and reshaped this particular generation, and the ripple effects are likely to play out for years, perhaps even decades to come.*<sup>3</sup>

Beyond humans, the pandemic also has had a dramatic impact on construction and renovation of health care facilities and likely will lead to increased use of engineering controls, designs, and planning to mitigate risk of exposures between those with possible infection and susceptibles and use of telehealth. This article includes examples of the impact of the COVID-19 pandemic on design and construction of health care facilities and reinforces core strategies that have been shown to be effective in protecting patients, health care personnel, visitors, and others when in these facilities.

The built environment encompasses a broad range of physical design elements, including spaces for care of patients; support services; electronics; patient care and major technical equipment; building systems that provide air, water, and surfaces; and finishes. This spectrum of spaces and surfaces collectively is referred to as the environment of care (EOC). In general, these are less frequently a source of microorganisms causing health care-associated infection (HAI) compared with other sources, such as the patient's endogenous microflora, especially when an invasive device is present, or a from surgical procedure.<sup>4</sup> Carriage of microbes on hands of health care personnel also is a more likely mechanism of exposure to potential pathogens. Even so, the proportional contribution of the EOC as a reservoir of pathogens is estimated at 20%.<sup>5</sup> Over the past several years there have been several studies that find the EOC is a significant source of multidrug-resistant organisms (MDROs), *Clostridioides difficile*, and norovirus.<sup>6</sup> In addition, investigation of the role of EOC has found admission to a patient room previously occupied by a patient with an MDRO or *C difficile* is a risk factor for their acquisition by the next occupant.<sup>7,8</sup>

**Fig. 1** shows the connection between occupants and the EOC. This complex ecosystem influences the risk of transmission of infection between occupants, and the EOC serves as a constant reservoir of microorganisms.<sup>9</sup>



**Fig. 1.** Interrelationship between occupants, environment, and microorganisms. HVAC, heating, ventilation, and air conditioning. (Adapted from National Academies of Sciences. Microbiomes of the Built Environment: A Research Agenda for Indoor Microbiology, Human Health, and Buildings. The National Academies Press; 2017:20.)

Specific pathogens can suggest an environmental source; for example, from demolition of drywall or gaps in maintenance of key mechanical systems, which include *Aspergillus* spp, *Fusarium* spp, *Rhizopus* spp, *Bacillus cereus*, *Legionella* spp, a wide range of gram-negative bacteria, and nontuberculous mycobacteria.<sup>4</sup> When HAIs are caused by opportunistic pathogens it is important to apply key principles such as chain of transmission and the following criteria to determine whether reservoirs are present in the environment and help guide implementation of mitigation strategies, if applicable.

### CRITERIA FOR EVALUATING THE STRENGTH OF EVIDENCE FOR ENVIRONMENTAL SOURCES OF INFECTION

1. The organism can survive after inoculation onto the fomite.<sup>4</sup>
2. The organism can be cultured from in-use fomites.
3. The organism can proliferate in or on the fomite.
4. Some measure of acquisition of infection cannot be explained by other recognized modes of transmission.
5. Retrospective case-control studies show an association between exposure to the fomite and infection.
6. Prospective case-control studies may be possible when more than 1 similar type of fomite is in use.
7. Prospective studies allocating exposure to the fomite to a subset of patients show an association between exposure and infection.
8. Decontamination of the fomite results in the elimination of infection transmission.

Coincident with this 1-year anniversary of the pandemic, the American Society for Healthcare Engineering (ASHE) 2020 Survey of Hospital Construction found increased use of building information modeling and cloud-based collaboration to improve efficiency, control costs, and provide a more nimble design process.<sup>10</sup> Other significant findings included prefabrication of elements of the built environment and using artificial intelligence to assist with design and construction.

From this ASHE survey, funding for new construction decreased slightly from 25% to 19%, investment in infrastructure increased from 18% to 20%, and renovation held steady at about 28%. Most projects involve renovations and expansions (74%) compared with new construction (31%), a trend likely to continue in 2020.<sup>10</sup> Investment in ambulatory care also remained very strong as a reflection of new payment models from agencies such as the Centers for Medicare and Medicaid Services (CMS) and to enhance convenience and access to care. This trend is reflected in the survey that finds more than 26% of hospitals are building or planning to build medical office buildings over the next 3 years, and roughly 22% have ambulatory facilities in the pipeline. Further, the pandemic has logarithmically increased use of telehealth, an essential administrative control measure to remotely triage patients with possible infection and direct them to a secure care location that mitigates risks.<sup>11</sup> CMS's support of response to the pandemic has also prompted the agency to encourage more efficient and safer care using strategies such as so-called hospital at home, when appropriate, and staffing flexibility to allow ambulatory surgical centers to provide greater inpatient care when needed.<sup>12</sup> The goal of the return of patients to continue their recovery at home relieves demand for inpatient beds and likely lessens risks of exposure to pathogens associated with prolonged hospitalization.

The 2020 ASHE survey also found important adherence to infection prevention and control; notably, 62% of projects underway required contractors to complete infection control risk assessments (ICRAs). Twenty-six percent of projects also require

contractors to have Certified Healthcare Constructor credentials, whereas 6% require ASHE's newest certification program, Certified Health Care Physical Environment Worker.<sup>10</sup>

A core strategy to incorporate infection prevention and control into construction and renovation from planning and design through occupancy is through use of an ICRA.<sup>13</sup> It includes tactical decisions to ensure sufficient handwashing stations; alignment of functional planning of involved spaces with heating, ventilation, and air conditioning (HVAC) requirements (eg, number and location of airborne-infection isolation rooms [AIIRs]); and use of physical barriers to contain and confine dust, soil, and contaminants. ICRA has been incorporated into design standards issued by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), and guidelines issued by the Centers for Disease Control and Prevention (CDC) Healthcare Infection Control Practices Advisory Committee (HICPAC) and Facility Guidelines Institute.<sup>4,14,15</sup>

### **A YEAR IN REVIEW: COVID-19 PANDEMIC AND IMPLICATIONS FOR THE FUTURE OF DESIGN AND CONSTRUCTION**

The American Hospital Association published a retrospective on the impact of the pandemic on hospitals.<sup>16</sup> The highlights listed here capture some of the unprecedented impact on health care delivery in the United States:

- Nearly 30 million cases of the virus were identified, with approximately 1.5 million people hospitalized, and more than 530,000 deaths, which have driven a 15% increase in the death rate, making 2020 the deadliest year in US history.
- In 2020, hospitals were projected to lose an estimated \$323 billion, leaving nearly half of America's hospitals and health systems with negative operating margins by the end of 2020.
- Emergency department visits also have experienced a nearly 25% decline from the same time last year, because many Americans remain skeptical of going to the hospital for critical care, such as heart attacks and strokes.

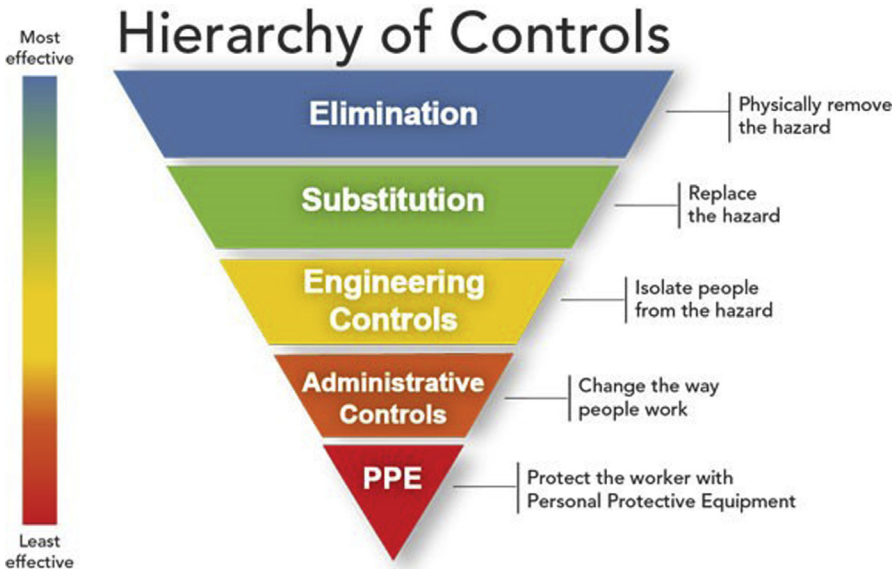
The pandemic triggered activation of emergency operations, most often using the Hospital Incident Command System. SARS-CoV-2 is not the only newly emergent pathogen, nor will it be the last. Rebmann<sup>17</sup> has provided a helpful review of this topic and the essential infrastructure to respond to pandemics and newly emergent pathogens. CDC's National Institute of Occupational Safety and Health (NIOSH) offers an effective framework for prevention and control of hazards, including emergent diseases, that can inform the design and construction of the EOC. This framework, referred to as a hierarchy of controls, is shown in **Fig. 2**. The concept is to give priority to control methods that are potentially more effective and protective than sole reliance on personal protective equipment (PPE).<sup>18</sup>

#### ***Reappraisal of Airborne Transmission from the COVID-19 Pandemic***

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The emergence of SARS-CoV-2 and its modes of transmission has prompted a reappraisal of transmissibility of pathogens through the air.<sup>19,20</sup> In particular the preexisting categorization of transmissibility based solely on the size of the pathogen is imprecise and misleading. Further, the epidemiology of this virus has been particularly difficult to control given that between 30% and 40% of those with infection may be presymptomatic or asymptomatic.<sup>21</sup>

SARS-CoV-2 is thought to spread mainly through close contact from person to person, including between people who are physically near each other (within about 2 m [6 feet]) by respiratory droplets containing the virus that are released by persons with



**Fig. 2.** Hierarchy of controls for safer systems of care. PPE, personal protective equipment. (From Center for Disease Control and Prevention (CDC). NIOSH. Hierarchy of controls. Available at: <https://www.cdc.gov/niosh/topics/hierarchy/>. Accessed 1/15/2021.)

infection when they talk, breathe, sing, cough, or sneeze. There is evidence that, under certain conditions, people with COVID-19 seem to have infected others who were more than 2 m away. These instances often occurred within enclosed spaces that had inadequate ventilation. Contaminated respiratory droplets can also land on surfaces and objects. It is possible that people could get COVID-19 by touching a surface or object that has the virus on it and then touching their own mouth, nose, or eyes. Transmission from touching surfaces is not thought to be a common way that COVID-19 spreads, but it is possible. Scientists from a broad range of disciplines have therefore recommended the following to prevent transmission of this virus, and these also are applicable to other emerging respiratory infections yet to be identified<sup>19</sup>:

- Provide enough and effective ventilation (supply clean outdoor air, minimize recirculating air), particularly in public buildings, workplace environments, schools, hospitals, and aged-care homes.
- Supplement general ventilation with airborne infection controls such as local exhaust, high-efficiency air filtration, and germicidal ultraviolet lights.
- Avoid overcrowding, particularly in public transport and public buildings.

The experience with this pandemic has also prompted some to recommend expansion of standard precautions to include universal pandemic precautions, which will have implications for design and operation of the built environment.<sup>22</sup> For the EOC, for example, it is likely there will be increased consideration to design patient care spaces with capability to activate negative pressure mode in response to presentation of patients with symptoms of undiagnosed respiratory infection. Other strategies under universal pandemic precautions described by Weber and others include source control (masks for all), addition of eye protection for health care personnel during

direct care of all patients, increased level of respiratory protection for aerosol-generating procedures, and screening of all for symptoms of acute respiratory protection before entering facilities.<sup>22</sup>

### ***Implications of Severe Acute Respiratory Syndrome Coronavirus-2 on the Environment of Care***

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CDC has published and frequently updated its infection prevention and control recommendations for this virus.<sup>23</sup> As mentioned previously, use of telehealth and remote triage are effective strategies to minimize exposure to others (under the hierarchy, this would be an example of eliminating the hazard). Examples of administrative controls include screening everyone (patients, health care personnel, and visitors) entering the facility for symptoms of COVID-19 or exposure to others with suspected or confirmed SARS-CoV-2 infection, physical distancing, and source control (wearing masks). All of these have and will influence how the built environment is designed and operated. Highlighted next are engineering controls to contain and remove this virus from the air and that are likely to be effective against other respiratory pathogens.

### ***Engineering Controls for Severe Acute Respiratory Syndrome Coronavirus-2***

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ASHRAE has published several resources, positions, standards, and guidance that involve use of engineering controls and mechanically engineered systems to help prevent and control transmission of this virus. The following points summarize select recommendations from ASHRAE's Epidemic Taskforce<sup>24</sup>:

- Ventilation, filtration, and air cleaning
  - Provide and maintain at least the required minimum outdoor airflow rates (eg, 2 air changes per hour [ACH] of outdoor air) for ventilation specified in applicable codes and standards.
  - Use combinations of filters and air cleaners to achieve minimum efficiency reporting value (MERV) 13 or better for recirculated air.
  - Use only air cleaners for which evidence of effectiveness and safety is clear.
- Air distribution
  - Where directional airflow is not specifically required, or not recommended as the result of a risk assessment, promote mixing of space air without causing strong air currents that increase direct transmission from person to person.
- HVAC system operation
  - Maintain temperature and humidity design set points.
  - Maintain equivalent clean air supply required for design occupancy whenever anyone is present in the space served by the system.
  - When necessary to flush spaces (eg, time to clear contaminants from spaces such as an inpatient room or AIIR after administering an aerosol-generating procedure [AGP]) between occupied periods, operate systems for a time required to achieve 3 air changes of equivalent clean air supply.
  - Limit reentry of contaminated air that may reenter the building from energy recovery devices, outside air intakes, and other sources to acceptable levels.

Soon after the onset of the pandemic, ASHRAE also updated its Position Document on Infectious Aerosols,<sup>25</sup> which calls for the following when designing and operating facilities under a range of occupancy types, including health care:

- Mitigation of infectious aerosol dissemination should be a consideration in the design of all facilities, and, in those identified as high-risk facilities, the appropriate mitigation design should be incorporated.

- The design and construction team, including HVAC designers, should engage in an integrated design process in order to incorporate the appropriate infection control bundle in the early stages of design.
- Based on risk assessments, buildings and transportation vehicles should consider designs that promote cleaner airflow patterns for providing effective flow paths for airborne particulates to exit spaces to less clean zones and use appropriate air-cleaning systems.
- Where a significant risk of transmission of aerosols has been identified by ICRA, design of AIIRs should include anterooms.
- Based on risk assessments, the use of specific HVAC strategies supported by the evidence-based literature should be considered, including the following:
  - Enhanced filtration (higher-MERV filters, better than code minimums, in occupant-dense and/or higher-risk spaces) (evidence level A)
  - Upper-room ultraviolet germicidal irradiation (UVGI) (with possible in-room fans) as a supplement to supply airflow
  - Local exhaust ventilation for source control
  - Personalized ventilation systems for certain high-risk tasks
  - Portable, free-standing high-efficiency particulate air (HEPA) filters
  - Temperature and humidity control
- Health care buildings should consider design and operation to do the following:
  - Capture expiratory aerosols with headwall exhaust, tent or snorkel with exhaust, floor-to-ceiling partitions with door supply and patient exhaust, local air HEPA-grade filtration
  - Exhaust toilets and bed pans (essential)
  - Maintain temperature and humidity as applicable to the infectious aerosol of concern
  - Deliver clean air to caregivers
  - Maintain negatively pressurized intensive care units where infectious aerosols may be present
  - Maintain rooms with infectious aerosol concerns at negative pressure
  - Provide 100% exhaust of patient rooms
  - Use UVGI
  - Increase the outdoor air change rate (eg, increase patient rooms from 2 to 6 ACH)
  - Establish HVAC contributions to a patient room turnover plan before reoccupancy

Because of the potential for increased contamination of the surrounding air and surfaces during care of patients with COVID-19, CDC has recommended placing patients for whom AGPs are needed into AIIRs, if available. Commensurate with this recommendation and response to surges of patients with COVID-19, health care facilities implemented both temporary negative pressure rooms and spaces. This change has also led to more permanent changes to the HVAC system to provide wider availability of AIIRs as well as an ability to run other inpatient rooms in net negative pressure with respect to the adjacent public corridor.<sup>26</sup>

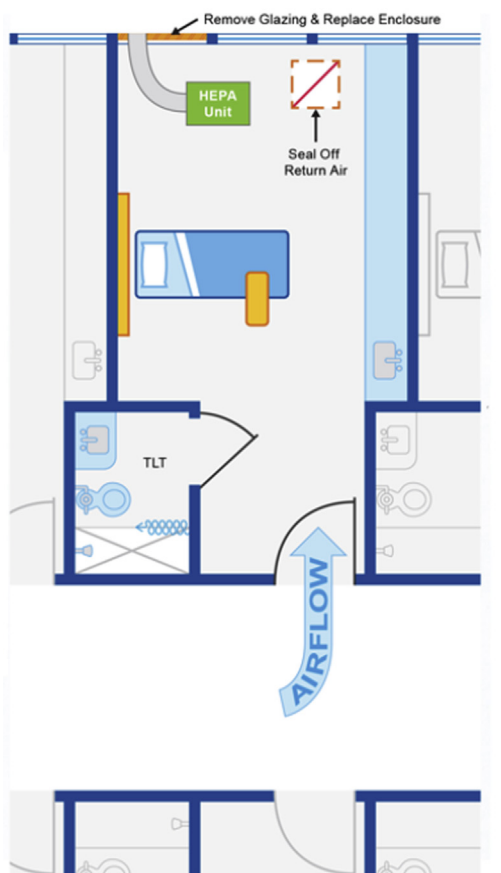
ASHE has recently published guidance on use of HVAC engineering controls to prevent transmission.<sup>27</sup> These controls encompass stations or zones to screen those with symptoms of possible COVID-19, containment in emergency departments, dedicated whole units to care for large cohorts of patients with infection, use of operating rooms during the pandemic, and options for both running temporary AIIRs and converting other rooms or spaces to negative pressure.



**Figs. 3–5** are included in this ASHE resource to enhance containment and removal of infectious aerosols from the patient care area. **Fig. 4** is an outdoor view of a deployment of the configuration in **Fig. 3**, wherein a HEPA unit is deployed inside the room with directed exhaust directly outdoor.

### ***Headwall Ventilation: an Engineering Controls Whose Time has Arrived***

CDC's NIOSH has been working tirelessly to support nationwide response to this pandemic, especially related to respiratory protection of healthcare personnel (HCP) and engineering controls. Notably, NIOSH researchers have published guidance on design and just-in-time deployment of a headwall ventilation system that uses a special inlet system just behind the patient's head for supplemental exhaust at the source that is then removed and filtered with a HEPA fan/filter unit.<sup>28</sup> The ventilated headboard and HEPA system can provide surge isolation capacity in either traditional health care facilities or alternative care sites. The ventilated headboard's improved inlet adopts a local control technique that provides near-instant capture of patient-generated aerosol. The retractable canopy allows for hands-on health care



**Fig. 3.** Use of portable HEPA device to create negative pressure patient room TLT, toilet. (From ASHE. Current/Updated Health Care Facilities Ventilation Controls and Guidelines for Management of Patients with Suspected or Confirmed SARS-CoV-2 (COVID-19), 2021; with permission.)



Fig. 4. Single-patient room negative air configuration through exterior windows.

procedures while still offering protection to attending health care personnel (Fig. 6). This system builds on prior investigations using a design called personal ventilation, which is containment and filtration as close to the source as possible.<sup>29</sup> Although the NIOSH guide is intended for just-in-time deployment, it may be used in the future

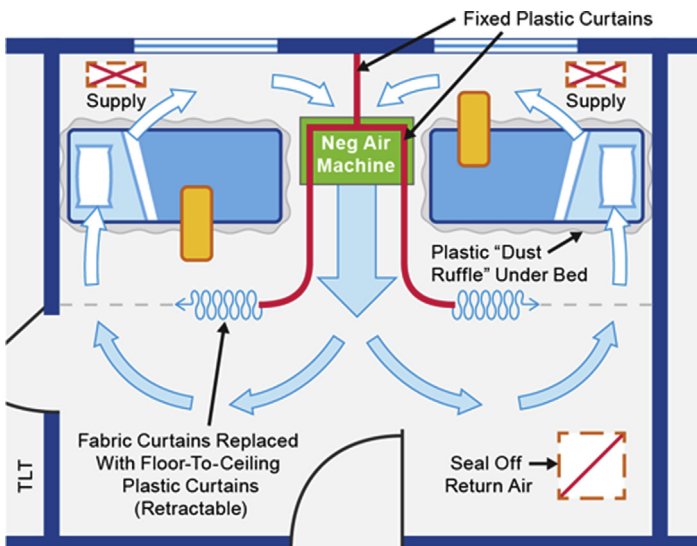
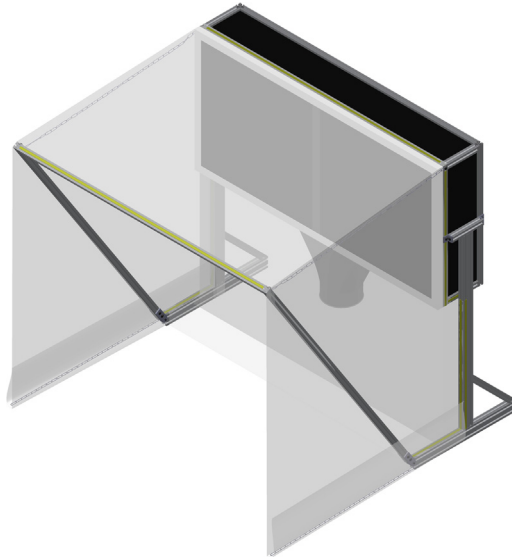


Fig. 5. Multibed zone-within-zone room. For this configuration, the negative air machine, which filters air in the room with HEPA filter, is recirculating filtered air in the same space. This system would be used when it is not feasible to discharge air to outdoors. (From ASHE. Current/Updated Health Care Facilities Ventilation Controls and Guidelines for Management of Patients with Suspected or Confirmed (SARS-CoV-2 (COVID-19).2021; with permission.)



**Fig. 6.** Headwall ventilation. (Courtesy of Ken Mead, PhD, PE, Cincinnati, OH.)

as a more permanent engineering control that designers can use for new construction or renovation of patient care areas. Some aspects that will need to be investigated if this does occur are the location of the ventilated headwall in relation to standard headwall that provides medical gas, suction, monitors and so forth. Also, there will be a need to capture potential contaminants as the bed is lowered or raised for various clinical needs.

### **DISEASE TRANSMISSION RISKS FROM CONSTRUCTION AND RENOVATION**

Both new construction and renovation involving the built environment can disrupt and release potential pathogens into the mechanically engineered systems that provide conditioned air and potable water to facility occupants. **Table 1** lists sources of these based on a comprehensive review of the microbiome of the built environment by National Academy of Sciences<sup>9</sup>:

Kanamori and colleagues<sup>30</sup> summarized outbreaks caused by fungi associated with construction and renovation published between 1974 and 2014. *Aspergillus* spp were the most common pathogens. The investigators described 28 definite outbreaks, with most involving invasive pulmonary aspergillosis, which also carries a high mortality of between 38% and 75%. Sixty percent of these outbreaks coincided with new construction projects, followed by renovation (30%), demolition (6.3%), and excavation (4.7%).

Water supplied to the health care facility is then distributed through an extensive network of plumbing to fixtures such as handwashing stations, ice machines, medical equipment (eg, automated endoscope reprocessors), and utility systems. This distribution network readily supports development of biofilm, and the microbial contaminants embedded in this matrix of extracellular polymeric substances mainly composed of exopolysaccharides, proteins, and nucleic acids protects microorganisms from disinfectants that are otherwise effective against planktonic forms. Stagnant water in this network, often from renovation of areas in the facility that results in redundant lengths of pipework that are left in place and capped, also enhances

**Table 1**  
Sources and reservoirs of potential pathogens in the built environment

Air	Water
<ul style="list-style-type: none"> <li>• Mechanical HVAC systems</li> <li>• Airborne particles that have been aerosolized via HVAC operation, from occupant activities, such as direct patient care or room cleaning, or removal of drywall that has prior damage from water intrusion</li> <li>• Outdoor air that enters through infiltration and natural or mechanical ventilation</li> <li>• Reservoirs in unfinished spaces, such as crawl spaces, basements, and attics, and concealed spaces that are linked to occupied spaces via a range of airflow pathways</li> </ul>	<ul style="list-style-type: none"> <li>• Municipal or well water supplies, harvested rainwater, recycled water, and drinking fountain water</li> <li>• Roof, foundation, and plumbing leaks</li> <li>• Condensation on or in walls and on cold water pipes</li> <li>• Mechanical equipment drain pans, coils, insulation, and filters</li> <li>• Cooling towers and natural or manufactured surface ponds</li> <li>• Hot water storage tanks, with subsequent aerosolization through plumbing fixtures</li> <li>• Aerosolized water from personal hygiene practices (eg, showering, bathing), splash from sink drain, and toilet flushing</li> <li>• Water features, including fountains, pools, hot tubs, whirlpool baths, and spas</li> </ul>

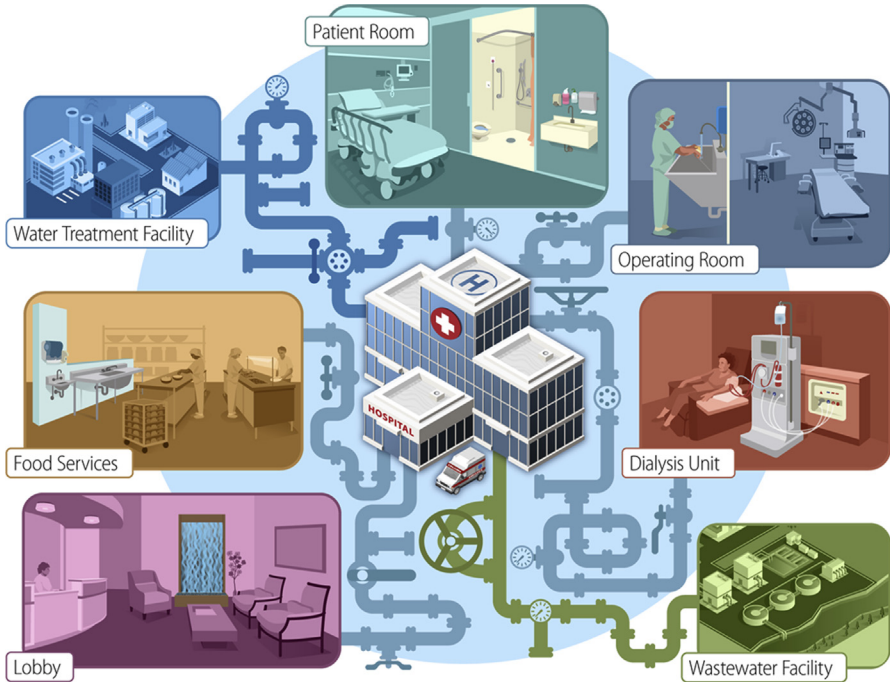
Data from National Academies of Sciences. *Microbiomes of the Built Environment: A Research Agenda for Indoor Microbiology, Human Health, and Buildings*. 2017. The National Academies Press; 2017.

development of biofilm. In addition, disruption of water utility systems during construction or renovation can disrupt biofilm and release contaminants into the water delivery network, posing a possible risk to patients, including those far away from the work area. This connection between occupants of health care facilities and water is shown in [Fig. 7](#):

A recent, extensive review of waterborne disease outbreaks finds that the more susceptible patient populations, such as critically ill, neonates, transplant recipients, surgical patients, and those with hematological disease, are often the sentinel signal of a new cluster.<sup>31</sup> Of late, the types of devices and architectural features that were a source of infections is growing in complexity. That review calls out these outbreak investigations and emphasizes the need to be vigilant for their detection and mitigation:

*...Waterborne healthcare-associated outbreaks and infections continue to occur and were mostly associated with well-recognized water reservoirs as previously described. Moreover, recent studies document electronic faucets (*Pseudomonas aeruginosa*, *Legionella* spp, *Mycobacterium mucogenicum*), decorative water wall fountains (*Legionella*), and heater-cooler devices used for cardiac surgery (*M. chimaera*) as water reservoirs...<sup>13</sup>*

Of 620 consultations involving water as a reservoir of pathogens conducted by CDC investigators, 134 (21.6%) resulted in water-related HAIs or infection control lapses.<sup>32</sup> Nontuberculous mycobacteria were involved in the greatest number of investigations (n = 40, 29.9%). Most frequently, investigations involved medical products (n = 48, 35.8%), and most of these products were medical devices (n = 40, 83.3%). A variety of plausible water-exposure pathways were identified, including medication



**Fig. 7.** Reservoirs and complex interconnectivity of waterborne pathogens. (From Center for Disease Control and Prevention (CDC). Reduce Risk from Water. 9/11/2019. Available at: <https://www.cdc.gov/hai/prevent/environment/water.html>. Accessed 3/20/2021.)

preparation near water splash zones and water contamination at the manufacturing sites of medications and medical devices.

Certain fixtures, such as handwashing stations, although essential for accomplishing hand hygiene, have also been associated with disease outbreaks. Parkes and Hota<sup>33</sup> reviewed reports of outbreaks of hospital sink-related infections, finding that this fixture can be a source of a diverse range of microorganisms that include *P aeruginosa* (most common), Enterobacterales (including those that are multidrug resistant), and nonfermenting gram negatives (eg, *Stenotrophomonas maltophilia*, *Acinetobacter baumannii*, *Elizabethkingia meningoseptica*, *Burkholderia* spp), as well as others such as *Fusarium* and *Mycobacterium mucogenicum*.<sup>33</sup> Design of sinks is an important aspect because some are more likely to disseminate water droplets contaminated with these organisms and there is increasing awareness that the biofilm is present in drains that capture wastewater and contaminate adjacent surfaces and hands of HCP during clinical care. The importance of the microbiome of the drain has been highlighted in a review by Carling<sup>34</sup> of 23 investigations of infection transmission associated with wastewater drains. Most involved multidrug-resistant gram-negative bacteria, and control strategies included attempts to disinfect the drain and its biofilm. Many of these were not successful and this led to replacement of the fixture.

A discussion of water and infection transmission would not be complete without highlighting the risk of water fixtures as a source of exposure to *Legionella* spp. According to the CDC, the number of cases of legionnaires disease in the United States is increasing, and associated mortality is substantial.<sup>35</sup> Gaps in maintenance that

could be addressed with a water management program to prevent legionnaires disease outbreaks were described in 23 (85%) of 27 investigated outbreaks. Outbreaks resulted from a combination of deficiencies, most frequently classified as process failures and human errors. In most outbreaks, inadequate water disinfectant levels and temperatures in the optimal range for *Legionella* growth were observed; implementing a functional water management program consistent with CDC's *Legionella* toolkit and ASHRAE Standard 188 could address these deficiencies.<sup>36,37</sup>

## **PREVENTION BY DESIGN: STRATEGIES TO PROTECT OCCUPANTS AND MITIGATE DISEASE TRANSMISSION**

### ***Infection Control Risk Assessment and Infection Control Risk Assessment Mitigation Recommendations***

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ICRA is the core framework of design and construction and renovation of health care facilities. It is a key element of Facility Guidelines Institute (FGI) guidelines, which are adopted and enforced by authorities having jurisdiction in 42 states in the United States. An ICRA calls for design recommendations and infection control risk mitigation recommendations (ICRMRs) that are applied to the construction, renovation, and facility maintenance projects. Key aspects that ICRA needs to address include:

- Design elements that support infection prevention and control
- Proactive planning for mitigating sources of infection both within and external to the construction project that will be affected
- Identify potential risk for transmission of airborne and waterborne pathogens during construction, renovation, and commissioning
- Develop ICRMRs to mitigate identified risks

The details and steps of ICRA, including a risk assessment matrix and associated risk mitigation tactics, are available elsewhere.<sup>38</sup>

As highlighted earlier, there have been important learnings from published investigations of infection transmission involving the EOC in health care facilities. Some of these elements that benefit from specific focus are highlighted next.

### ***Water Infection Control Risk Assessment***

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A water ICRA (WICRA) is a new adaptation of the traditional ICRA. The cumulative number of outbreaks of waterborne infection has identified the need for and benefit from careful attention and monitoring of water safety both for construction and renovation and as part of ongoing operation of health care facilities. The CDC describes WICRA as a process to assess water sources, modes of transmission, patient susceptibility, patient exposure, and program preparedness to prevent transmission of infection. A tool for conducting the WICRA is available from CDC.<sup>39</sup>

Scanlon and colleagues<sup>40</sup> recently analyzed the literature on risks associated with construction and waterborne infection. They describe that activity “associated with the most waterborne disease cases and deaths was inadequate commissioning of the building during beneficial occupancy (i.e., while preparing for the building opening to the public).” In addition, gaps in prevention strategies were identified, and they identified several risk factors that can be modified when construction or renovation is undertaken.

### ***Specific Elements of Designing in Prevention***

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#### ***Handwashing station design features***

- Basins should reduce risk of splashing and be made of porcelain, stainless steel, or other solid-surface material.<sup>15</sup>

- Basin size and depth of no less than 929.08 cm<sup>2</sup> (144 square inches) with 22.86-cm (9-inch) width or length is recommended.
- Sealed to prevent water intrusion into supporting cabinet, wall, and countertop.
- Install barriers (eg Plexiglas) to prevent splashes of contaminated water droplets to adjacent surfaces, especially if these are used for aseptic work such as medication preparation.
- Discharge of water from faucet spout is at least 25.4 cm (10 inches) above the bottom of the basin to prevent water stream from dropping directly into drain. In addition, the drain location should be offset so that it is not directly below the water outlet.
- Water pressure in station fixture is regulated.
- Allows controls for sink fixture to be wrist blade, single lever, or sensor activated.

**Water feature: not allowed<sup>15</sup>**

Decorative water features have been a popular element of design. These features are also referred to as decorative fountains and have an open reservoir through which water is recirculated on a continuous basis by a submerged pump. However, there have been several outbreaks of legionnaires disease associated with them. The FGI guidelines strongly recommend against inclusion of this element in any planning phase. In lieu of the difficulty in mitigating contaminants in water features, even with preventive cleaning and disinfection, facilities teams are advised to decommission this architectural feature.

**Inpatient room design, surfaces, and finishes**

There is a significant risk of acquisition of pathogens such as MDROs or *C difficile* related to infection or colonization in the room's prior occupant as after as long as 3 weeks.<sup>8</sup> However, this contamination can be removed with attention and focus on thorough cleaning and disinfection of surfaces in the room that are touched with high frequency when combined with real-time feedback.<sup>41,42</sup>

The evidence that MDROs can persist in the environment for prolonged time, as described earlier, in combination with observed efficiency of cross-transmission of these in multibed rooms, has led to a preference for single-patient rooms. This design also enhances safety related to a variety of other potential harms, supports patient privacy, and lessens disruption from ambient noise.<sup>43</sup> Newer models of room design have identified opportunities to lessen risk of transmission of *C difficile* and other MDROs. These designs include introduction of improved handwashing stations, and expanded HVAC infrastructure to increase the area of relative humidity control and increase the number of negative pressure rooms.<sup>44,45</sup>

**Heating, ventilation, and air conditioning.** HVAC is a building system that is designed to provide comfort, support aseptic procedures, remove contaminants from air, and deliver an acceptable indoor air quality. FGI 2018 guidelines include the ASHRAE 170 standard for design of HVAC for health care facilities.<sup>14,15</sup> This standard provides a wide range of parameters for HVAC systems that supply patient care, procedural (eg, surgery suite), and support areas. Parameters included in ASHRAE 170 include air changes per hour, design temperature and relative humidity ranges, and pressure relationships to adjacent areas.<sup>14</sup>

**Universal or acuity-adaptable and single-occupancy patient care rooms.** FGI commissioned a systematic review of available evidence on the value of single-patient rooms,<sup>43</sup> which found suggestive, albeit low-quality, evidence that this prevents infection and improves overall patient safety and experience of care. The addition of

adaptability of these based on the patient's need also is worth considering. Additional elements for adult intensive care units have been described elsewhere and support this need for flexibility to accommodate changes in care practices and advances in technology.<sup>46</sup>

**Airborne-infection isolation room.** Planning for AIIR has increasingly taken center stage under the pandemic of COVID-19, and earlier in this article there are examples of new design features, including ventilated headwalls, that are likely to be incorporated into new construction and renovation.

**Protective environment room.** Protective environment (PE) rooms are designed to provide HEPA-filtered air to rooms used to care for patients who are severely immunocompromised (eg, solid organ transplant patients or allogeneic neutropenic patients). These rooms need to be designed to ensure that they are well sealed by maintaining ceilings that are smooth and free of fissures, open joints, and crevices; sealing walls above and below the ceiling; and, once occupied, to monitor for leakage. Additional details are available elsewhere.<sup>4</sup>

## OPERATIONAL ASPECTS OF PRECONSTRUCTION AND INTRACTION PROJECTS

### *Environmental Containment at Point of Work*

**Figs. 8** and **9** provide examples of containment within the facility. Buchanan and colleagues<sup>47</sup> recently investigated the efficacy of this type of containment and found this containment significantly reduced the potential for aerosolization of pathogenic fungi, especially in above-ceiling spaces with high levels of fungi.



**Fig. 8.** Portable containment device for above-ceiling work. (From Olmsted RN. Prevention by Design: Construction and Renovation of Health Care Facilities for Patient Safety and Infection Prevention. *Infect Dis Clin North Am.* 2016 Sep;30(3):713-28; with permission.)





**Fig. 9.** Barrier separation and containment of active construction zone from occupied areas. (From Olmsted RN. Prevention by Design: Construction and Renovation of Health Care Facilities for Patient Safety and Infection Prevention. *Infect Dis Clin North Am.* 2016 Sep;30(3):713-28; with permission.)

### TRAINING OF CONTRACTORS

Orientation and training of contractors and subcontractors that provide the talent to fulfill designs is an important and critical element of the ICRA process. Mousavi and colleagues<sup>48</sup> surveyed construction companies working on projects in health care facilities and found that 52% of owners (of the organizations contracting for the projects) always or often required the contractor's personnel to receive training. However, the recipients of these training modules most often were upper management personnel, not the employees providing the direct labor to install and build the work. Fifty-nine percent of respondents indicated that ICRA training was provided before the construction project and then every 6 (7%) or 12 (21%) months thereafter. Clearly these findings highlight the need for training to reach front-line contractors and subcontractors who are implementing ICRMRs throughout the project. There are several organizations that provide comprehensive training for contractors (see the resources listed later).

### SUMMARY

The COVID-19 pandemic has left, and continues to leave, an indelible impact on delivery of care. Its prolonged trajectory will significantly influence design and construction of health care facilities. Some notable developments to date include dramatic increase in use of telehealth, innovative alternative models of care such as hospital at home, and emphasis on source control and physical distancing. Mechanical systems for delivery of conditioned air will increasingly be relied on to remove contaminants from patient care areas, and there are many projects in progress that are designed to increase use of negative pressure.

Infection prevention and control is an essential component of the built environment. When absent or there are disruptions, risk of exposure of patients and disease outbreaks often result. However, there are well-established, evidence-based guidelines to assist infection preventionists and health care epidemiologists with identifying strategies for prevention in collaboration with the multiple disciplines involved in construction and renovation.<sup>4,15</sup> The ICRA remains the keystone of designing in prevention at the inception of the concept of a project through the completion and commissioning phases. Future trends in care delivery in the United States, are going to have a significant impact on construction and renovation of health care facilities; however, involvement and subject matter expertise provided by infection preventionists/health care epidemiologists will remain a core component now and into the future.

## CLINICS CARE POINTS

- The SARS-CoV-2 pandemic has affected, and will continue to affect, construction and design of health care facilities. As such, the role of infection preventionists and health care epidemiologists has grown in importance in planning for construction and renovation of the built environment in health care facilities to design the environment for an ability to ensure adequate ventilation and containment of emerging respiratory infections.
- Infection preventionists and health care epidemiologists are key stakeholders in planning for construction or renovation; notably, this engagement needs to be early and often because it is common to encounter unexpected work in progress that involves changes in the EOC.
- Establish effective awareness for routine operations work by facility maintenance, information technology, and contracted personnel; for example, work orders for repairs, running cables above dropped ceilings.
- Ask about ICRA training for contractors and subcontractors to ensure this training has not been limited to supervisory personnel.
- Expand risk assessment to include focus on the potable water system because this engineering also is an important reservoir of potential pathogens.

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#### **ADDITIONAL RESOURCES**

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