HIGH-PRESSURE STAKES: HEALTHCARE HVAC DESIGN & PRESSURIZATION IN RESPONSE TO COVID-19
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Now, more than ever, the state of air and airflow’s acute relationship to the spread of airborne diseases matters. But, how do we prepare ourselves and equip our healthcare facilities with the mechanical systems that ensure safety for patients and healthcare workers and help eliminate the spread of disease via air transmission?

In light of the COVID-19 global pandemic, hospitals and healthcare facilities are looking for solutions that help prevent the spread of airborne infectious diseases. As with other airborne infectious diseases, engineering and mechanical systems are noble tools in the fight against airborne infections in controlled environments. Although mechanical systems, airflow, and pressure relationships are part of the larger picture in preventing the spread of airborne diseases in a healthcare facility, the solutions devised must embrace a full collaboration with scientists, architects, and healthcare professionals to maintain a safe and healthy environment of care.

Engineers are uniquely positioned to understand a building’s design and operational states and can help mitigate vulnerabilities and develop strategies to repair, adjust, and adapt to support new requirements through mechanical system planning. This role is key in reducing disease transmission in healthcare facilities, but what are the implications of these mechanical design adaptations or changes and how are they implemented?

In controlled healthcare environments, airborne infectious disease transmission can be reduced using various methods: dilution ventilation, directional ventilation, in-room airflow regimes, room pressure differentials, personalized ventilation, source capture ventilation, filtration, and ultraviolet germicidal irradiation (UVGI). Specifically, well-designed and maintained HVAC systems with supplementation filtration, UVGI, and additional ventilation rates, including the total air change rate and the fraction of air that is ventilation or from the outside, are key. Such systems separate high-risk areas, have upgraded filtration and increased ventilation (even as high as 100 percent outside air), and can humidify air (ASHRAE, 2020). When dealing with airborne infectious diseases, the state of air has a high-pressure stake in the fight against the overall spread. Specifically, negative pressurization strategies play a key role in stopping the spread of airborne infectious diseases within a healthcare facility.
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HVAC & Negative Pressure

Typically, Airborne Infection Isolation Rooms (AIIR) are used to keep patients isolated in ideal states for recovery without air recirculation into other parts of the hospital, eliminating further contamination and keeping conditioned air from these spaces from mixing with air in other parts of the hospital.

However, most hospitals have a limited number of dedicated AIIR rooms to treat patients for diseases that have high infectious rates. During an airborne infectious disease pandemic, the need for these rooms in response to the surge of patients requiring acute care can become astronomical, putting pressure on hospital staff to find safe spaces for infected patients. By placing patients in AIIR rooms, the virus cannot migrate to the HVAC system and hallways and expose others.

For patients with an infectious disease such as COVID-19, the Centers for Disease Control and Prevention (CDC) advises placing them in an AIIR room. At negative pressure, the air for the room is pulled from other sections of the hospital and is then exhausted outside, protecting the safety of others in the hospital as well as the hospital environment.

The CDC recommends that these patients should not be placed in rooms where the air is recirculated within the building without High Efficiency Particulate Arrestance (HEPA) filtration (CDC, 2019). Most hospital air is conditioned and recirculated, relying on dilution and filtration for protection. However, during a pandemic with a highly infectious airborne disease, further precautions need to be taken. For example, since COVID-19 has primarily been transmitted through respiratory droplets and contact routes, filtration is important in blocking the droplet nuclei — various filters can block a significant range of micron sizes.

The current COVID-19 situation is causing healthcare facilities to address fear, concern, and panic over how spaces should be controlled. With great implications, healthcare facilities are turning to their HVAC systems to deduce if reconfiguration of mechanical systems can help lead to better patient outcomes. Facility engineers are being asked to accommodate requests to modify air flows and adjust pressure relationships in an effort to react to the new paradigm and its requirements. But, HVAC systems are dynamic, complex, and designed with intent. Changes in one area or wing of the hospital can affect the entire hospital’s airflow balance.

ASHRAE & Airborne Infectious Diseases

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) recommends exceeding their standard measures and guidelines in preparation of an airborne infectious disease outbreak. Based on previous airborne infectious disease trends in the past, an airborne infectious disease pandemic has been a perceived threat for many years. During a pandemic, there are many implications for the design, installation, and operation of HVAC systems — and as a result, HVAC operators and professionals have been thrust onto the frontlines.

These HVAC operators and professionals play a part in reducing disease transmission. In some cases, these operators are asked to make changes to air flows or other HVAC parameters that can possibly have far-reaching impacts to the building’s air system and pressure balances. These changes should not be made without consultation of the proper engineering input.

Regarding HVAC systems, transmission is defined as cross transmission or person-to-person transmission by small airborne particles that contain microorganisms. Small airborne particles are generated through coughing, sneezing, shouting, or talking. HVAC systems may contribute both to the transmission of diseases and to the reduction of transmission risk if operated improperly or used for a purpose they were not designed (ASHRAE, 2020).

A Focus on Design

Healthcare facilities are specifically designed from an architectural and HVAC perspective to mitigate the transmission of airborne infectious diseases. However, most infections are transmitted in ordinary occupancies in the community and not in industrial or healthcare occupancies. Although the implications of transmission in other types of facilities is important, our expertise is our ability to create HVAC and mechanical systems that mitigate the spread in hospitals and healthcare facilities (CDC, 2007, 2019).

HVAC system designers can assist architects and plumbing engineers to understand other sources of unplanned airflow that can impact airborne infectious disease transmission. Specific design features that control airborne infectious disease transmission through HVAC systems are ventilation rates, airflow regimes, filtration, and UVGI.
Per ASHRAE, the ventilation and air-cleaning strategies that HVAC professionals can employ are: supplying clean air to susceptible occupants, containing contaminated air and/or exhausting it to the outdoors, diluting the air in a space with cleaner air from outdoors and/or by filtering the air, and cleaning the air within the room (ASHRAE, 2020).

With highly infectious airborne diseases, in-room flow regimes and differential room pressurization — which are important for controlling airflow between areas — play an even bigger part in outbreak control.

**Guidelines & Standards for Environmental Infection Control in Healthcare Facilities**

Consistently implemented infection control strategies and engineering controls can help decrease the transmission of airborne infectious diseases in healthcare facilities. With the goal of providing a safe environment for quality healthcare, HVAC systems in healthcare facilities are designed to maintain the indoor air temperature and humidity, control odors, filter particles, remove contaminated air, facilitate air-handling requirements, and minimize the risk for transmission of airborne pathogens (CDC, 2007, 2019).

The control of air pollutants, i.e., microorganisms in this instance, is the most effective way to maintain clean air. Typically, healthcare facilities use recirculated air, but with airborne infectious diseases, recirculated air without extensive filtration is cause for further transmission. Southland has specialized in the implementation of unique designs that leverage 100 percent outside air with heat recovery, which significantly improves air quality while maintaining energy efficiency.

Per code, hospitals are required to have a small number of AII rooms, but with a surge of COVID-19 patients, the need for negative pressurization rooms can exceed the availability. To address the amplified need for AII rooms, the partnership between overall engineering, facility engineers, and infection control is put into greater use to stop the transmission of airborne infectious diseases from one room to another.

During a pandemic this partnership is tested, and complete cooperation is required to efficiently address transmission concerns. As solutions are devised to adapt, it is critical that any changes made are done with a clear awareness of how the room design (e.g., an operating room, emergency exam room, patient room, etc.)
connects to the HVAC design and how the design supports the safety of the occupants. When planning for changes, the constraints that exist in HVAC systems (fan design, air flows, duct pressure drop) and the building management systems that control them must be considered. In addition to this partnership, non--HVAC strategies such as physical distancing and other scientific approaches are necessary in fighting against airborne infectious diseases.

Backed with the guidelines, recommendations, and expertise, how do HVAC professionals use mechanical systems to counter-attack airborne infectious diseases? Engineers can play a key role in reducing disease transmission in healthcare facilities in normal times and as part of emergency response in mitigating vulnerabilities and developing quick interventions.

The ASHRAE 170 standard defines the requirements and provides key guidance on the ventilation needed for healthcare industry facilities. These requirements help engineers enable mechanical systems to effectively provide the correct number of air changes in the right places with the proper ventilation and the correct level of filtration.

### Humidity Ranges to Control Viruses

Some HVAC systems are designed specifically to control indoor humidity and temperature, which can in turn influence transmissibility of infectious agents. These systems are designed to maintain humidity in a specific range (e.g., 30 percent–60 percent) through the use of properly designed cooling systems in coordination with humidification equipment.

It is possible that controlling relative humidity (RH) can reduce transmission of certain airborne infectious organisms (Eisenhower, 2020). ASHRAE 170 provides

<table>
<thead>
<tr>
<th>MERV Rating</th>
<th>Air filter will trap air particles size .03 to 1.0 microns</th>
<th>Air filter will trap air particles size 1.0 to 3.0 microns</th>
<th>Air filter will trap air particles size 3 to 10 microns</th>
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<th>Removes these particles</th>
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<tr>
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<td>70% – 85%</td>
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Source: Illustration by LakeAir/www.lakeair.com

**MERV Chart**
recommendations by space type for the control of relative humidity. The idea of operating with a minimum RH of up to 40 percent, which is higher than current ASHRAE 170 standards is being greatly discussed by many industry professionals. With an evolving health situation, definitive conclusions have yet to be made regarding humidity and the transmission of airborne infectious diseases across the industry.

An Engineered Response

In unprecedented times, it is difficult to discern the outcome of each action, but as healthcare providers turn to engineers for help, our industry is key in helping control the transmission of airborne infectious diseases via airflow in healthcare facilities.

But, during a pandemic, how can we quickly and effectively respond to the urgent needs of patients and healthcare workers?

Healthcare providers request changes to the pressure relationships between rooms and changes to air change rates for specific areas including operating rooms, patient rooms, emergency room exam bays, and more. Specifically, many hospitals have requested increasing air change rates because there is a required wait time after an infected patient occupies a space for the ventilation system to “clean the air” before the space is sanitized and available for the next patient. This is especially critical in emergency departments where it can be a rate-limiting activity for patient throughput. Engineers and HVAC professionals offer safe, efficient, and fast solutions, focusing on return air paths and air change rates, which are critical.

Proposed Solutions

For operating rooms conforming to ASHRAE 170 filtration guidelines, systems can operate with a return or up to 100 percent outside air and be positively pressurized. The infectious diseases are controlled via the air path and return air. Southland has implemented many systems designed around the use of 100 percent outside air with heat recovery, which provides significant advantages and flexibility when there is a need react to changing requirements and to ensure that the return is never mixed with the supply air.

Southland has been approached during the pandemic regarding converting existing operating rooms to be negatively pressurized. Although costly, this is possible through the addition of a vestibule and reconfiguration of the rooms’ HVAC design to facilitate the proper pressure cascade between corridor, vestibule, and operating room. A recommended alternative solution is to rebalance the operating room(s) in question to a slightly positive state, which maintains the original operating room design intent while minimizing impact to adjacent spaces.

For patient rooms conforming to ASHRAE 170, systems can be return or up to 100 percent outside air. The patient rooms can be negative or neutrally pressurized with infectious disease control via the air path and return air. Key considerations are the return air path and infection boundaries.

For emergency department exam rooms, across the industry, professionals are still discussing the best way to implement airflow changes to create an infection boundary for airflow and return path. By looking closely at the existing controls and air system design and performance by space, it is in many cases possible to rebalance systems to ensure it is configured optimally, providing air flow where it is most beneficial such as in exam and triage areas.

There are many alternative solutions that can be implemented and there isn’t a one size fits all solution for every hospital. For example, a hospital’s fundamental HVAC design may facilitate dedication of an entire wing or flow as an isolation area with limited redesign and proper controls. Since every hospital is unique in its design, it is vital that the proper solution be uniquely engineered to satisfy the specific set of requirements and the overall needs of the facility, workers, and patients.

A Step Forward

In the midst of a pandemic, it’s hard to see beyond the frontlines. Although mechanical systems and airflow management are not visible fighters against airborne infectious diseases, they are still a tool in helping healthcare workers and facilities prevent further transmission and provide clean air. With an uncertain timeline and so many unknowns, the way forward may not be entirely linear, but responsible, quick, and safe engineering responses can support healthcare workers and facilities as well as patients.
About the Authors

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As the Director of Project Development and Engineering for Southland Energy, Eric Nyenhuis is responsible for the technical development of energy projects, including coaching and leading project developers, energy engineers, and measurement and verification specialists. By providing strategic support to Southland’s business development organization regarding strategies, markets, and specific project opportunities, Mr. Nyenhuis ensures that each team member is equipped to approach client’s of varying market segments and develop innovative solutions that deliver long-term value.

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As a Senior Mechanical Design Engineer, Joshua Fait leads Southland Engineering project teams by delivering cost responsible solutions that are innovative, constructible, and maintainable. With extensive experience in healthcare engineering, energy efficiency, and integrated project delivery, Mr. Fait is able to help Southland Engineering strategically bring complex engineering solutions to market and meet clients’ business and energy goals.

References


Recommendations:

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