The Wells-Riley Equation and COVID-19: Reducing Risk in Indoor Environments

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Disclaimer

The AEE Utah Chapter is composed of engineers and professionals in the energy management community. While we are experts in HVAC, we are not a medical institution and do have the authority of the CDC or the doctors, epidemiologists, and countless medical professionals studying and fighting the disease. While we are confident in the research reviewed and the views presented in this document, we strongly recommend reviewing and implementing the guidelines presented by ASHRAE, CDC, local government, and other reputable organizations.

TL;DR

- Using the Wells-Riley equation and medical research, the probability of an individual with COVID-19 infecting a healthy individual inside of a commercial building via the HVAC system can be estimated.
- To reduce the contribution of the HVAC system to the probability of infection, the ASHRAE recommendations of increasing ventilation and improving filtration to at least MERV-13 are validated by this equation.
- The risk is halved while wearing a mask. If both the sick and healthy individuals are wearing masks, this reduces risk by a factor of 4. Alternatively, wearing masks could reduce the minimum recommended ventilation rate.
- These estimates are only valid in well-ventilated rooms where social distancing of 6 feet and proper surface sanitization procedures are observed. As more research is performed, more accurate estimates will be made.
- While staying at home is still the safest option, proper HVAC modifications in conjunction with mask-wearing, distancing etiquette, and a comprehensive safety plan can help reduce the risk of becoming sick.

The coronavirus is with us for the long term

As the global coronavirus pandemic has stretched into months, it has become increasingly clear that this virus may be with us for the long term. In order to return to some of our normal activities, it has become increasingly important to modify our behaviors to help reduce the spread of the virus. While it is well understood that we should be wearing masks and social distancing, aligning with recommendations from the CDC and local government, one more contentious topic, at least within scientific communities, is the role of HVAC in the spread of the virus **[1, 2]**. While studies are still ongoing and likely will be for months and years, ASHRAE, the leading authority on the HVAC, has taken a more proactive approach in considering the role of HVAC in the spread of COVID-19. ASHRAE prepared the following statements regarding the pandemic:

"*Transmission of SARS-CoV-2 through the air is sufficiently likely that airborne exposure to the virus should be controlled. Changes to building operations, including the operation of heating, ventilating, and air-conditioning systems, can reduce airborne exposures…*
"*Ventilation and filtration provided by heating, ventilating, and air-conditioning systems can reduce the airborne concentration of SARS-CoV-2 and thus the risk of transmission through the air. Unconditioned spaces can cause thermal stress to people that may be directly life-threatening and that may also lower resistance to infection. In general, disabling heating, ventilating, and air-conditioning systems is not a recommended measure to reduce the transmission of the virus*" **[3]**.

With these considerations, it is prudent to review the capabilities of a building's HVAC system and implement the modifications recommended by ASHRAE to help reduce the spread of the coronavirus **[3]**. However, as more information has become available, it has become possible to quantify how much the HVAC system can contribute to the spread of the virus via the well-understood Wells-Riley equation.

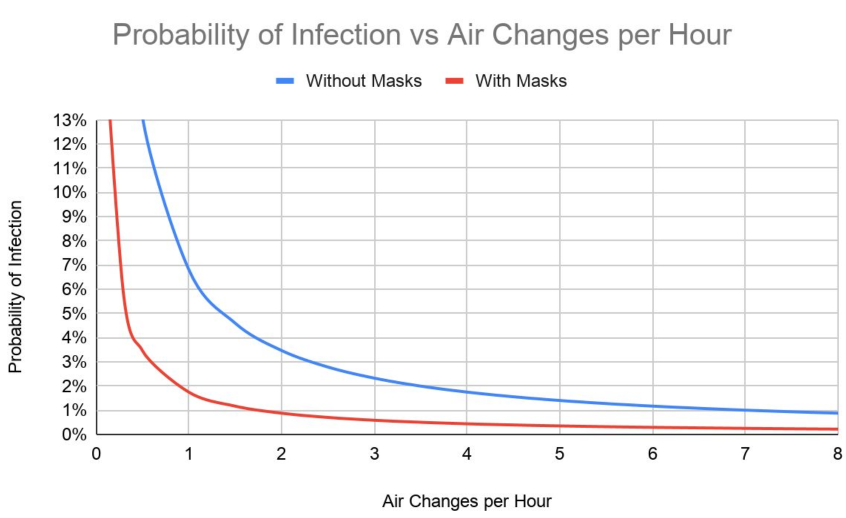
What is the Wells-Riley Equation?

The Wells-Riley equation, derived in 1978, was initially used to model measles outbreaks in schools **[4]**. While it has many shortcomings, this approach is well suited at this point in the coronavirus pandemic. The Wells-Riley equation "provides a simple and quick assessment of the infection risk" and "implicitly considers many influencing factors, which provide convenience for risk assessment" **[4]**. Simply put, by inputting the airflow delivered by the HVAC system and for a given length of exposure time, the equation can calculate the probability of infection for a healthy individual in a defined space. For this article, the equation takes on the form as follows:

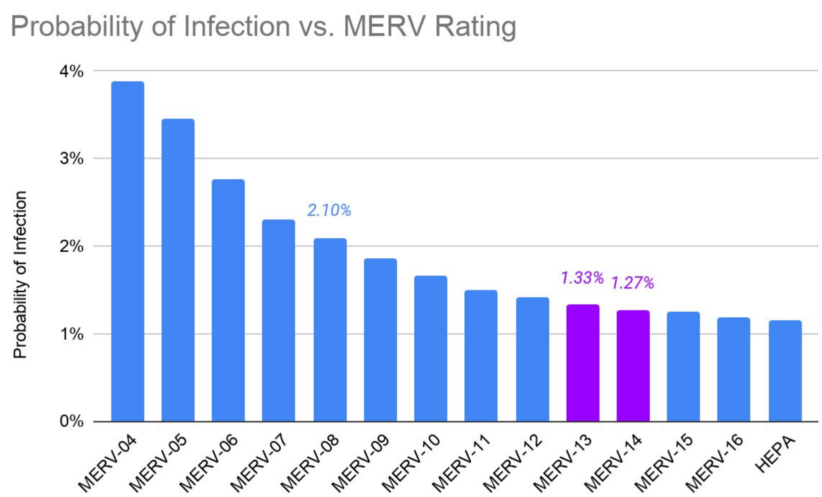
$$P = 1 - e^{-\frac{Ipqt}{Q}}$$

$$P = Probability\ of\ infection$$
$$I = Number\ of\ infector\ individuals$$
$$p = Breathing\ rate\ of\ individuals$$
$$q = Quanta\ generation\ rate$$
$$t = Exposure\ time$$
$$Q = Air\ flow\ rate\ from\ HVAC\ system$$

The first consideration when using the Wells-Riley equation is the availability of the quanta generation rate, *q*. Currently, there is not enough known about this coronavirus to explicitly calculate *q*, but it can be estimated by using the reproductive value, *R* **[5]**. By comparing the *R*-value of viruses with known *q* values to the *R*-value of this coronavirus, the quanta generation rate can be estimated to fall between 14 and 48 1/hr **[6]**. This value represents the number of infectious doses a sick individual exhales every hour **[7]**. Using this information, it becomes possible to estimate the probability of infection for individuals within a defined space. It can be applied to whole buildings or individual rooms. The equation's most significant shortcoming comes from only considering airborne particles as a pathway to infection, not accounting for fomite transmission, or even non-aerosolized respiratory droplets, which are both very important with this coronavirus. While more rigorous models do exist that will give us a more accurate estimate in the future, not enough information is known about this coronavirus at this time **[8]**.



One ASHRAE recommendation to reduce the spread of COVID-19 is to increase the ventilation rate. This graph shows the probability of infection for different air changes per hour, both with and without a masking policy. These numbers are for a typical office environment for a building size around 20,000 ft^2. While increasing the ventilation rate is important, the only way to economically reduce the probability of infection in an economic way is to enforce a masking policy for every individual in the building.



The other ASHRAE recommendation is to upgrade the air filters to at least MERV-13, or MERV-14 if possible. This graph shows the probability of infection for different MERV filters for the same building size as before. For many existing installations, upgrading to MERV-13 or 14 could reduce the probability of infection by half. Upgrading beyond MERV-14 can be beneficial but will see diminishing returns. For systems where the filters cannot be upgraded to MERV-13, moving to the highest compatible MERV rating can still contribute to reducing risk.

Preparing for the Future

The COVID-19 pandemic will likely be with us for months to come, and as more businesses and schools attempt to return to normal operations, creating and maintaining a safety plan is more important than ever. The CDC, ASHRAE, and many other agencies have several recommendations that should be reviewed and implemented. The most vital aspects of these safety plans include wearing masks, social distancing, contact tracing, and staying home while feeling sick **[9, 10]**. The purpose of using the Wells-Riley equation at this stage of the pandemic is to help building operators understand the contribution of the HVAC system to the overall risk of spreading the disease and the utility of different strategies, such as increasing the ventilation rate or improving the filtration, in decreasing that risk. Due to the generalized form of the Wells-Riley equation and the ongoing research into the coronavirus, the number should be taken with a few large grains of salt. This approach is best used to validate modifications to the HVAC system as one part of a comprehensive safety plan.

Sources

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