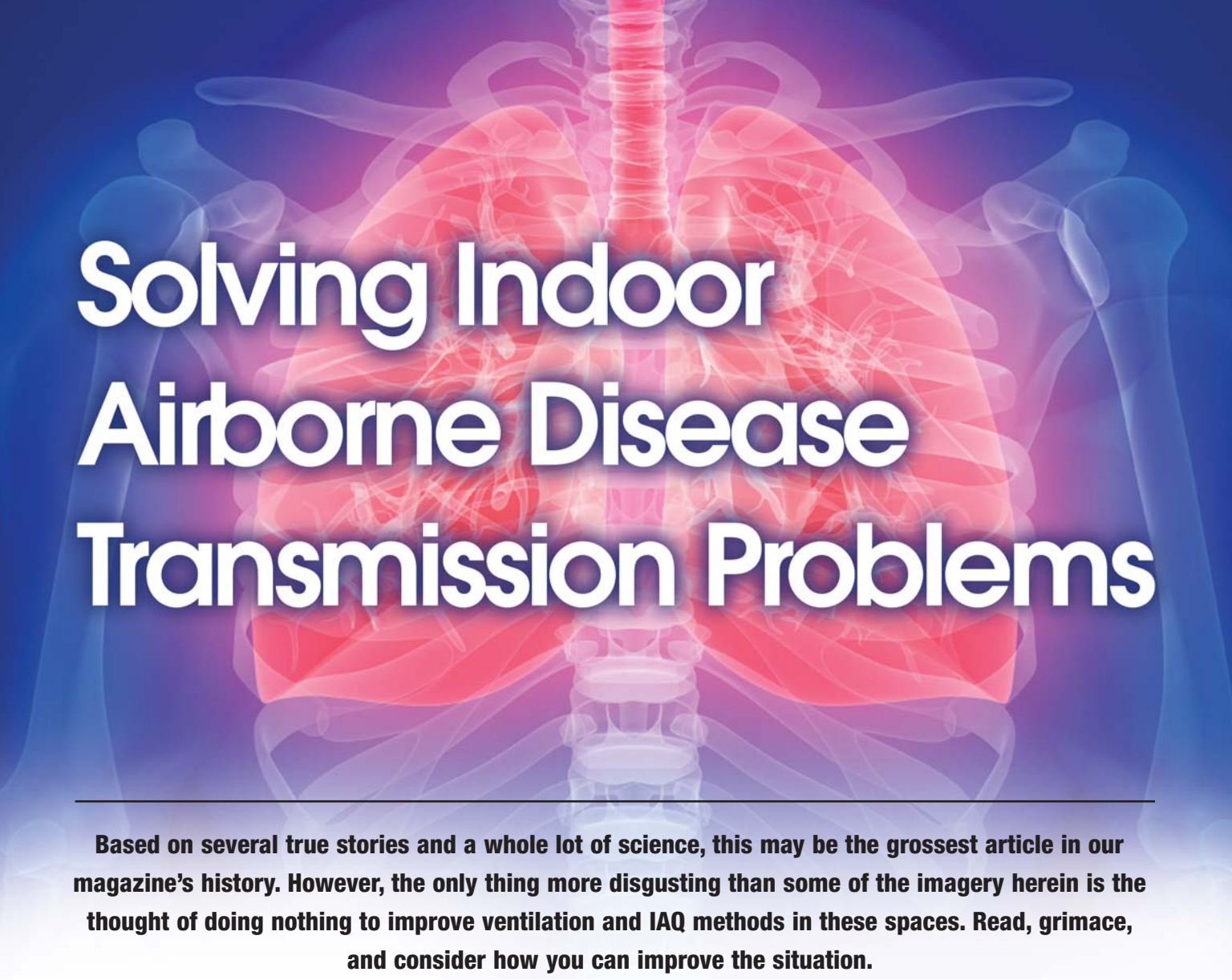

Solving Indoor Airborne Disease Transmission Problems

Based on several true stories and a whole lot of science, this may be the grossest article in our magazine's history. However, the only thing more disgusting than some of the imagery herein is the thought of doing nothing to improve ventilation and IAQ methods in these spaces. Read, grimace, and consider how you can improve the situation.

STEVEN WELTY LEED®, AP, CIE, CAFS

MRSA, C-Difficile, and Norovirus are floating around your hospital and won't stop infecting your patients, staff, and even visitors with those dreaded hospital-acquired infections (HAIs). Your infection control people have hit a brick wall and can't stop the infection rates nor prevent periodic outbreaks that can last several months. The hospital's CFO is tearing his hair out because major insurance companies and Medicaid/Medicare are no longer reimbursing for HAIs. Ouch. By focusing on what impact HVAC systems, pressurization, filtration, and sterilization technologies can have on airborne germs, you can proactively (or reactively) address these problems. There are rather simple explanations to previously flummoxing airborne disease problems, so relax and read on.

AIRBORNE MRSA, C-DIFFICILE, AND NOROVIRUS: THE FEARSOME THREESOME

The pestilences swarming hospitals worldwide are ever-mutating super-bacteria like Methicillin Resistant Staphylococcus Aureus (MRSA) and Clostridium-Difficile (C-Diff). Norovirus (NV) is a highly infective virion (virus0, and studies have shown that you only need one NV virion to get infected. Many infection prevention specialists continue to be thwarted in reducing these pathogen's infection rates because the current guidelines are to wash your hands and wear gloves and a gown in order to have protected contact with patients, both of which do not directly address airborne disease transmission.

The critical questions to slice and dice on airborne disease transmission are:

- How do infected humans shed bacteria and virions?
- How do germs like MRSA, C-Diff, and NV become airborne?
- How do humans breathe in these germs to make them sick?
- How do toilet flushes aerosolize these germs?
- How do airborne germs move between rooms?
- What technologies and strategies are available to help drive down airborne infections rates?

WASH OR SANITIZE YOUR HANDS

On June 3, 2009, I briefed1 the EPA's Federal Interagency Committee on Indoor Air Quality2 and showed how the pandemic H1N1 airborne influenza flu virions can easily land in your lungs

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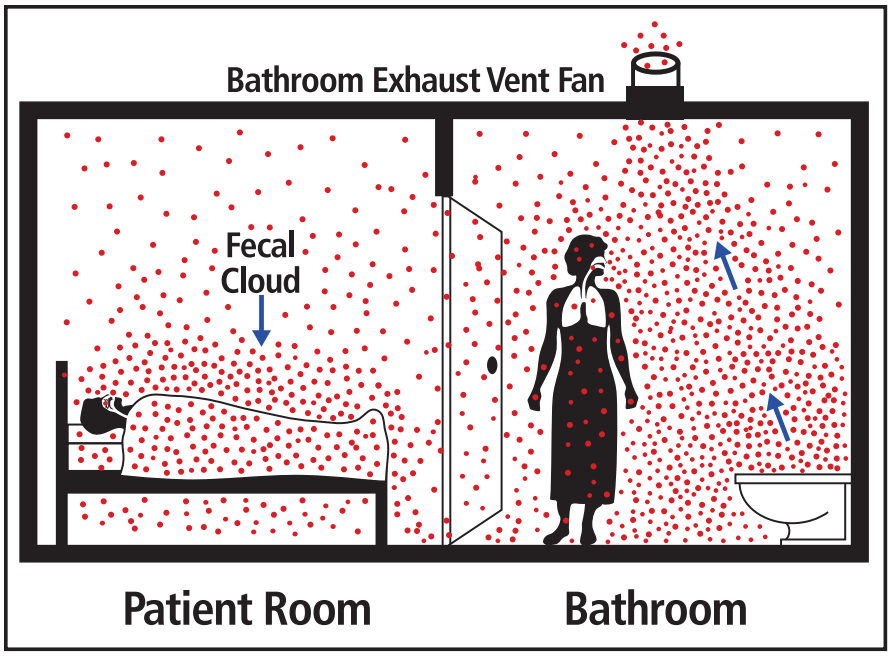

FIGURE 1. Caption to come.

to replicate and infect you. I minimized the importance of handwashing thusly: "No matter how sterile your hands are, you'll still be fully exposed to airborne Influenza virions entering and depositing into your lungs to cause disease."

This controversial position was (and still is) contrary to the Center for Disease Control's (CDC) advice that washing or sanitizing your hands is the best advice to preventing yourself from being infected. A CNN reporter pressed the CDC to produce the science backing their handwashing/sanitizing recommendation and forced the CDC to admit that handwashing to prevent influenza flu transmission was not supported by any peer-reviewed, published papers anywhere3. Handwashing for preventing staph infections already was weakening in 2008 when Professor Beggs showed4 that vigilant hand washing can only lower staph infections by around 20%, and additional handwashing protocols have less additional disease reduction impact. This leaves airborne transmission as the next empire to conquer.

HOW MRSA, C-DIFF, AND NV GET AIRBORNE

MRSA, C-Diff, and Norovirus aren't traditional respiratory diseases, which are well accepted as easily coughed or sneezed out, sending them airborne. Since C-Diff and NV are primarily intestinal diseases, they cause vomiting and diarrhea (think of it as reverse vomiting) and both these events can launch and aerosolize C-Diff & NV5,6,7 germs into indoor air spaces. In addition, any intestinally infected MRSA patients can also aerosolize their germs by these means. MRSA, C-Diff, and NV can grow in your perineal region and surrounding private areas and their airborne dispersal in a bathroom exacerbates the total impact of toilet aerosolization. Staph species thrive in many healthy peoples' noses, and many asymptomatic carriers have no clue about their condition. Sneezing was documented as the most efficient way to aerosolize nasal MRSA8 when a sneezy doctor on rounds infected many of his patients with his nasal MRSA, thereby toasting his bedside manner.

HOW AIRBORNE MRSA, C-DIFF, AND NV INFECT US

When unlucky humans breathe in airborne MRSA, C-Diff, and NV, those germs can impale themselves on the mucus lining our entire respiratory system (from nose to lungs) which is your very own airborne disease filtration system. Your tiny cilia (hairs) undulate the mucus's new prisoners back up through your trachea (windpipe) into your pharynx (area behind your tongue) where you swallow them down. Once they snuggle into our stomachs, most diseases are killed by our stomach acids but these monsters thwart that and quickly amplify (grow) to start wreaking havoc throughout the intestinal tract. They either exit out our bottom or through our mouths and that's where properly designing bathroom ventilation, supply, and exhaust vent placement, room pressurization, filtration, sterilization, and more can ground their flight as airborne infectious diseases.

Pull Quote to come.

TOILETS FLUSHES AS EXPLOSIVE GERM-LAUNCHING EVENTS

A toilet flushing event to a bacteria or virion is like millions of ping pong balls riding down Niagara Falls and being whipped up in the frothing undercurrent which then launches them airborne9. Once airborne, these germs are usually riding on a water droplet that is being sucked upwards at supersonic speeds by the bathroom fan's vacuum power. That droplet quickly evaporates (in less than a second) and the remaining naked germs are called "droplet nuclei," which can stay airborne for hours if not days depending on the air movement within the room. Toilet-aerosolized droplet nuclei lifted up into the breathing zone allow unsuspecting people to breathe

Solving Indoor Airborne Disease Transmission Problems

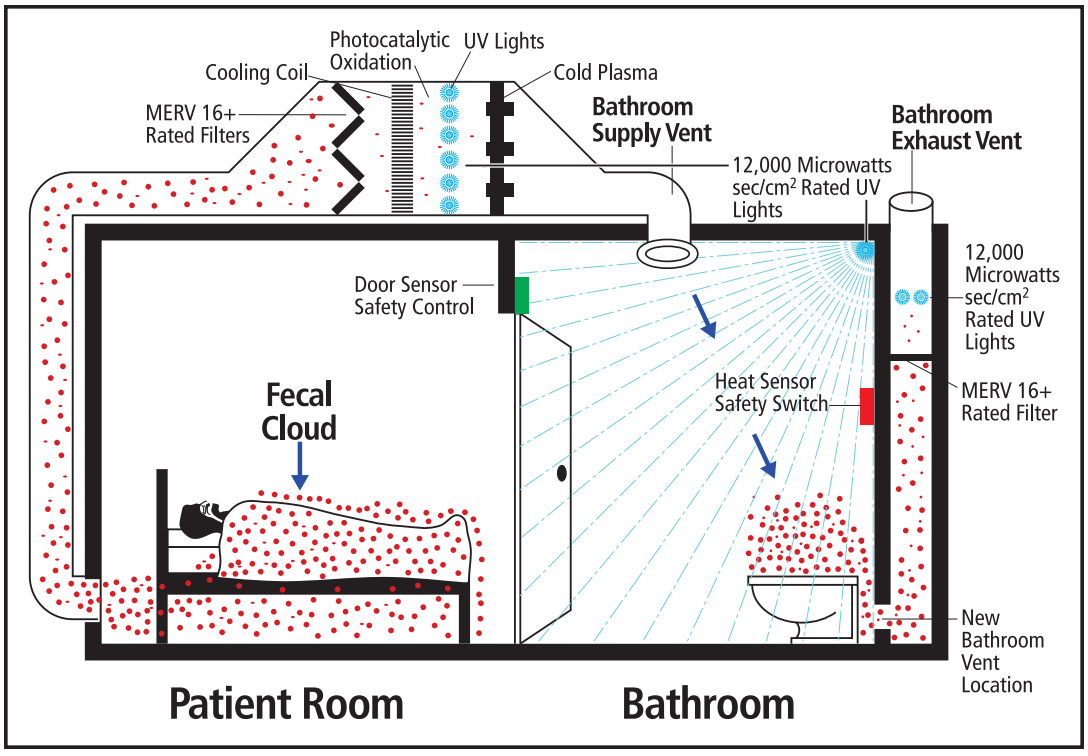

FIGURE 2. Caption to come.

them in. Eventually bacteria and virions fall (plate out) like party confetti, dusting every single surface in the bathroom and then spilling over into the patient rooms and eventually out their doors into the hospital:

- Making it nearly impossible to kill them all10
- Providing infinite opportunities for anyone to infect themselves though hand inoculation.

In 1959, British toilet aerosolization pioneers Ms. Darlow and Mr. Bale711 succinctly described toilet aerosolization. "Apart from explosive exhalations such as coughs and sneezes, the commonest process predisposing to the formation of infective aerosols must surely be the flushing of a water closet (toilet). Any process involving splashing or frothing produces droplets … if the fluid contains solid matter in solution (diarrhea) or suspension, an aerosol of droplet nuclei will persist after the evaporation of the rest of the droplet. This may be infective".

Their experiments successfully captured airborne bacteria up to 4 ft above the toilet due to flushing aerosolization concluding, "Experiments have demonstrated that flushing a washdown type of water closet can produce a bacterial aerosol. The size of the particles is such that bacteria tend to persist in the air and may reach the lower respiratory tract. Aerosol formation was not prevented by closing the lid before flushing. It was still produced after the closet had been flushed twice in succession."

It took Professors Gerba12 in 1975 and Barker13 in 2005 to show how bacteria and virions bore into porous ceramic toilet surfaces to be pulled out on each successive flush and aerosolized for up to seven flushes and even hours or days later. Barker showed that a diarrhea event "seeds" 10 billion bacteria and virions into the toilet water. Barker captured aerosolized germs that equated to 1.2 million airborne bacteria and 2.4 million airborne virions per cubic meter above the toilet. Professor Wilcox14 found C-Diff spores all over the bathrooms surfaces and adjoining patient rooms from the toilet aerosolization explosions.

These facts diminish fecal-oral transmission as the only way that MRSA, D-Diff, and NV can infect patients and others. Since the 1930's, scientists have found have found bacteria and virions in every nook and cranny all over hospitals whose surfaces were sampled especially when MRSA, C-Diff, and NV patients were shedding these missiles nearby. Since patients don't crawl all over the bathroom, their room, or the entire hospital touching every single surface to spread their fecal germs, it must be airborne transmission, right?

New Clostridium Difficile airborne transmission studies by Beggs15 in 2008 and Wilcox16 in 2010 found that C-Diff patients are surrounded by their own airborne C-Diff spores, which infection prevention specialists labeled as a "fecal cloud." (No one defined it, so I gave it a go17.) How did this cloud magically appear like Finnegan's rainbow? Here are the likely suspects:

Pull Quote to come.

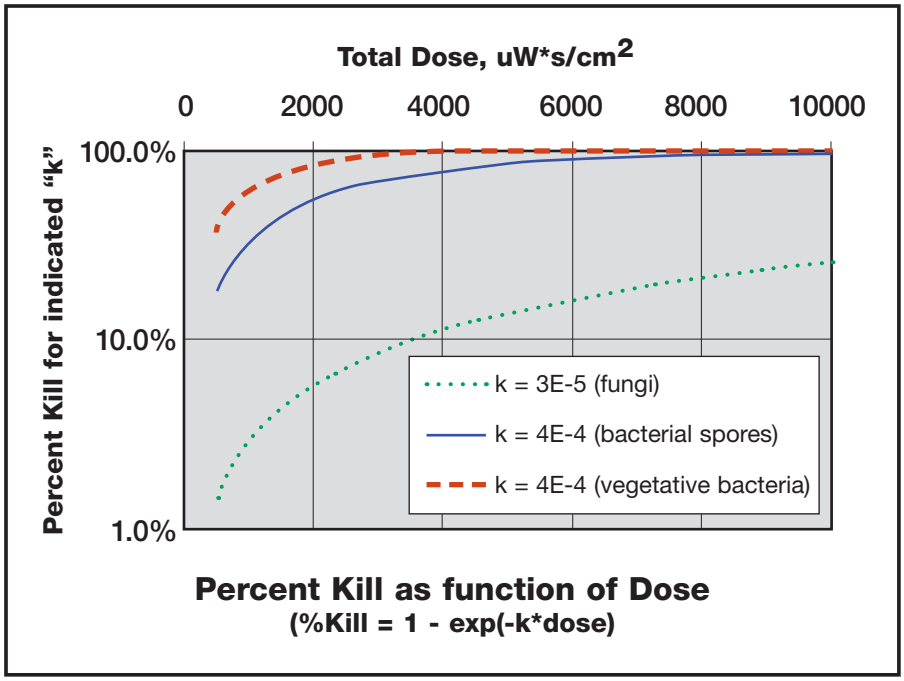

FIGURE 3. Caption to come.

- Flatulence
- Rubbing and friction
- Underwear removal
- Bed changing
- Toilet flush aerosolization

Studies have shown that an intestinal or perineal area staph (S in MRSA is staph) infected person's flatulence event can aerosolize this bacteria infecting innocent patients. Underwear removal and bed changing unleash massive infected skin flake storms contributing to the fecal cloud phenomenon. Wake Forest University Professor Robert Scherertz18 documents how normal adults can surrounded by staph "clouds" illustrating that we're a bunch of Pigpens® whom he names "Cloud Adults."

The "baby cloud19" phenomenon was documented in hospital nurseries where nasally staph infected babies were infecting their neighbors. Like the innocent babies, asymptomatic human infectors (carriers) are clueless that they are blasting (shedding) airborne germs. They're responsible for many anonymous HAIs that consistently daunt (and then haunt) infection prevention specilists. Now it's easier to imagine how a known MRSA, C-Diff, or Norovirus carrier having flatulence or shedding infected skin flakes creates their resulting fecal cloud.

MRSA, C-Diff, and NV happily living on human skin easily become airborne when the skin they're nesting on silently flakes off and goes airborne. Since patients are always rubbing their legs against each other, this liberates germ infested skin flakes contributing to their fecal cloud. Anyone in the area, including the patient, can breathe and then eventually swallow those grenades, thereby reinfecting themselves or newly infecting others breathing their fecal cloud. Lastly, toilet aerosolization and flatulence can cover the entire patient with their own disease known as a "fecal veneer," which infects those touching it and breathing it when goes airborne.

EPIDEMIC VALIDATION OF TOILET AEROSOLIZATION

Toilet aerosolization was the key factor in spreading the 2003 SARS epidemic around the world. A SARS-infected Chinese doctor stayed at the Metropole Hong Kong hotel and had diarrhea events in his bathroom located next to the room's entry door. Since his room was positively pressurized to the hallway, his aerosolized SARS virions were pushed out into the hallway creating a SARS fecal cloud. As nine unlucky guests and visitors passed through his SARS fecal cloud outside his door, they became infected and:

- Flew worldwide spawning multiple infections (the World Health Organization [WHO] shut down travel to Hong Kong and Toronto);
- Went to local hospitals, infecting patients, staff, and visitors, causing the largest recorded hospital superspreading HAI event,20 which infected a visiting dialysis patient named Wang Kaixi and 98 others.

Wang left the hospital clueless about his SARS infection and stayed in this brother's Amoy Gardens E Block apartment21. Common with SARS victims, Wang had diarrhea and his SARS- laced diarrhea toilet water created the world's largest fecal cloud(s) as it was aerosolized and blasted outdoors by a large window fan. His outdoor fecal clouds then surfed on the wind currents coming off Kowloon bay infecting 285 of his downwind neighbors, eventually killing 40 of them.

Post-facto, University of Hong Kong Professor Yuguo Li elegantly documented20 the unprecedented Amoy superspreading events using computational fluid dynamics and scaled mock-ups of the Amoy Garden apartments, illustrating Wang's fecal clouds flowing from his brother's 16th floor bathroom. I've written22 about both these SARS events and problems with the resulting WHO reports.

I met with Dr. Li in Orlando at ASHRAE 2009 and he generously gave me his 2004 Powerpoint presentation showing how his investigations found that 34.5% of hospital rooms tested were contaminated by airborne infiltration from neighboring bathrooms. It also showed how a SARS toilet aerosolization hospital HAI outbreak in Beijing resulted from a SARS patient's bathroom that dumped their toilet aerosolized fecal cloud into a shared bathroom ventilation shaft, infecting four patients directly above them whose bathroom was connected to the same shaft. Their aerosolized SARS viral fecal cloud(s) penetrated into the upper floor bathrooms, anonymously infecting these unsuspecting victims. Clearly there was no fecal-oral vector in that outbreak.

BATHROOM VENTILATION IS BACKWARDS

Most bathroom air is vented up through a ceiling exhaust duct, and Figure 1 illustrates why it's the exact wrong design to prop-

erly control toilet flush aerosolization. Ceiling exhaust exacerbates toilet flush aerosolization supporting how MRSA, C-Diff, and especially Norovirus hosts re-infect themselves and many persons who use their bathroom after their diarrhea event. It explains why MRSA, C-Diff, and Norovirus epidemics continue long after the hospital or cruise ship has been thoroughly "cleaned" with disinfectants, which clearly failed since 20% of cleaned toilets are still infected.

Anytime asymptomatic hospital staff or crew members have a diarrhea or flatulence event(s) they start the infection cycle all over again. There are many studies documenting how asymptomatic infected patients are still shedding their germs within their diarrhea and are still able to aerosolize them for months or years (10+) later. This explains why many MRSA, C-Diff, and NV patients return back to the hospital because they re-infect themselves with every flush or flatulence event. Aerosolizing millions of the fearsome threesome, when it only takes a couple of them to infect you, can be Vegas odds that anyone can appreciate.

AIRBORNE-GERM ENGINEERED BATHROOMS

In order to minimize the impact of toilet aerosolization and shedding in bathrooms, consider the following.

- Ventilate from the top down. (Figure 2) Bathroom supply vents must be at the ceiling, and return vents should be behind the toilet and below the seat level.
- Toilets are source contamination sites. Engineer behind the toilet exhaust flows to meet a 500 feet per minute (fpm) velocity at the vent opening to produce enough suction to remove toilet aerosolized germs. The ceiling supply duct must provide enough CFM to negatively pressurize the bathroom to prevent aerosolized germs exfiltration into the adjacent patient room and further. These high volume ventilation systems must be on whenever the bathroom is occupied.
- Sterilize/kill/capture ("clean") airborne germs. Bathroom air must be cleaned before it is exhausted outdoors, to prevent airborne virions and bacteria from re-entering through the building's fresh air ducts to infect others. All outside and supply air must be totally cleaned before it is circulated indoors (Figure 2). Your weapons of choice are:
    - MERV 16+ filters. Install the highest MERV rated filter you system can handle and ensure that the filter are correctly sealed.
    - Ultraviolet light systems. Start with a 12,000 microwatts seconds per square centimeter (μWs/cm2). A 2011 UV study treating the supply air helped drop pneumonia infection rates in a Neonate ICU by 40%24. UV effectiveness depends on wattage, exposure time, distance, reflectivity, temperature, air velocity, and more. It's widely accepted to install UV lights downstream of cooling coils to sterilize them, the drain pans, and the airstream passing through them.25

While I'm prevented from disclosing my bioterrorism project specifications, Lackland Air Force Base publicly specified 12,000 μWs/cm2 of UV photons for airborne infectious disease control. Figure 3 illuminates another specification in a UV kill graph from a 2003 study done by Research Triangle Institute26 showing 99%+ kill rates using 10,000 μWs/cm2 of UV photons on airborne bacteria and their spores (with some fungi thrown in for garnish).

A 2010 study26 provides impressive UV kill rates of C-Diff, MRSA and VRE using 12,000 and 22,000 μW s/cm2 of reflected UV light providing yet more specification reference points. Since virions have no exoskeleton (outer shell) like bacteria or their spores, virions typically require 50% or less UV power for sterilization, so by killing/sterilizing 99%+ of airborne bacteria you'll easily get 99%+ of airborne virions. It's critical that radiometers be installed to monitor each and every UV light's photon output, as these fail-safe devices will alert your BAS system if a lamp fails.

Make sure you have an independent expert calculate the final UV wattage needed to meet your specification as many factors must be custom calculated both for the specific airborne germ you want to neutralize and each AHU configuration that UV systems will mounted in. Make sure that you specify sealed and encapsulated UV lamps in case of accidental drops. A 12,000 μW s/cm2 spec could require high output UV lamps (not standard) spaced less than four (4) inches on center so make sure you have the properly custom calculated data to support the specification.

- Second generation needlepoint cold plasma systems. Cold plasma devices (with nearly non-detectable ozone levels) are now widely installed so you can add them as a bioterrorism tool to your weapons cache. While the sun makes plasma, down here on earth I've seen national lab tests which verify a needlepoint cold plasma system's 90% airborne MRSA kill rate in 24 min with 99% of MRSA killed after 60 min. Since cold plasma energy can be delivered into any indoor space, flooding occupied bathrooms with cold plasma may lower airborne MRSA transmission rates.
- Photocatalytic oxidation. Since UV light is a component of photocatalytic oxidation (PCO) systems, we know that UV works. A 2011 study27 validated that PCO can be 95% effective in sterilizing and killing airborne staphylococcus, so adding PCO to your HVAC systems may enhance its ability to prevent airborne disease transmission and keep your cooling coils sterile.
- In-bathroom UV sterilization system. Flood the entire bathroom with UV photons after the patient has exited to sterilize any human aerosolized germs. Keep them activated during and after the toilet flush for an expert-calculated time to attack aerosolized airborne germs. Bioterrorism Bio-Safety level 4 labs at Ft. Detrick labs use UV technology and they've never had an outbreak.

In addition, new patent-pending compression pole installation systems with pre-built custom hardware have dropped UV installation cost by 50%+, so UV is even more affordable. Fellow ES author Firouz Keikavuosi documented how UV provided energy savings because of higher cooling coil Btu heat transfer, lower pressure drops, and shortened fan run times due to a 4° drop in leaving air temperatures. 25 Now as a private consultant, he shared how his clients, who use UV light technology, have HAI rates to well under 50% of the national average.

- Delay timer and safety devices. Patients push a 30-second delay toilet flush button and quickly leave the bathroom to wash their hands outside. A mounted closed-door safety switch with a backup bathroom-mounted heat sensor will redundantly assure that the UV lights are not on when someone is in the room. The

UV lights should produce 12,000 μWs/cm2 with light placement and tile reflectivity playing a large role in any specification.

I've shared a lot of ideas here, and some of them may have rattled your noggin, but that's the point. Hopefully my science-based recommendations will move you to make changes and even question previously unchallenged assumptions, so go out and apply your newly acquired knowledge. If you have any questions, e-mail me and be patient, I will answer them. If you want to borrow any study for personal or academic reasons only, then let me know. Send me any news of the projects that you've incorporated my ideas into, so that I can update and include any improvements that you've made into future articles and lectures. **ES**

Welty is an airborne germ expert who solves complex problems in "sick" buildings and airborne disease infection problems in hospitals. He is also an HVAC energy efficiency consultant and president of Green Clean Air (Reston, VA).

CITED WORKS

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