Breathe Easy

Two basic steps to improve patient outcomes and healthcare reimbursement

by Stephanie Taylor, MD, M Arch, FRSPH(UK), MCABE
September 29, 2016

Table of Contents

"Is the added expense of treating infections which patients acquire during their hospitalization partly responsible for the high cost of hospital care, and are current infection control protocols missing an important component in their prevention?"

Executive summary

This paper will present new data on the influence of the hospital physical environment on healthcare-associated infections. Most importantly, with this new data, we will offer evidence to support the revision of indoor air standards to improve patient outcomes.

Challenges for hospitals in 2016

Hospital leaders are currently challenged by two significant misalignments in health care.

The first discrepancy is that, despite robust infection control practices, many in-patients are contracting serious healthcare-associated infections (HAIs) which threaten their health and very survival.

The second incongruity is a lack of correlation between the high cost of in-patient care and patient outcomes. This is more evident in some countries, but the trend exists globally.[1] While both disconnects have many variables, a question begs to be asked - is there a connection between the two?

In other words, is the added expense of treating infections which patients acquire during their hospitalization partly responsible for the high cost of hospital care, and are current infection control protocols missing an important component in their prevention?

> “33 out of every 100 patients experience some type of medical error during their hospitalization. Of these, 18% will get an HAI.”

Patient Care

People hospitalized for serious sickness or injury are much too often harmed by medical errors during their in-patient stay. A patient gets the wrong dose or type of medication, contracts an HAI, forms a pressure sore while immobilized in bed, has surgery on the wrong part of their body, or falls in their room - these all are preventable events!

The exact toll of these errors on patient lives and hospital budgets is very difficult to quantify, however, conservative studies report that 33 out of every 100 patients experience some type of medical error during their hospitalization. Of these, 18% will get an HAI.[2]

This means that at least 9% of patients acquire a new infection while in the hospital. The full costs of HAIs on the American society, not just the incremental cost to hospitals, is estimated to be $96-$147 billion in the United States alone. Globally, HAIs kill more people than AIDS, breast cancer and auto accidents combined.[3]

This is a horrible situation! The surgeon and patient safety champion, Dr. Atul Gawande, describes victims of HAIs as, “the easiest 100,000 lives we can save”, because no new cure is needed. Instead, hospitals need systems in place that will help to solve this costly and preventable problem.[4]

Hospital Finances

The high cost of health care in conjunction with the excessive number of patients harmed by HAIs has brought hospitals under scrutiny from individuals, reimbursement organizations and the US government. This scrutiny has stimulated a demand for disclosure of HAI rates as well as financial “incentives” to decrease errors.

Toward this end, the Center for Medicare and Medicaid now uses a Value-Based Purchasing program to reward hospitals with low error rates, penalize those with high rates and withhold hospital reimbursement for many costs associated with HAI treatment. Private payers are following this performance-based reimbursement model, further incentivizing efforts to reduce HAIs.[5]

In addition to reimbursement penalties, HAI litigation costs to hospitals can be enormous. According to the 2008 Hospital Professional Liability Benchmark Analysis, HAIs accounted for 12% of total legal liability costs incurred by healthcare facilities, and one out of every six claims was related to an HAI injury.[6]

“According to the 2008 Hospital Professional Liability Benchmark Analysis, HAIs accounted for 12% of total legal liability costs incurred by healthcare facilities, and one out of every six claims was related to an HAI injury.”

> “A better understanding of how indoor conditions influence both the infectivity of microbes and the ability of patients to fight infections will help identify best practices to decrease HAIs.”

As healthcare leaders struggle to balance their budgets with decreased reimbursement rates and increased operating costs, and patients stagger under the burden of HAIs, we need to ask if there are facility management strategies which we are missing, ones that would alleviate both of these healthcare crises.

This paper will discuss management of the hospital built environment, the setting in which patients contract HAIs during their interactions with caregivers, visitors and a vast array of medical instrumentation. A better understanding of how indoor conditions influence both the infectivity of microbes and the ability of patients to fight infections will help identify best practices to decrease HAIs.

"Centuries after constructing the first shelters, we are experiencing an unanticipated consequence of our sealed indoor environments – worsening chronic illnesses."

Buildings and health

Dynamics of indoor microbes

Thousands of years ago when humans started building shelters, we also unknowingly began to influence the communities of microscopic viruses, bacteria and fungi that cohabitate with us. As construction technology progressed and energy conservation was prioritized, indoor building climates became tightly controlled and sealed from the outdoor air. Mechanical systems regulating temperatures and humidity created indoor micro-climates with evolutionary pressures ("survival of the fittest") not found in the natural outdoor environment. Consequently, microbial communities in buildings have become distinct from those outdoors.[7]

Now, centuries after constructing the first shelters, we are experiencing an unanticipated consequence of our sealed indoor environments – worsening chronic illnesses. At least some percentage of these illnesses are related to daily exposure to microorganisms which have adapted to indoor conditions and become more infectious and allergenic to humans.[8]

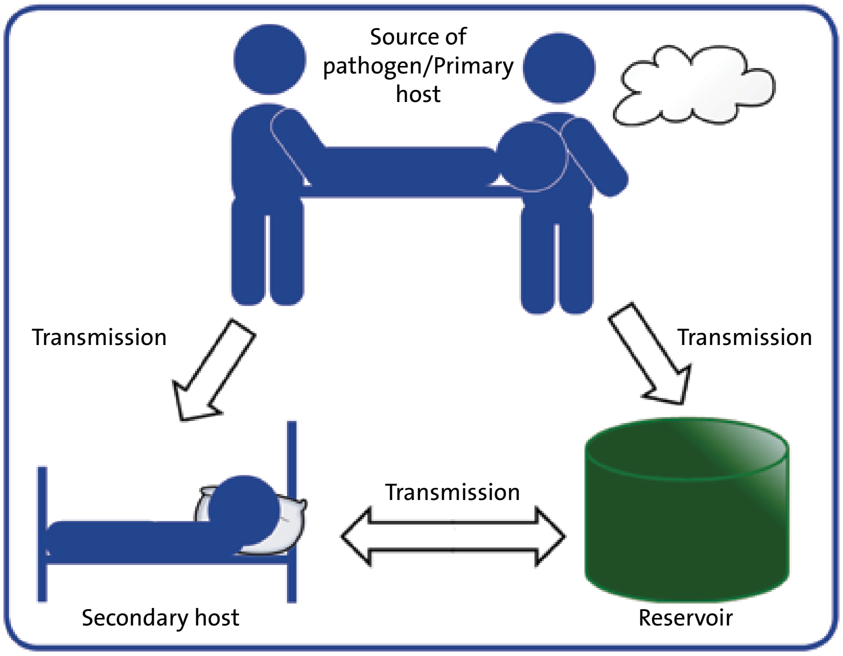
> Each time a person enters a building they shed approximately 37 million bacteria per hour into the surrounding air or onto surfaces touched, spreading microorganisms all over the room.

Each time a person enters a building they shed approximately 37 million bacteria per hour into the surrounding air or onto surfaces touched, spreading their microorganisms all over the room.[9] The resulting community of microbes, referred to as the microbiome, is unique in each building depending on how it is constructed, operated and on the activities of the occupants.

For example, one hospital study showed that patient rooms with mechanical ventilation had much higher numbers of circulating human-related bacteria compared to patient rooms with open windows which brought in outdoor air.[10]

Hospitalized patients are exposed to infectious HAI microbes from two main sources: people and building reservoirs. A wide array of pathogens carried into the hospital by sick patients, visitors and staff are expelled into the building through common activities such as talking, coughing, vomiting, skin shedding and toilet-flushing. A single sneeze injects approximately 40,000 infectious aerosols into the room air, so clearly the indoor microbial load can become huge.[11]

Figure 1
The cycle of infectious microbes in hospitals

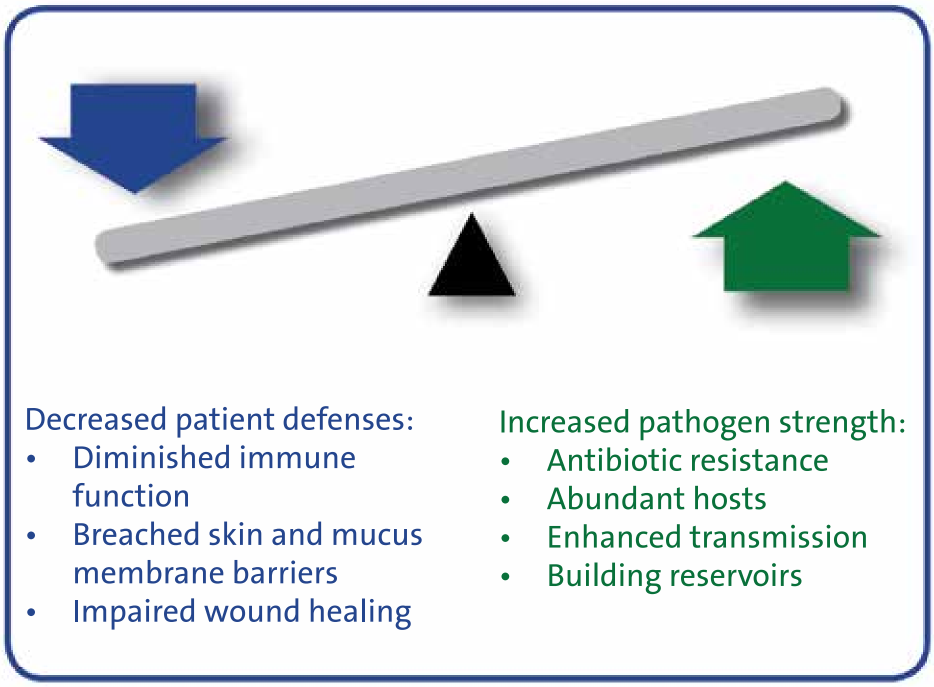


An imbalance of power

In addition to the sheer number of pathogens in hospital buildings, there also exists an unfortunate imbalance of power which favors the development of HAIs. In confined hospital spaces, biological extremes of virility and defenselessness coexist.

On one side are patients who may be especially vulnerable to infections because of decreased immune defenses from illness and medications, breached skin barriers from surgery or indwelling catheters and impaired respiratory system defenses from dry indoor air.

Figure 2
Patient defense versus pathogen strength



On the other extreme are microbes that have survived the powerful selection pressures from anti-microbial medications, housekeeping disinfectants and indoor building climates.

Micro-organisms carrying medication resistant genes rapidly reproduce and through transmission modes keenly adapted to the indoor environment, repopulate the hospital with microbial communities of decreased diversity yet increased infectivity.

The availability of protected building reservoirs and an abundance of secondary hosts (patients) help microbial communities become well established. Furthermore, these reproduction cycles occur in the presence of visitors and healthcare staff who are also shedding microbes. Not surprisingly, hospitals have unwittingly become reservoirs and vectors for ubiquitous HAI pathogens.

"Despite robust surface hygiene interventions to control HAIs, the number of recorded cases has increased by 36% in the last 20 years and continues to grow every year."

Current infection control focus

Emphasis on hand hygiene and procedure protocols

Today's hospital infection control protocols focus largely on hand, instrument and surface hygiene, as well as on cough etiquette and facial masks.

These strategies target the interruption of transmission through contact and short-distance, large-droplet spray. They do not, however, immobilize tiny, aerosolized droplets which can spread infectious microorganisms over significant distances and for extended periods through the air.

Indoor air management downplayed

This lack of attention on managing long distance transmission of infectious aerosols occurs for several reasons. One reason is that epidemiologists continue to debate about the importance of the airborne route because there is a lack of easily-compared data on aerosolized microbes and infectivity.[12]

While the magnitude of airborne droplet transmission continues to generate disagreement, epidemiologists do concur that despite robust surface hygiene interventions to control HAIs, the number of recorded cases has increased by 36% in the last 20 years and continues to grow every year.[13]

> “10% to 33% of all HAI pathogens move through the air at some point between the initial source, the reservoir and the secondary patient.”

The infectivity of airborne pathogens depends on their survival while suspended in air, their ability to revive after landing on a surface or secondary host-patient, and their ability to overcome the defense mechanisms of the secondary host-patient. Until recently, environmental monitoring for infection control has relied on cell-culture tests which only detect microbes which appear to be alive at the time of collection. This is deceiving!

While suspended in tiny airborne aerosols, infectious microbes are often temporarily in “travel mode”, appearing dead and non-infectious when collected during air sampling.[14] But, when re-exposed to physiologic conditions in the next patient, many of these microbes rehydrate and are highly infectious.

Air sampling that mistakenly excludes dormant pathogens in tiny aerosols, and therefore underestimates the infectious load of indoor air, contributes to the infection prevention focus on clinician-behavior and contact transmission which misses the importance of airborne transmission of aerosols.

Authors of current, comprehensive review articles conclude that 10% to 33% of all HAI pathogens move through the air at some point between the initial source, the reservoir and the secondary patient.[15] Until airborne transmission of infectious aerosols is controlled, even excellent adherence to existing contact hygiene protocols will not curtail the HAI epidemic.

> "New genetic sequencing techniques can identify both active and dormant microbes through their DNA and RNA 'fingerprints'."

The new "microscope" of metagenomics

New genetic analysis tools

We now have exciting new genetic sequencing techniques that can identify both active and dormant microbes through their DNA and RNA "fingerprints".

Similar to the increased focus on the microscopic world following the invention of the microscope in the 1700's, the powerful tools of metagenomics are broadening our understanding of the vast and dynamic hospital microbiome, the origin of HAIs and the evolution of antibiotic resistance.[16]

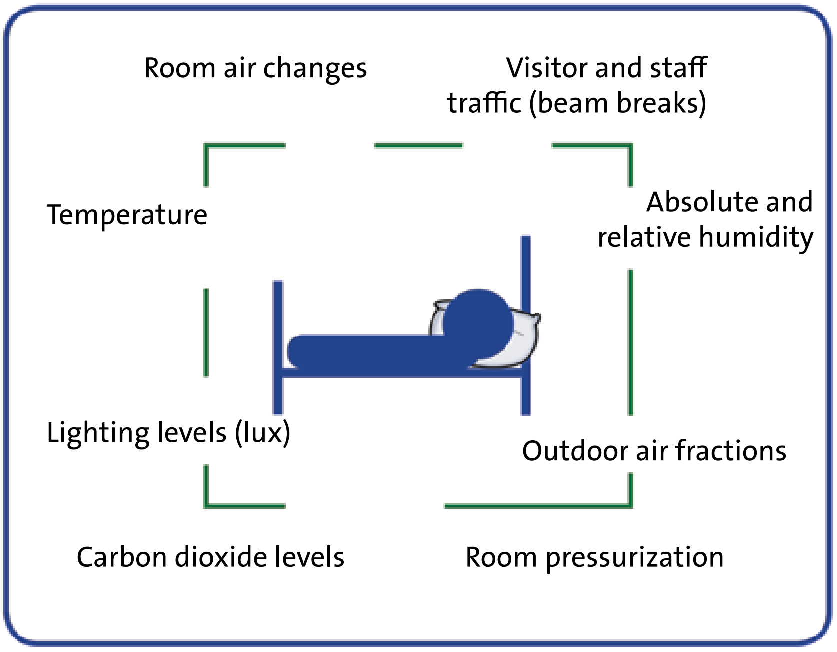
Former hypotheses and assumptions about HAI pathogen survival and transmission can now be confirmed, adjusted or discarded!

New data: the hospital microbiome

To get a better understanding of the relationship between indoor air parameters in patient rooms and the incidence of HAIs, a study was recently done in a newly constructed, approximately 250 bed academic hospital in the north central US. Over a 13-month period, hourly measurements of room temperature, absolute and relative humidity, lighting levels (lux), room air changes, outdoor ventilation fractions, carbon dioxide levels and room traffic were monitored in ten patient rooms.

Figure 3

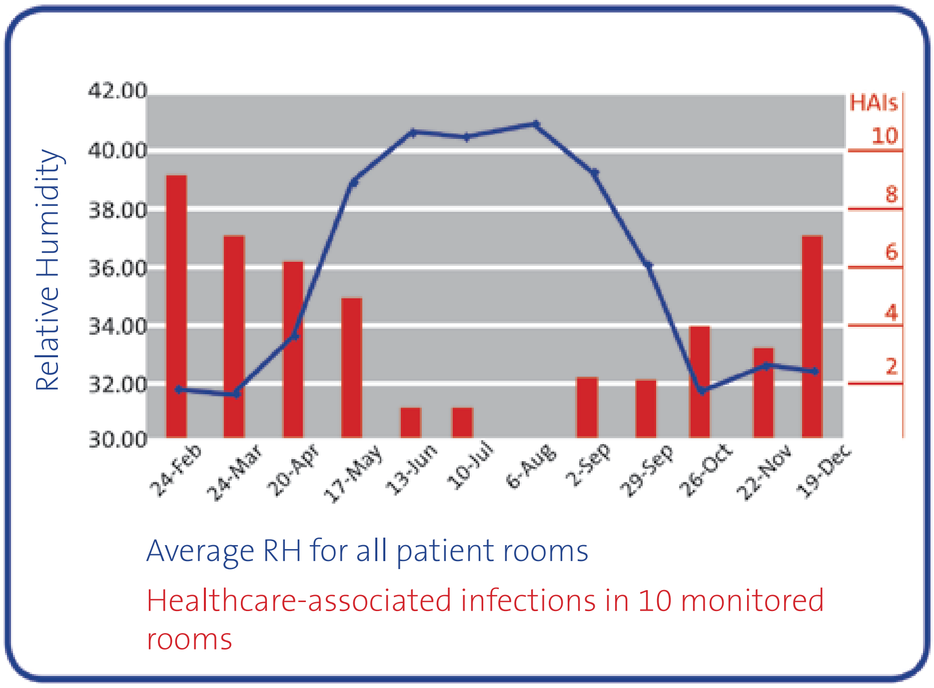
Indoor measurements of patient rooms



During the same period, ICD-9 codes of patients admitted to these rooms were analyzed for the presence of HAIs and multi-variable statistical analysis was run to determine if any indoor conditions independently correlated with these patient infections. Of all the climate measurements tracked, indoor RH was found to be the most closely related to HAI rates.

Figure 4

Correlation of room measurements



RH was inversely proportional to HAIs ($p < .02$) in other words, as indoor RH increased, the patient HAI rate decreased. (This hospital has requested anonymity.)

These findings reinforce the need to understand, monitor and manage indoor air hydration, or humidification, to decrease patient HAIs.

> "When infected people breathe, talk or cough their naturally humid airways expel thousands of droplets containing saliva and mucus with embedded microbes into the ambient air."

Indoor air hydration is essential

A cleaner hospital: pathogen transmission and viability

What are the mechanisms through which indoor RH relates to infection prevention? RH indicates the percentage of water vapor held by the air at a given temperature. The amount of gaseous water carried in air, or RH, impacts both the transmission and survival of pathogenic microbes as well as the integrity of patient physiologic defenses.

Transmission

When infected people breathe, talk or cough their naturally humid airways expel thousands of droplets containing saliva and mucus with embedded microbes into the ambient air.[15] Thermodynamic equilibria between ambient air and the expelled droplets during condensation and evaporation dictate energy and mass changes. The vapor equilibrium, expressed as RH, of room air determines the resulting droplet size, concentration of salts and the viability of the infectious micro-organism.

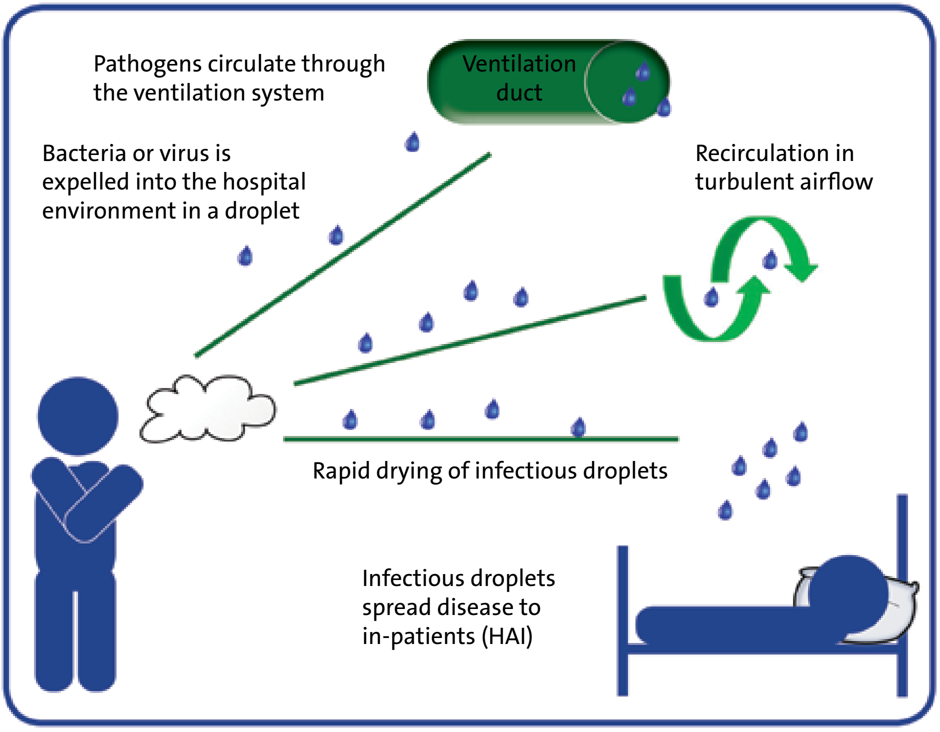
When expelled droplets encounter dry room air with RH less than 40%, they instantly shrink by roughly 90% as rapid equilibration occurs between the moisture levels in room air and in the droplet.

The resulting tiny droplet nuclei with diameters less than 0.5 microns can then remain airborne for extended periods of time and be carried over great distances, thereby increasing the chance that they will reach a secondary patient.

When a patient inhales the desiccated droplet nuclei into their moisturized airways, the droplets rehydrates and pathogens are able to begin a new infectious cycle.[14]

Figure 5

Pathogens travel well in dry air



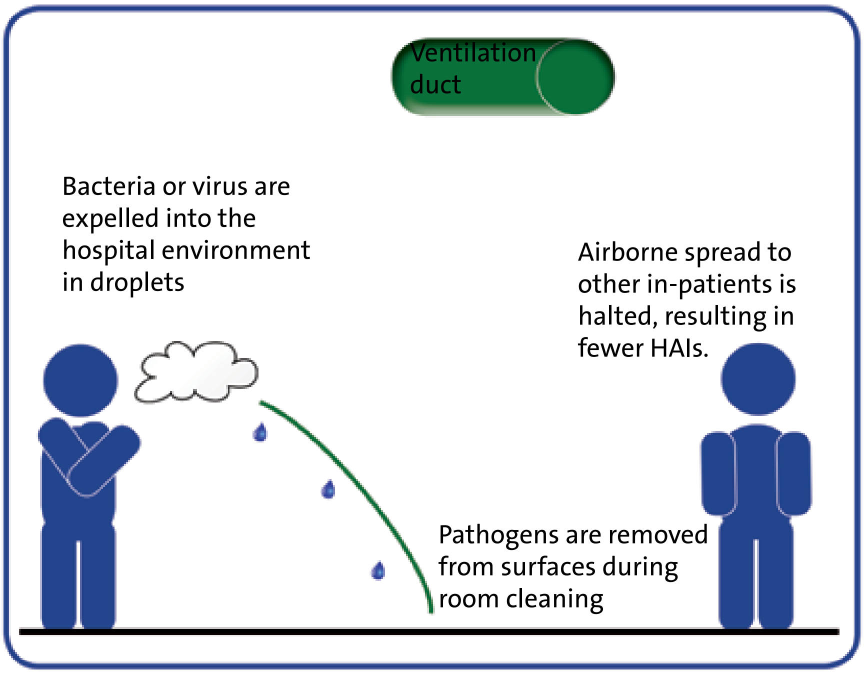
Dry indoor air (RH < 40%)

A very different scenario unfolds in a patient room with indoor air RH from 40% to 60%. In this setting, the respiratory droplets maintain diameters around 100 microns. Because the droplet diameter dictates the settling distance and rate, these larger droplets land on surfaces within four - six feet of their source (a person sneezing, toilet flushing) where they can be efficiently removed with surface cleaning.

Transmission through room air or mechanical systems is decreased and therefore the possibility of a secondary patient being exposed is proportionately decreased.

Figure 6

Patients are healthier in hydrated air

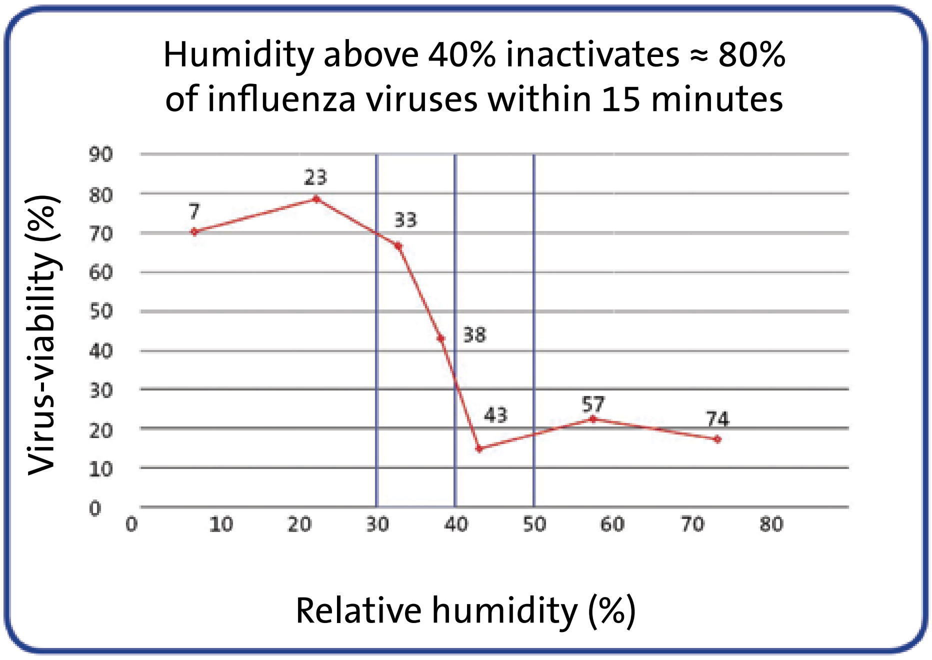


Hydrated indoor air with RH 40% - 60%

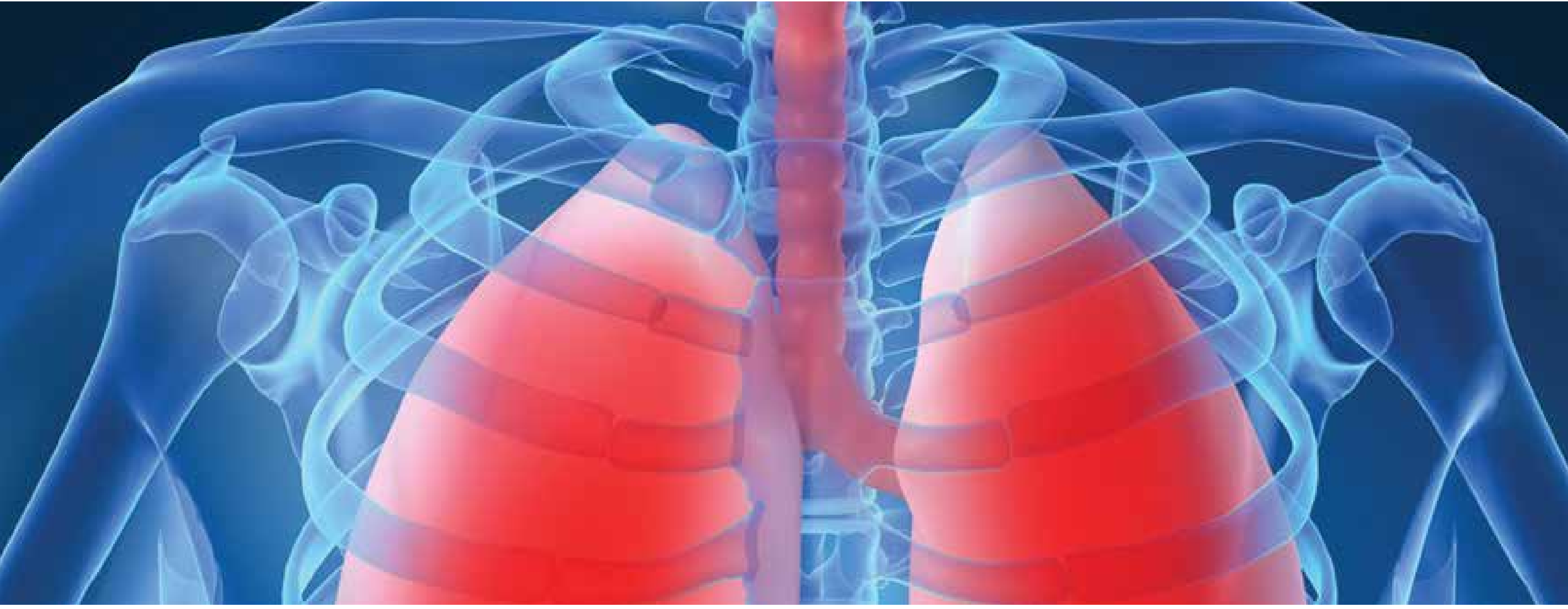
Viability

In addition to reduced pathogen transmission in properly humidified air, many aerosolized bacteria and viruses have decreased survival when RH levels are between 40 - 70%. This reduction in pathogen survival decreases subsequent patient infections.[17]

Figure 7
Virus inactivation by moderate humidification of air



“Moisture content may , indeed, be the most important environmental factor influencing the survival of airborne microbes”. Dimmick, Naval Biological laboratory, Univ. CA, Berkeley



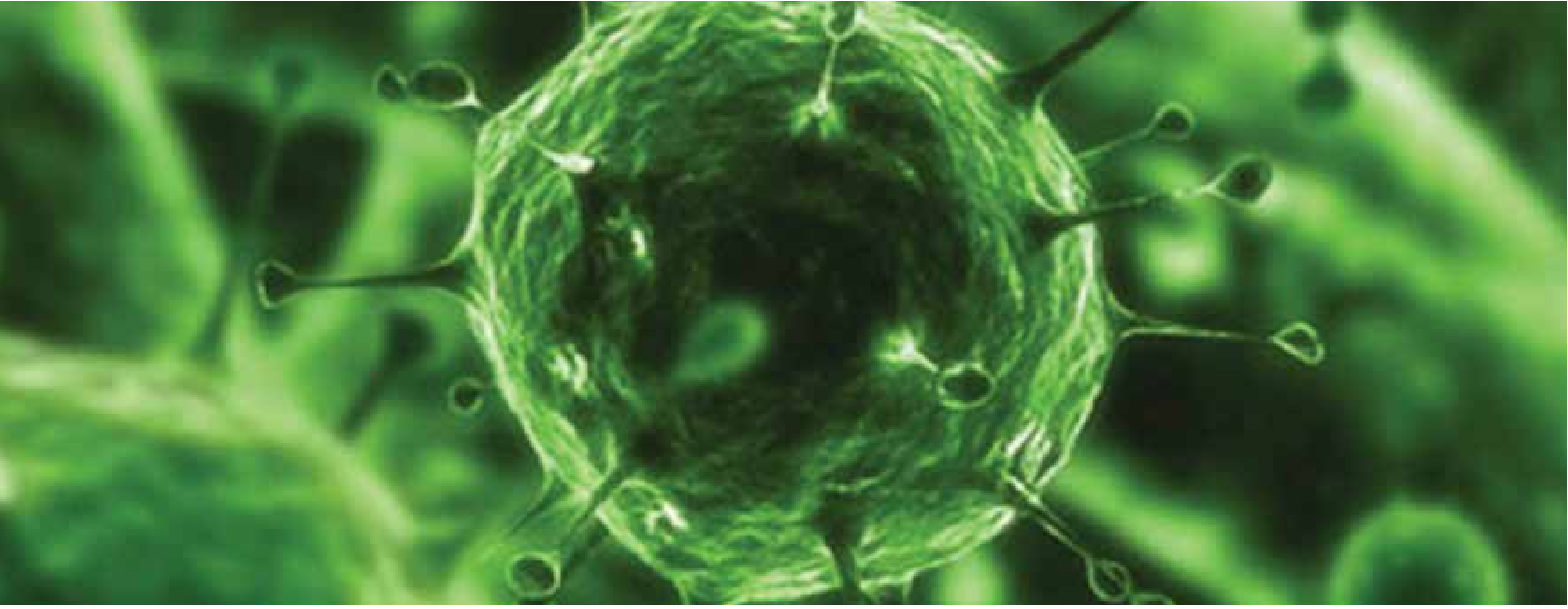
Healthier patients: barriers, immunity and hydration

While pathogens fare poorly in properly hydrated air, people are much healthier! What are the reasons for this?

Human lung physiology demands provision of 100 percent saturated air heated to 98.6 degrees Fahrenheit for their essential function: gas exchange. In the lungs, inhaled oxygen is exchanged for the metabolic waste product carbon dioxide across delicate, one cell membranes of the alveoli.

Deep in the lung tissue, fragile alveoli sacs are in close proximity to blood vessels. To prevent infectious particles from settling into the alveoli where pneumonia or systemic blood infections could easily result, physiological barriers trap particulate matter in the upper regions of the respiratory system.

Ambient air moisture is necessary for optimal functioning of this defensive mechanism. Respiratory mucosa from the nose to the small bronchial tubes moistens and heats inhaled air before it reaches the alveoli.



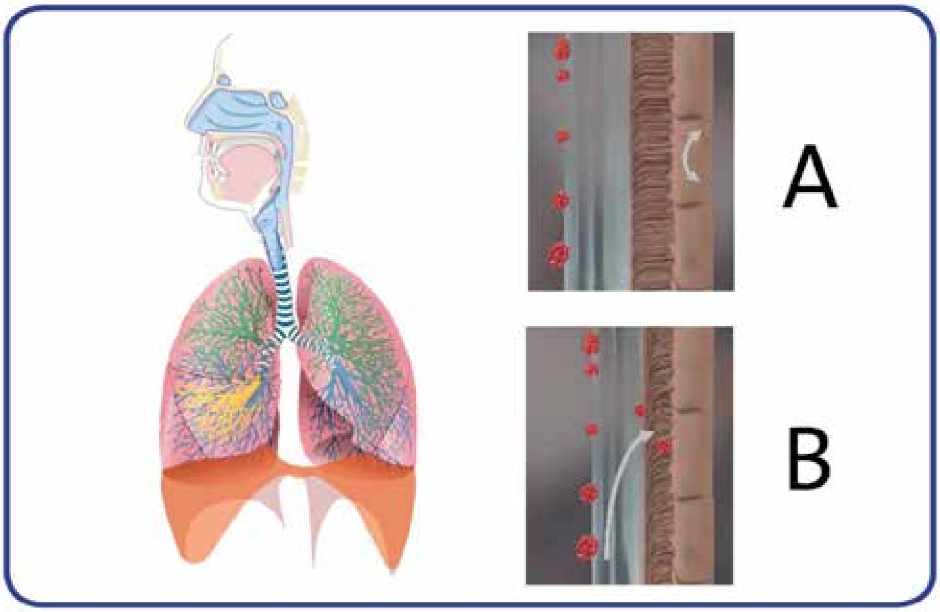
> “Instead of pathogens reaching deep lung tissues where they could cause deadly infections, they became part of the intestinal microbiome where they may well contribute to our health.”

Cells lining respiratory passages capture infectious particles on a surface mucus layer, then move the particles away from the lungs by continuous upward movement of numerous hair-like projections, the cilia, which sweep at rates up to several hundred cycles per minute.

The inhaled particles, trapped by mucus and moved upwards into the throat, are swallowed and incapacitated by acidic stomach and alkaline small intestinal tract conditions.

Instead of pathogens reaching deep lung tissues where they could cause deadly infections, they became part of the intestinal microbiome where they may well contribute to our health.[18]

Figure 8
The respiratory tract and ambient air moisture

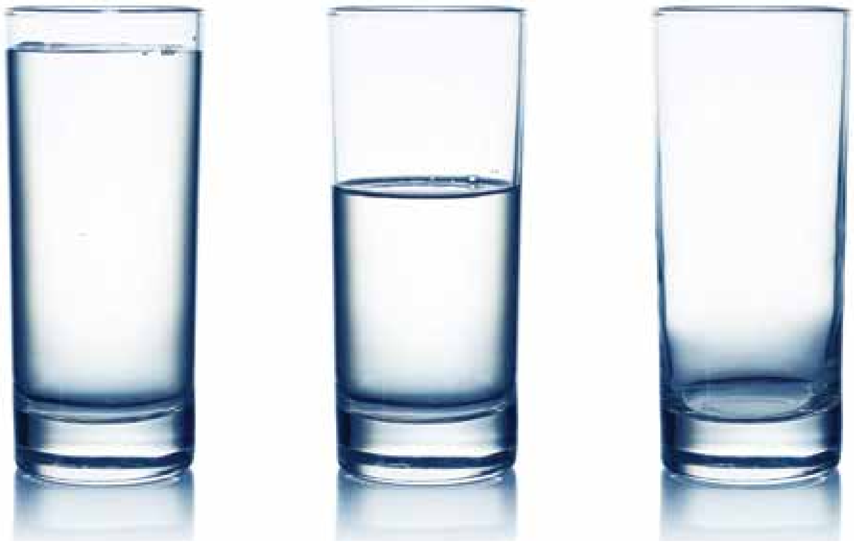


A. RH 40% - 60%

Well hydrated mucus and cilia brush-layer. Cilia movement washes particles upwards to the larynx, where they are then swallowed or coughed out.

B. RH < 40%

In dry ambient air, both layers become quickly dehydrated. The cilia are compressed and immobilized. Mucus transport stops and pathogens can penetrate the respiratory epithelial cells, initiating infection.

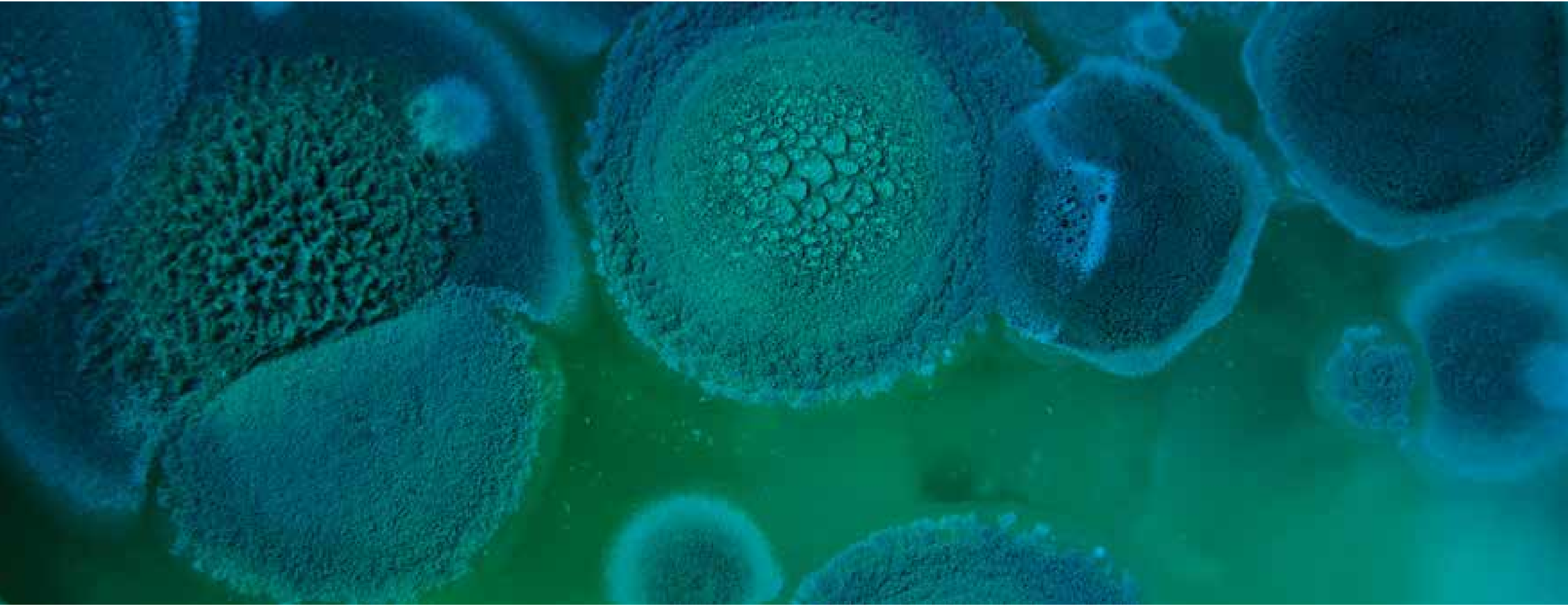


> “When ambient air is dried to RH of 20%, patients lose 60 to 80 grams/hour (1½ to 2 liters/day) of water.”

When ambient air is dried to RH of 20%, patients lose 60 to 80 grams/hour (1½ to 2 liters/day) of water. The water loss by airways alone is 300 to 500 milliliters per day.

In addition to drying the upper respiratory tract mucosa and reducing clearance of infectious droplets, the patient struggles to maintain adequate hydration needed for immune cell functioning and wound healing.

Given the clear health advantages of balanced air hydration with RH of 40%–60%, why are not all buildings humidified to provide this indoor climate?

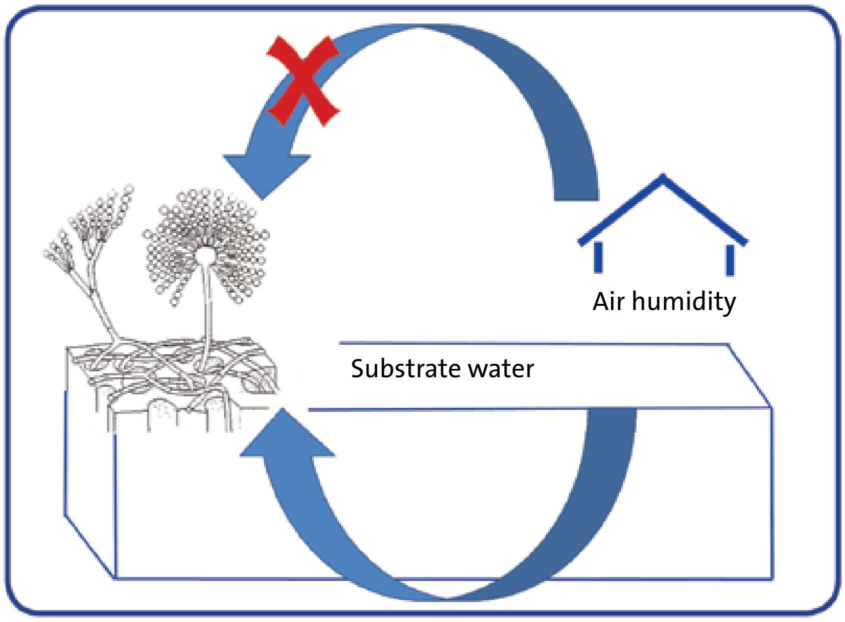


Barriers to change

Misconception about mold

Figure 9

Fungi cannot utilize water in the gas phase for growth



“Mold does not, and cannot extract moisture from the atmosphere.”

Many people think that fungal organisms, or mold, can extract moisture from the air and use this water as a necessary factor for growth in building materials. Contrary to this popular belief, mold does not, and cannot extract moisture from the atmosphere![19] The water in buildings that mold uses comes from spills, leaks or from condensation.

> “As the temperature of a surface falls the water saturation in the boundary layer progressively increases until condensation results at 80% vapor pressure, called the dew point. If sufficient liquid water and nutrients are available, mold growth can start.”

Whether condensation occurs or not at a given moisture level depends entirely on material properties like surface temperature, hygroscopicity, wettability and scale of pores.

Differences between outdoor and indoor temperatures and humidity levels create gradients across the building enclosure which can result in a zone within the exterior wall where water condensation is possible.

It is helpful to think about RH as a “condensation potential”. As the temperature of a surface falls the water saturation in the boundary layer progressively increases until condensation results at 80% vapor pressure, called the dew point. If sufficient liquid water and nutrients are available, mold growth can start.

When the room temperature is pre-set, lowering the indoor humidity pushes the dew point closer to the outside of the building envelope. If the outside temperature is low, attempting to “push” the dew point outside the wall construction results in very low indoor humidity, close to a continental desert climate!

> Exposure via inhalation of airborne fungal parts (spores and fragments) puts peoples health at risk.

What intervention would improve this situation? Prevention of mold growth, reduced to a simple formula, does require keeping the dew point outside of the wall construction. Proper insulation is the only effective way to accomplish this because the problem is not the air, but the cold surface. Compensating for insufficient wall insulation or design errors by lowering indoor RH is both an ineffective and unhealthy approach.

When mold already exists, it is unpleasant, lowers the building value and creates a health risk for occupants. However, does surface mold necessarily expose the occupants to health risks, and if so, in what ways?

We know that exposure via inhalation of airborne fungal parts (spores and fragments) puts people's health at risk. Research, however, has not established an exposure-response relationship for surface mold that explains clinical symptoms and diseases. In fact, fungi growth patterns are dynamic-responding to surrounding climatic forces and exhibiting both dormant and active stages of vegetative, aerial and reproductive hyphae.

> “Health risks increase in dry air and decrease in properly humidified air.”

Studies that measure aerial mold hyphae and spores indicate that airborne exposure depends inversely on air RH, therefore health risks increase in dry air and decrease in properly humidified air.[20]

We do have the ability to construct buildings with optimal indoor climates, including RH levels of 40 to 60%, without incurring mold problems. Thousands of museums and libraries all over the world, built more than one hundred years ago, tightly control RH at 50% and do not have mold problems.

> There is strong evidence associating air turbulence in hospitals and the transmission of infectious diseases.

Misconceptions about energy costs

Hospitals are currently the second most energy-intensive building type in the United States, with heating, cooling, and ventilation accounting for 52% of their energy use. Because high ventilation rates in patient care spaces contribute significantly to high energy use, ventilation measures are again being scrutinized.[21] Studies correlating volume exchange ventilation with patient infection rates have not documented a relationship between room air changes air and clinical outcomes.

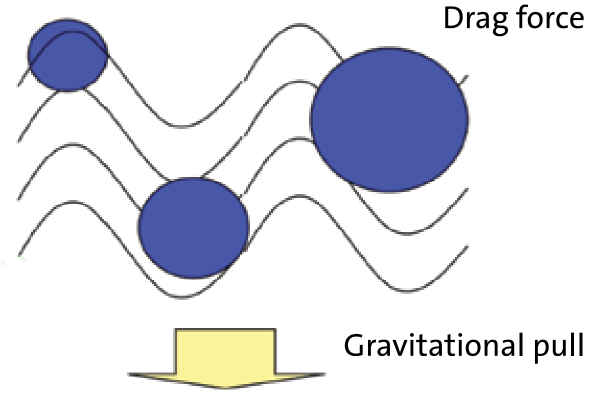
Conversely, there is strong evidence associating air turbulence in hospitals and the transmission of infectious diseases.[21] Resuspension of particles, which includes droplet nuclei, is dependent on the balance between upward forces of turbulent air flow and water adhesive forces, therefore RH has a decisive influence on this balance by increasing adhesive forces. Infectious aerosols originating from watery environments (breathing, speaking, coughing, toilet flushing, vomiting and diarrhea) shrink to become tiny droplet nuclei below RH 40%.

When the upward velocity of room air with circulating droplets aerosols exceeds the terminal settling velocity of the aerosols, they remain suspended in the air for prolong periods.

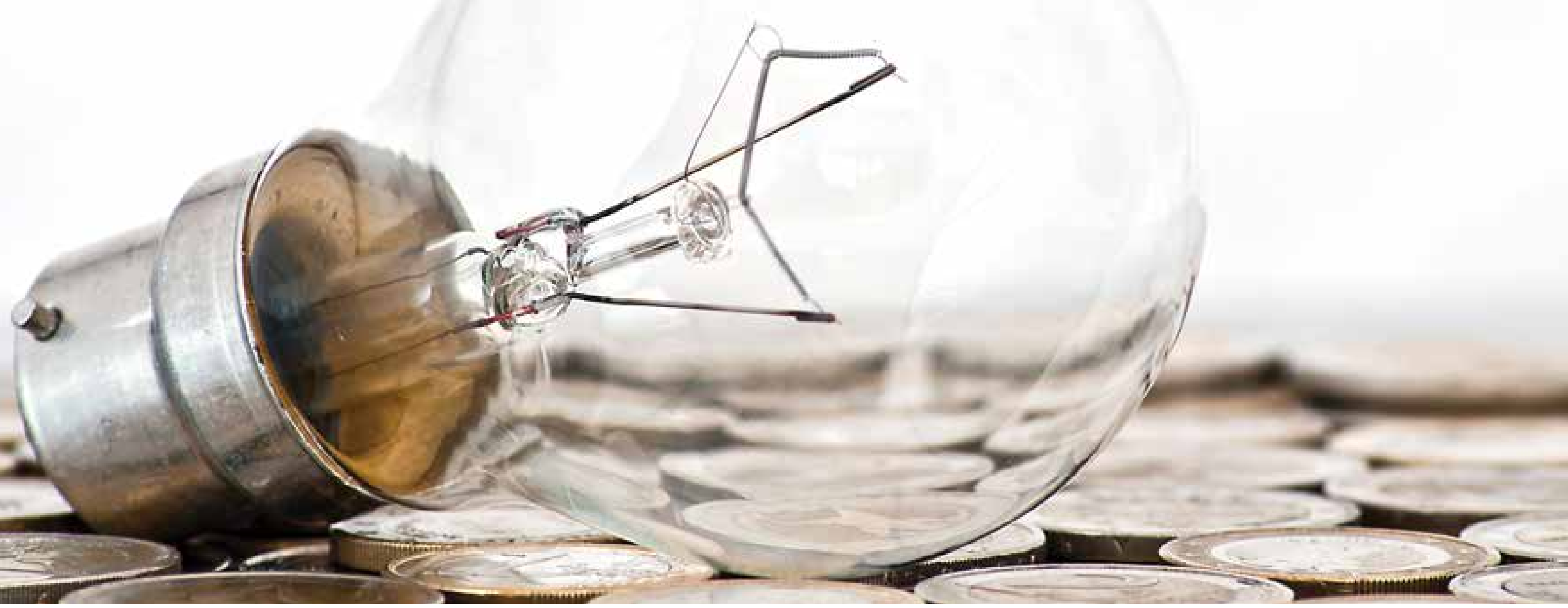
Because airborne droplets have larger volumes in air with RH 40 to 60% (see previous discussion) compared to those in dry indoor air, maintaining indoor RH within this range can significantly reduce the room air changes required for infection prevention, and thus conserve energy and hospital dollars.

Figure 10

Turbulence from high room air changes re-suspends aerosols



The deposition and resuspension of aerosols is closely related to air turbulence.



Anticipated benefits

Patient outcomes and hospital finances

Figure 11
Projected financial impact of room air humidification for a 250-bed hospital

Cost-reduction analysis if healthcare-associated infections were decreased by 20%

		Q1	Q2	Q3	Q4
BENEFITS - Year One		Dollars			
Increased Revenue	Maximize per day bed value by decreasing LOS	1,310,126	1,310,126	1,310,126	1,310,126
	Decrease non-reimbursable HAI costs	764,890	764,890	764,890	764,890
Cost Avoidance	3% CMS penalty for HAI readmissions	91,787	91,787	91,787	91,787
	CMS Quality Index penalty	TBD			
	JCA citations and hospital closure	TBD			
	Employee absenteeism	TBD			
	Quarterly total	2,166,803	2,166,803	2,166,803	2,166,803
	Cumulative value	2,166,803	4,333,606	6,500,409	8,667,212
INVESTMENTS					
	Gas				
	Installation & Integration of New System	(1,198,500)			
	Maintenance	(23,850)	(23,850)	(23,850)	(23,850)
	Operating Cost	(34,573)	(34,573)	(34,573)	(34,573)
	OR & PT Room Down Time	(10,000.00)	-	-	-
	Quarterly total	(1,266,923)	(58,423)	(58,423)	(58,423)
	Cumulative investment	(1,266,923)	(1,325,347)	(1,383,770)	(1,442,194)
NET VALUE					
	Quarterly total	$ 899,880	$ 2,108,380	$ 2,108,380	$ 2,108,380
	Cumulative total	$ 899,880	$ 3,008,259	$ 5,116,639	$ 7,225,018
	1st year net return	*$7,225,018*			
	Breakeven point	*1st Quarter*			
	ROI (1st year)	*500.97%*			

Conclusion

The hospital's physical environment has a significant impact on the health of patients. Unfortunately, too many patients are harmed and hospitals waste money on avoidable HAIs.

The dry air in most hospitals create habitats for microorganisms that are unprecedented in the natural world, and have untold consequences for the selection and transmission of pathogens. By maintaining RH in patient care spaces between 40 to 60%, the transmission and infectivity of airborne pathogens will be reduced, and surface cleaning will be more effective due to less resuspension and re-deposition of pathogens.

In addition to creating a less infectious environment, indoor air hydration will support patients' physiologic skin and respiratory tract defenses, immune cell functioning, wound healing and total body fluid balance - all natural defenses against HAIs.

Current indoor air guidelines for hospitals do not specify a lower limit RH in patient care areas and are even promoting lowering the minimum acceptable RH level in operating rooms from the current 35% down to 20%.

This is a mistake! Management of healthcare facilities must focus on the number one priority - patient healing.

Next Steps

40 is the new 20! Reduce HAIs with balance indoor air hydration

To best protect patient health, optimize clinical outcomes and decrease excess healthcare costs, we must maintain the indoor RH between 40 to 60%. Hence, 40 is the new 20!

Proper indoor air hydration with hygienic, low energy consuming humidification systems provides an underutilized opportunity to improve clinical outcomes by reducing HAIs, thereby shortening in-patient stays, decreasing readmissions, and reducing non-reimbursable hospital expenditures.

- ☑ Take an open minded approach, putting patient wellbeing over the "status quo" facility management
- ☑ Monitor the RH in patient rooms and adjoining support spaces
- ☑ Accurately record patient outcomes, especially HAIs, in the monitored rooms
- ☑ Inspect HVAC systems and the building envelope for water infiltration
- ☑ Choose indoor air hydration (humidification) specialists with both engineering and healthcare knowledge and expertise to address the unique challenges of hospitals
- ☑ Install hygienic and low energy humidification systems to maintain balanced indoor RH
- ☑ Record patient outcomes while monitoring and maintaining indoor RH
- ☑ Communicate changes in patient outcomes, revenue and ROI from implemented humidification solutions so others can learn from your experience

The two steps: monitor indoor RH, maintain RH between 40% - 60%!

Unanswered questions and future research

1. Does transportation in airborne aerosols increase antibiotic resistance?
2. To what extend are antibiotic resistant genes from soil organisms infiltrating into buildings? How does indoor climate affect this?
3. To what extent does indoor RH from 40%–60% contribute to a more diverse indoor microbiome?
4. To what extent are bacteria in desiccated aerosols (surviving prolonged periods of time) an infective reservoir which out of reach for disinfectants?

About the author

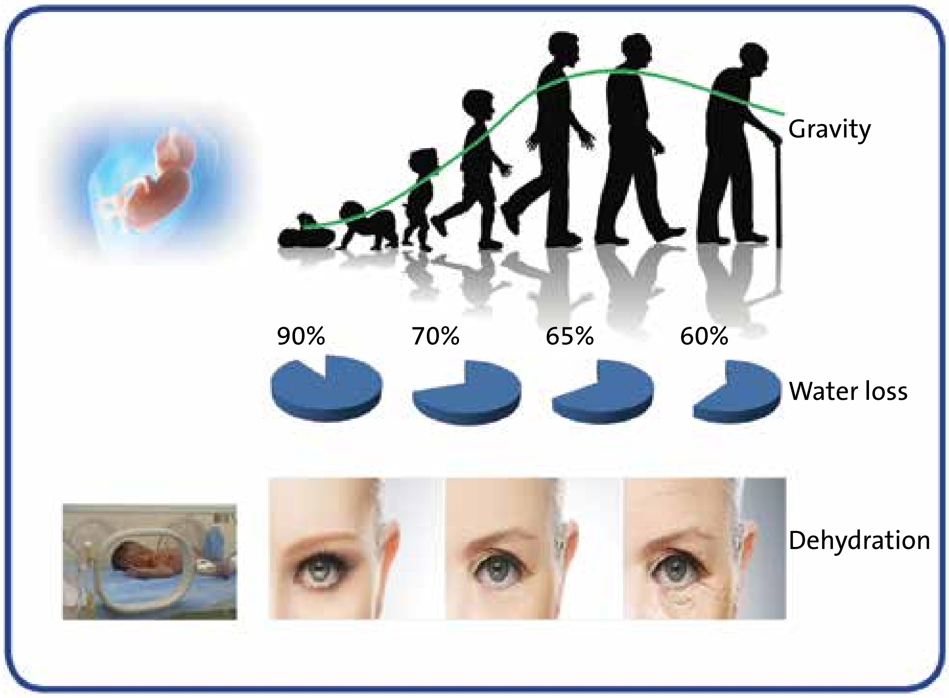
Dr. Stephanie Taylor is the CEO of Taylor Healthcare Consulting, Inc. After working as a physician for many decades, Dr. Taylor obtained a Masters in Architecture as well as Infection Control certification. Her lifelong commitment to patient care now includes working to improve the healthcare physical environment and clinical work processes to help patients heal quickly and save hospitals valuable dollars. Dr. Taylor received her MD from Harvard Medical School, and her Masters in Architecture from Norwich University. She has numerous research publications in Nature, Science, and other peer-reviewed journals.

Acknowledgements

M.Colin Tasi, MD and MBA Candidate
Traci Hanegan, PE
Walter Hugentobler, MD

Figure 12

Human life is an ongoing struggle against gravity and dehydration ... let's not make this worse by drying out the air



References

1. Hussey PR, Wertheimer S, Mehrotra S. 2013. The Association Between Health Care Quality and Cost: A Systematic Review. Ann Intern Med.158: 27-34.
2. Murphy D, et al. 2007. Dispelling the Myths: The True Cost of Healthcare-Associated Infections. APIC Briefing. February.
3. James John T. 2013. A New, Evidence-based Estimate of Patient Harms Associated with Hospital Care. Journal of Patient Safety. 9(3):122–128.
4. Gwande A. 2007. In Conversation with Atul Gawande, MD, MA, MPH. Perspectives on Safety, Patient Safety Network, AHRQ.
5. Center for Medicare and Medicaid. 2015. Hospital-acquired Condition Reduction Program, http://www.cms.gov/Medicare/Medicare-Fee- for-Service-Payment/Acute Inpatient PPS/FY2015-IPPS-Final-Rule-Home-Page. CMS.gov.
6. Hospital Professional Liability and Physician Liability Benchmark Analysis. 2008. American Society for Healthcare Risk Management. NYSE: AOC.
7. Meadow J, Altrichter E, Kembel S, Kline J, Mhuireach G, Moriyama M, Northcutt D, O'Connor T, Womack A, Brown G, Green J, Bohannan B. 2014. Indoor airborne bacterial communities are influenced by ventilation, occupancy, and outdoor air source. Indoor Air. 24:41–48.
8. Hospodsky D, Qian J, Nazaroff W, Yamamoto N, Bibby K, et al. 2012. Human Occupancy as a Source of Indoor Airborne Bacteria. PLoS ONE 7(4): e34867. doi:10.1371/journal.pone.
9. Nazaroff W. 2014. Indoor bioaerosol dynamics. Indoor Air. 26:61–78.
10. Kembel SW, Meadow JF, O'Connor TK, Mhuireach G, Northcutt D, Kline J, et al. 2014. Architectural Design Drives the Biogeography of Indoor Bacterial Communities. PLoS ONE 9(1): e87093. doi:10.1371/journal.pone.
11. Bourouiba L, Dehandschoewercker E, Bush, J. 2014. Violent expiratory events: on coughing and sneezing. Journal of Fluid Mechanics. 745: 537–563.
12. Aliabadi A, Rogak S, Bartlett K, Sheldon I. 2011. Preventing Airborne Disease Transmission: Review of Methods for Ventilation Design in Health Care Facilities. Advances in Preventive Medicine. 2011: Article ID 124064.
13. Burke, J. 2003. Infection control - a problem for patient safety. N Engl J Med, 348(7): 651-656.
14. Tang J. 2009. The effect of environmental parameters on the survival of airborne infectious agents. Journal of Hospital Infection. 64: 100e114.
15. Tang JW, Li Y, Eames I, Chan PKS, Ridgeway GL. 2006. Factors involved in the aerosol transmission of infection and control of ventilation in healthcare premises. J of Hospital Infection 64, 100-114.
16. Westwood J et al. 2014. The hospital microbiome project: meeting report for the UK science and innovation network UK-USA workshop 'beating the superbugs: hospital microbiome studies for tackling

References (continued)

antimicrobial resistance. Standards in Genomic Sciences 10:1186–1944.

17. Noti JD, Blachere FM, McMillen CM, Lindsley WG, Kashon ML, et al. 2013. High Humidity Leads to Loss of Infectious Influenza Virus from Simulated Coughs. PLoS ONE 8(2): e57485. doi:10.1371/journal.pone.0057485.
18. Shreiner A, Kao J, Young V. 2016. The Gut Microbiome in Health and in Disease. Current opinion in gastroenterology 31(1): 69–75.
19. World Health Organization. 2009. Guidelines for indoor air quality, dampness and mould.
20. Green B, Tovey E, Sercombe J, Blachere F, Beezhold D, Schmechel D. 2006. Airborne fungal fragments and allergenicity. Med Mycol. Sep;44 Suppl 1:S245-55.
21. English T. 2016. A brief History of healthcare ventilation, ASHRAE proceedings.