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Energy Recovery Ventilation

DEFICIENT INDOOR AIR QUALITY: A SERIOUS THREAT TO ALL CAMPUS BUILDINGS, ESPECIALLY HOSPITALS AND SCHOOLS

Cleaner and healthier indoor air achieved via energy recovery ventilation improves the health, cognitive function, productivity and wellbeing of all building occupants

By Nick Agopian

Buildings in campus settings, in particular hospitals and K-12 schools, are extremely vulnerable to deficient indoor air quality (IAQ). This is especially true with improved air-sealing methodologies on the rise that not only trap in air but also numerous internally generated contaminants from structures and occupants via off-gassing and activities. Deficient IAQ has many adverse effects on the occupants of these campus buildings, such as increased infection rates in hospitals and impaired academic performance for students in schools, to name just a few.

The best way to enhance IAQ is with increased ventilation, but conventional systems waste energy and therefore lead to additional costs. So how can IAQ be enhanced energy-efficiently, cost-effectively and sustainably in order to support both the physical and mental health of hospital and school occupants? The answer is through balanced energy recovery ventilation, a process that reuses otherwise-wasted heat and humidity from the exhaust air going out to precondition the outdoor air coming in, resulting in cleaner and healthier indoor air and HVAC energy costs reduced by up to 40 percent.

Deficient IAQ threatens all campus buildings, especially hospitals and schools
Image courtesy of Cleaning Management Institute

The Situation: Deficient IAQ Threatens all Buildings—Especially Hospitals & Schools

With buildings becoming increasingly air-sealed, a consequence is a rise in deficient IAQ, which is a serious—yet often unnoticed—threat to occupant health, cognitive function, productivity and general wellbeing. Deficient IAQ is especially concerning since people are indoors about 90 percent of the time (the elderly 95 percent) and the Environmental Protection Agency (EPA) found that indoor air may be two to five times, and occasionally greater than 100 times, more polluted than outdoor air. Hence the EPA ranks indoor air pollution among the top-five environmental risks to public health.[1]

If that's not enough to instill concern over deficient IAQ, the World Health Organization (WHO) determined that in 2012, 4.3 million deaths globally were attributable to indoor air pollution.[2] The WHO also found that 30 percent of all new or renovated buildings suffer from deficient IAQ, that 24 percent of U.S. workers perceived indoor air quality problems and that 20 percent of these workers believed their performance was hampered as a result.[3] Further, the average person uses 33 pounds of air a day compared to only about two pounds of food and about four pounds of water, thus underlining the importance of high-quality indoor air.[4]

What causes deficient IAQ? A complex array of internally generated contaminants, such as toxins, vapors, gases, chemicals, odors and other Volatile Organic Compounds (VOCs), can build up and diminish IAQ in hospitals, schools and all homes and buildings. Contaminants are introduced in many ways, but the primary means is by being off-gassed from sources such as construction materials, furniture, fabrics, carpets, paints, sealants, finishes, cleaning supplies, human activity and even the human metabolic process that emits bioeffluents.

Hospitals and schools are at particular risk of experiencing deficient IAQ due to their high-occupant densities, constant maintenance needs and budget constraints. Regarding hospitals, there are so many indoor air contaminants being introduced constantly that the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) stated in its HVAC Design Manual for Hospitals and Clinics that, "Healthcare facilities are environments of controlled hazards."[5]

Schools also suffer considerably from deficient IAQ. The EPA determined that schools can have up to four times the number of occupants as an office building of similar size, meaning that more carbon dioxide (CO_2)—which is considered an indoor air contaminant—is exhaled into the air.[6] What's more, the EPA listed deficient IAQ as a serious problem faced by the U.S.'s schools since it found that about 50 percent of school buildings have problems linked to poor indoor air quality.[7]

[1] All EPA facts from this paragraph are sourced from: "Why Indoor Air Quality is Important to Schools," EPA, https://www.epa.gov/iaq-schools/why-indoor-air-quality-important-schools.

[2] "Burden of disease from ambient and household air pollution," World Health Organization (WHO), http://www.who.int/phe/health_topics/outdoorair/databases/en/.

[3] "Indoor Air Pollution: Introduction for Health Professionals," U.S. Consumer Product Safety Commission, http://www.cpsc.gov/en/Safety-Education/Safety-Guides/Home/Indoor-Air-Pollution-Introduction-for-Health-Professionals/.

[4] M. Ramaswamy, Farooq Al-Jahwari, Saif M. Masoud Al-Rajhi, "IAQ in Hospitals—Better Health through Indoor Air Quality Awareness," Texas A&M University, 2010, https://oaktrust.library.tamu.edu/bitstream/handle/1969.1/94139/ESL-IC-10-10-88.pdf?sequence=1&isAllowed=y.

[5] Dan Pollock, "Surgical Suite: Creating the Optimal Environment," Trane, October 2009, https://www.trane.com/content/dam/Trane/Commercial/global/markets/healthcare/Surgical_Suite.pdf.

[6] "Air Indoor Resources," Florida Department of Education, http://www.fldoe.org/finance/edual-facilities/air-indoor-resources.stml.

[7] "Indoor Air Quality (IAQ) in Schools," Minnesota Department of Health, http://www.health.state.mn.us/divs/eh/indoorair/schools/.

Specifically for hospitals and schools, the primary indoor air contaminants found inside each building type are listed below:

Indoor Air Contaminants in Hospitals & Schools[8]		
Contaminants	**Sources**	**Adverse Effects**
Humidity	Exhaled breath, water sources (faucets, showers, leaks)	Aggravated allergies and asthma
Carbon dioxide	Exhaled breath	Headaches, fatigue, drowsiness, eye and throat irritations, cognitive impairment, decision-making difficulty
Formaldehyde	Off-gassed from adhesives, fabric treatments, stains, varnishes	Irritations to respiratory system, eyes, nose and throat, carcinogen potentially causing cancer
Other Volatile Organic Compounds (VOCs), toxic gases, vapors	Off-gassed from furniture, carpets, paints, cleaners, solvents, glues, other building materials	Headaches, fatigue; irritations to eyes, nose, throat and skin
Odors	Bathrooms, kitchens, pets, occupants	Headaches, dizziness, nausea
Bioeffluents	Human metabolic process	Headaches, fatigue, drowsiness; irritations to eyes, nose, throat and skin
Molds, microbial contaminants, fungi	Stagnant water, drains, condensate pans, damp areas	Aggravated allergies and asthma
Bacteria, viruses	Skin microbiota, coughing	Sicknesses, diseases, infections (such as Methicillin-resistant Staphylococcus aureus or MRSA)
Radon	Uranium decaying in the soil	Cell damage, carcinogen potentially causing cancer
Dust mites	Carpets, fabric, foam cushions	Aggravated allergies and asthma
Phthalates	Off-gassed from adhesives, vinyl flooring, wood finishes, plastic plumbing pipes, other building materials	Obesity, reproductive problems, carcinogen potentially causing cancer
Carbon monoxide	Gas heating systems, gas stoves, gas hot-water heaters, cigarette smoke, cars inside parking garages	Headaches, fatigue, dizziness
Tobacco smoke	People smoking inside or near a home or building (first-hand, second-hand, third-hand)	Headaches, dizziness, carcinogen potentially causing cancer
Ozone	Off-gassed from office equipment, electric motors, electrostatic air cleaners	Chest pain, asthma, respiratory irritations
Lead	Pipes, paint	Problems with central nervous system, kidney and blood cells; impairment of mental and physical development; convulsions, comas and death at high levels
Asbestos	Insulation	Long-term risk of chest and abdominal cancers and lung diseases

In addition to the indoor air contaminants listed above that are found in both hospitals and schools, the below chart outlines the indoor air contaminants particular to hospitals:

Indoor Air Contaminants Particular to Hospitals[9]		
Contaminants	**Sources**	**Adverse Effects**
Formaldehyde, acetaldehyde	Off-gassed from medical disinfectants, fixatives, preservatives	Irritations to respiratory system, eyes, nose and throat; carcinogens potentially causing cancer
Glutaraldehyde	Off-gassed during sterilization process	Bodily irritation, asthma, difficulty breathing
Ethylene oxide	Off-gassed during sterilization process	Gastric irritation, liver injury, respiratory irritation, lung injury, headache, nausea, vomiting, diarrhea, shortness of breath, cyanosis, carcinogen potentially causing cancer

[8] Sources: U.S. Environmental Protection Agency (EPA), U.S. Centers for Disease Control and Prevention (CDC), Canadian Centre for Occupational Health and Safety (CCOHS), Occupational Safety & Health Administration (OSHA), Wikipedia.

[9] Sources: U.S. Environmental Protection Agency (EPA), U.S. Centers for Disease Control and Prevention (CDC), Canadian Centre for Occupational Health and Safety (CCOHS), Occupational Safety & Health Administration (OSHA), Wikipedia.

Indoor Air Contaminants Particular to Hospitals[9]		
Aromatic hydrocarbons, such as benzene	Hand sanitizer	Carcinogen potentially causing cancer
Respirable suspended particulates, such as tiny airborne particles or aerosols ($PM_{2.5}$)	Combustion, industrial processes, power generation, use of lasers and electrosurgical dissection devices	Permanent DNA mutations, heart attacks, premature death
Latex allergens	Off-gassed from latex gloves	Allergic reactions, skin irritations

The Challenge: Deficient IAQ has Many Adverse Effects on Occupants of Hospitals & Schools

Deficient IAQ has numerous adverse effects on the on the health, cognitive function, productivity and general wellbeing of all indoor occupants. Below are the adverse effects of deficient IAQ that are specific to hospitals and schools:

Adverse Effects of Deficient IAQ on Occupants of Hospitals	
Increased infections	Hospital-acquired infections are a serious problem in U.S. hospitals, and the issue is aggravated by deficient IAQ, especially since many infection threats in hospitals are airborne.[10] According to the Centers for Disease Control and Prevention (CDC), more than two million patients a year acquire a variety of infections in U.S. hospitals while they are hospitalized for other health problems, and that 88,000 of these patients die as a direct or indirect result. Out of these deaths, it's estimated that about 5,000 are related to poor construction and maintenance practices, which can increase indoor air pollution.[11] Furthermore, up to one-third of all hospital-acquired infections are caused by airborne contaminants—such as inorganic particles, mold and bacteria—which means that poorly ventilated hospitals suffer from greater instances of airborne infections due to their poor-quality indoor air.[12]
Transmitted diseases and viruses	When patients are sick, they can easily spread their diseases and viruses through the air via skin microbiota and coughing, thus contributing to deficient IAQ. In fact, patients are the source of some of the most potent contaminants in hospitals, such as MRSA.[13] Therefore, it's essential for a ventilation system to remove these diseases and viruses from the indoor air to prevent their transmission.
Aggravated patient harm	Patients are already in a vulnerable state due to their weakened condition and therefore are apt to suffer aggravated harm due to deficient IAQ. This is especially true for patients with compromised immune systems who aren't allowed to move around a hospital due to infection risks, yet are just as exposed in their own bed to contaminants if a hospital is poorly ventilated. Moreover, according to the EPA, 50 percent of all illnesses are either caused by, or aggravated by, polluted indoor air.[14]
Compromised surgeries	Patients undergoing surgeries are particularly vulnerable to deficient IAQ since sensitive tissues and organs are often exposed to the air and therefore can be negatively impacted by airborne bacteria, viruses and other microbes, which can increase infections.[15]
Cognitive impairment of staff	Deficient IAQ causes cognitive impairment, as shown in studies by NASA, the Harvard School of Public Health and the Lawrence Berkeley National Laboratory in which CO_2 negatively impacted thinking and decision-making at levels commonly found inside most buildings, including hospitals. NASA even found instances of cognitive impairment in astronauts at much lower CO_2 levels than expected.[16] Therefore, this means that nurses, doctors and all hospital staff are at risk of their cognitive function being seriously impaired, which can severely impact patient care.
Productivity decline for staff	Deficient IAQ causes serious losses in productivity for businesses of every type, including hospitals, due to worker sickness and absenteeism. In fact, worker absenteeism due to deficient IAQ is estimated to cost the U.S. economy $168 billion annually, according to the Building Ecology Research Group.[17]
Increased financial costs	According to the CDC, the overall annual direct medical costs of hospital-acquired infections to U.S. hospitals can be up to $45 billion after adjusting to 2007 dollars using the Consumer Price Index (CPI) for inpatient hospital services.[18] A large amount of these financial costs can be attributed to increased instances of infections due to deficient IAQ.

[9] Sources: U.S. Environmental Protection Agency (EPA), U.S. Centers for Disease Control and Prevention (CDC), Canadian Centre for Occupational Health and Safety (CCOHS), Occupational Safety & Health Administration (OSHA), Wikipedia.

[10] Laura Rygielski Preston, "Breath of fresh air: Indoor air quality critical to effective infection control," Medical Construction & Design, January/February 2011, https://www.trane.com/content/dam/Trane/Commercial/global/markets/healthcare/FdMCD0111_52-54-IF-IAQ.PDF.

[11] D. Riley, J. Freihaut, W. P. Bahnfleth, Z. Karapatyan, "Indoor Air Quality Management and Infection Control in Health Care Facility Construction," Penn State College of Engineering, 2004, http://www.engr.psu.edu/iec/publications/papers/indoor_air_quality.pdf.

[12] Dan Pollock, "Surgical Suite: Creating the Optimal Environment," Trane, October 2009, https://www.trane.com/content/dam/Trane/Commercial/global/markets/healthcare/Surgical_Suite.pdf.

[13] Christopher J. Stipe, "Indoor air quality in hospitals," Consulting-Specifying Engineer, July 14, 2015, http://www.csemag.com/single-article/indoor-air-quality-in-hospitals/b4a355bfbd61c4902f08216c20be3e8e.html.

[14] Mike Barrett, "Indoor Air Pollution Could Cause 50 Percent of Illnesses Globally," Natural Society, October 21, 2011, http://naturalsociety.com/indoor-air-pollutants-cause-50-of-illnesses-globally/.

[15] Andrew J. Streifel, "A Guide to Best Practices in Hospital IAQ," ACHR News, November 19, 2007, http://www.achrnews.com/articles/105354-a-guide-to-best-practices-in-hospital-iaq.

[16] Joe Romm, "Exclusive: Elevated CO2 Levels Directly Affect Human Cognition, New Harvard Study Shows," Climate Progress, October 26, 2015, http://thinkprogress.org/climate/2015/10/26/3714853/carbon-dioxide-impair-brain/.

[17] Hal Levin, "Commercial Building Indoor Air Quality: Introduction to the Problem," Building Ecology, November 1999, http://www.buildingecology.com/articles/commercial-building-indoor-air-quality-introduction-to-the-problem/.

[18] R. Douglas Scott II, "The Direct Medical Costs of Healthcare-Associated Infections in U.S. Hospitals and the Benefits of Prevention," Centers for Disease Control and Prevention (CDC), March 2009, http://www.cdc.gov/hai/pdfs/hai/scott_costpaper.pdf.

Adverse Effects of Deficient IAQ on Occupants of Schools	
Health problems	Deficient IAQ in schools has many adverse health effects on students, teachers and staff, including acute allergies, headaches, coughs, asthma, skin irritations and breathing difficulties, as well as chronic illnesses such as cancer, liver disease, kidney damage, nervous-system failure and even premature death. In fact, the EPA found that the presence of dampness and mold increases the risk of asthma and related adverse respiratory health effects by 30-50 percent.[19] Further, the EPA determined that schools are at particular risk of deficient IAQ due to insufficient maintenance of facilities and HVAC systems. And the problem is even worse in older buildings that need constant upkeep, which characterizes the majority of the U.S.'s schools since more than 75 percent were built before 1970.[20] All of these facts are particularly alarming considering so many people spend so much time inside schools. More than 55 million school children and about three million adults in the U.S.—equaling 20 percent of the country's population—enter the nation's schools everyday.[21] And the average child spends about 1,300 hours inside a school each year, while teachers and other employees spend even longer.[22]
Problems magnified in children	Children are disproportionately vulnerable to the adverse effects of inhaling indoor air contaminants, according to the WHO. Compared to adults, children breathe in more pollutants per pound of body weight, plus children's airways are narrower, thus leading to greater obstruction caused by contaminants.[23] What's more, children's immune systems are less developed and therefore provide a weaker defense when challenged.
Cognitive impairment	As noted previously, NASA, Harvard and the Lawrence Berkeley National Laboratory determined that deficient IAQ can cause cognitive impairment due to CO_2 exposure. This means that anyone inside a school building, including students, teachers and staff alike, is especially at risk because of the higher-than-average occupant density of schools, and hence the greater amount of CO_2. In fact, Harvard found that, on average, a typical participant's cognitive scores dropped 21 percent with a 400 parts per million (ppm) increase in CO_2.[24] And such a rise isn't hard to reach since even though the design standard for CO_2 levels in most buildings is 1000 ppm, the Lawrence Berkeley National Laboratory found average CO_2 concentrations in elementary schools in California and Texas to be above 1,000 ppm, with a substantial proportion exceeding 2,000 ppm and 21 percent of Texas classrooms exceeding 3,000 ppm.[25]
Diminished academic performance	The EPA determined that a school's physical environment also can play a major role in academic performance, and that negative environmental factors, such as deficient IAQ, can harm students' ability to perform academically. Specifically the EPA found that: ◆ When the school environment is unhealthy, which occurs with poor ventilation, children can be exposed to allergens, pollutants, chemicals and adverse classroom conditions that can cause their academic performance to suffer.[26] ◆ Children in poorly ventilated classrooms tend to score lower on standardized tests in math and reading than children in classrooms with higher outdoor-air ventilation rates.[27] ◆ Modest increases in room temperature negatively affect student's abilities to perform tasks requiring mental concentration. Supporting this notion is a study done by the Science Research Club from Westview High School in Beaverton, Oregon, which found that at the ideal indoor temperature of 72°F, students scored an average of 90 percent (out of 100) on a test, yet when the indoor temperature was increased to 81°F, average test scores dropped dramatically to 72 percent (out of 100).[28]
Increased absenteeism	Many students, teachers and staff alike suffer from Sick Building Syndrome (SBS), which occurs when a person experiences severe health issues and discomfort that have no other cause except for time spent in a building with deficient IAQ. In fact, the WHO found that up to 64 million U.S. workers are at risk of suffering from SBS.[29] What's more, the EPA found that schools with a major maintenance backlog have a lower average daily student attendance rate.[30]

[19] "How Does Indoor Air Quality Impact Student Health and Academic Performance?," U.S. Environmental Protection Agency (EPA), https://www.epa.gov/iaq-schools/how-does-indoor-air-quality-impact-student-health-and-academic-performance.

[20] Sherry Everett Jones, PhD, MPH, JD, Nancy D. Brener, PhD, Tim McManus, MS, "Prevalence of School Policies, Programs, and Facilities That Promote a Healthy Physical School Environment," American Journal of Public Health, September 2003, http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1448012/#r4.

[21] "Healthy Schools: Environmental Factors, Children's Health and Performance, and Sustainable Building Practices," U.S. Environmental Protection Agency, October 8, 2013, https://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.rfatext/rfa_id/568.

[22] "Healthy Schools: Environmental Factors, Children's Health and Performance, and Sustainable Building Practices," U.S. Environmental Protection Agency, October 8, 2013, https://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.rfatext/rfa_id/568.

[23] "Children's Health and the Environment," World Health Organization (WHO), July 2008, http://www.who.int/ceh/capacity/Indoor_Air_Pollution.pdf.

[24] Joe Romm, "Exclusive: Elevated CO2 Levels Directly Affect Human Cognition, New Harvard Study Shows," Climate Progress, October 26, 2015, http://thinkprogress.org/climate/2015/10/26/3714853/carbon-dioxide-impair-brain/.

[25] Joe Romm, "Exclusive: Elevated CO2 Levels Directly Affect Human Cognition, New Harvard Study Shows," Climate Progress, October 26, 2015, http://thinkprogress.org/climate/2015/10/26/3714853/carbon-dioxide-impair-brain/.

[26] "About the State School Environmental Health Guidelines," U.S. Environmental Protection Agency (EPA), https://www.epa.gov/schools/about-state-school-environmental-health-guidelines.

[27] "Evidence from Scientific Literature about Improved Academic Performance," U.S. Environmental Protection Agency (EPA), https://www.epa.gov/iaq-schools/evidence-scientific-literature-about-improved-academic-performance.

[28] Josean Perez, Julio Montano, Jose Perez, "Healthy Schools as a Learning Tool," Healthy Schools, http://healthyschools.cefpi.org/index.html.

[29] William Fisk, "How IEQ Affects Health, Productivity," ASHRAE Journal, 2002, https://publications.lbl.gov/islandora/object/ir%3A120146/datastream/PDF/download/citation.pdf.

[30] "How Does Indoor Air Quality Impact Student Health and Academic Performance?," U.S. Environmental Protection Agency (EPA), https://www.epa.gov/iaq-schools/how-does-indoor-air-quality-impact-student-health-and-academic-performance.

The Solution: Energy Recovery Ventilation is the Best Choice for Enhancing IAQ

What's the best way to provide cleaner and healthier air inside campus buildings, such as hospitals and schools? The answer is increased and balanced ventilation. As long as enough controlled and filtered fresh outdoor air is coming in and stale indoor air is exhausted out, indoor spaces will enjoy high-quality air. In fact, the American Lung Association states that proper ventilation is essential for keeping the air fresh and healthy indoors.[31]

So how can IAQ be enhanced while also minimizing costs and even generating savings? The best way is via energy recovery ventilation (ERV), which enhances IAQ while maximizing sustainability and safeguarding the environment. The ERV process optimizes energy efficiency by preconditioning the outdoor air coming in with the exhaust air's heat and humidity that's otherwise wasted by conventional systems. This leads to substantial reductions in energy and equipment costs, thus spurring the EPA to state that, "ERV systems provide excellent opportunities for saving energy, controlling humidity and providing sufficient outside air to promote IAQ."[32]

Below are the specific benefits realized through energy recovery ventilation:

Benefits of Energy Recovery Ventilation	
Cleaner and healthier indoor air	IAQ is enhanced since internally generated contaminants are removed by exhausting stale indoor air, while outdoor contaminants are prevented from entering through filtration.
HVAC energy costs are decreased by up to 40 percent	This is possible by optimizing energy efficiency, reducing HVAC loads, decreasing capital and operating costs and cutting peak demand.
Significant annual long-term energy savings	Due to optimized energy efficiency and reduced HVAC loads every year for the life of the system—which can be over 25 years—significant annual energy savings are generated over the long-term.
Increased structural asset value and longevity	When buildings suffer from deficient IAQ, not only are indoor occupants feeling the adverse effects, but a poor indoor environment also produces a diverse assortment of potentially negative impacts on the asset value and longevity of the structure. For example, the growth of microbiological organisms might be encouraged, mold might be more apt to propagate, upkeep and maintenance demands could increase and premature construction-material failure could be more common, just to name a few damaging scenarios. Enhanced IAQ assists in preserving the overall health and integrity of the actual structure, thus increasing its asset value and longevity.
Lowered capital and operating costs	By downsizing HVAC equipment and streamlining operations, capital and operating costs are lowered.
Strengthened sustainability	Less HVAC energy used means a reduced environmental footprint, which strengthens sustainability efforts.

The Results: Enhanced IAQ Improves the Health, Cognitive Function, Productivity & Wellbeing of Hospital & School Occupants

Enhancing IAQ energy-efficiently, cost-effectively and sustainably through energy recovery ventilation results in numerous benefits for the occupants of hospitals and schools. Below are the specific benefits achieved for each building type as a result of providing cleaner and healthier indoor air:

Benefits of Enhanced IAQ for Occupants of Hospitals	
Reduced infections	According to the CDC, 70 percent of hospital-acquired infections are preventable.[33] Indoor air contaminants are a primary contributor to increased infection rates, and therefore, by enhancing IAQ, the number of hospital-acquired infections can be reduced. Along these lines, the Center for Health Design found that: ◆ Providing clean filtered air and effectively controlling indoor air pollution through ventilation are two key aspects of maintaining good air quality, which is possible through the use of HEPA filters since they're highly effective in preventing airborne infections from entering the hospital environment.[34] ◆ Controlling airflow, temperature and humidity in hospitals can help maintain excellent IAQ, which can help control the growth of molds, bacteria, viruses and other pathogens that can cause infections and diseases.[35]
Faster patient recovery	According to a study by Texas A&M University, patients in a controlled indoor environment with high-level IAQ have more rapid physical improvement compared to patients in an uncontrolled environment.[36] Maintaining the right temperature can also help create an indoor environment that promotes healing and prevents pathogens from growing and spreading.[37]

[31] "Ventilation: How Buildings Breathe," American Lung Association, http://www.lung.org/our-initiatives/healthy-air/indoor/at-home/ventilation-buildings-breathe.html.

[32] "Indoor Air Quality and Energy Efficiency," U.S. Environmental Protection Agency (EPA), https://www.epa.gov/indoor-air-quality-iaq/indoor-air-quality-and-energy-efficiency.

[33] Laura Rygielski Preston, "Breath of fresh air: Indoor air quality critical to effective infection control," Medical Construction & Design, January/February 2011, https://www.trane.com/content/dam/Trane/Commercial/global/markets/healthcare/FdMCD0111_52-54-IF-IAQ.PDF.

[34] Anjali Joseph, Ph.D., "Impact of the Environment on Infections in Healthcare Facilities," The Center for Health Design, 2006, https://www.healthdesign.org/chd/research/impact-environment-infections-healthcare-facilities.

[35] Anjali Joseph, Ph.D., "Impact of the Environment on Infections in Healthcare Facilities," The Center for Health Design, 2006, https://www.healthdesign.org/chd/research/impact-environment-infections-healthcare-facilities.

[36] M. Ramaswamy, Farooq Al-Jahwari, Saif M. Masoud Al-Rajhi, "IAQ in Hospitals—Better Health through Indoor Air Quality Awareness," Texas A&M University, 2010, https://oaktrust.library.tamu.edu/bitstream/handle/1969.1/94139/ESL-IC-10-10-88.pdf?sequence=1&isAllowed=y.

[37] Laura Rygielski Preston, "Breath of fresh air: Indoor air quality critical to effective infection control," Medical Construction & Design, January/February 2011, https://www.trane.com/content/dam/Trane/Commercial/global/markets/healthcare/FdMCD0111_52-54-IF-IAQ.PDF.