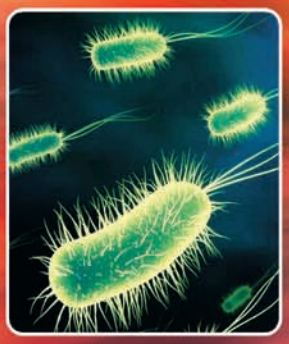
Importance of efficient HVAC designing in Hospitals to improve Indoor Air Quality (IAQ)



Patient Safety Goals

In the United States, ventilation control in hospitals has been part of design since the US Hill Burton Act in 1947 began the specification process for hospital design and construction. Ventilation design in hospitals involves the utilization of a combination of design guidelines and specifications provided by the American Institute of Architects (AIA) Guidelines for Design and Construction of Health Care Facilities and American Society for Heating Refrigeration and Air-Conditioning Engineers (ASHRAE) plus the National Fire Protection and applicable local building codes. Patient safety is crucial and management of hazards in healthcare is constantly challenging in an ever-changing medical technology market. Risk management, when it applies to ventilation, requires understanding of design intent and hazard control. While some risks specifically pertain to chemical control in laboratories, other risk aspects target infectious diseases generated by patients and occupants of the Health Care Facility.

Design

Hospital design requires consideration of comfort levels of patients, healthcare workers and visitors. Because hospitals (in particular) are occupied 24 hours per day/7 days per week, 365 days per year, they require stringent codes for fire management because most patients cannot escape on their own. The presence of flammables and other reactive chemical types necessitates ventilation management for fire risk mitigation. Additionally, in hospitals we isolate patients with infectious diseases. Some of these patients have contact spread microbes while others, to a lesser degree, have airborne spread microbes. We attempt to design our hospitals to anticipate control of these types of infectious agents. However, best practice for these ventilation controls requires validation for functional performance and therefore all controls should be tested.

Table 1. Microorganisms associated with airborne transmission*

	Fungi	Bacteria	Viruses
Numerous reports in health care facilities	Aspergillus spp. Mucorales (Rhizopus spp)	Mycobacterium tuberculosis	Measles (rubeola) virus Varicella-zoster virus
Atypical, Occasional reports	Acremonium spp. Fusarium spp. Pseudoallescheria boydii Scedosporium spp. Sporothrix cyanescens	Acinetobacter spp. Bacillus spp.Brucella spp.Staphylococcus aureus Group A Streptococcus	Smallpox virus (variola) Influenza viruses Respiratory syncytial virus Adenoviruses Norwalk-like virus
Airborne in nature: Airborne transmission in health care settings not described	Coccidioides immittis Cryptococcus spp.Histoplasma capsulatum	Coxiella burnetii (Q fever)	Hantaviruses Lassa virus Marburg virus Ebola virus Crimean-Congo virus
Under investigation	Pneumocystis carinii	-	-

**This list excludes microorganisms transmitted from aerosols derived from water.*

Table 2. Ventilation Parameters for Special-ventilation Rooms

Ventilation Parameters	Airborne Infection	Protective Environment
Air changes per hour	More than 12	More than 12
Filtration:		
Supply	90 % dust spot	99.97 % at 0.3 µm
Return	99.97 % at 0.3 µm	Back through filter or 100 % exhaust
Toilet	100 % exhaust	100 % exhaust
Supply versus exhaust offset	More than 3.6 m^3	More than 3.6 m^3
Air-flow direction	Into room	Out of room
Pressure differential	Over 2.5 Pascal's	Over 2.5 Pascal's
Minimum room leakage	18 cm cm^2 to 38 cm^2 /9.2 m^2 surface	18 cm cm^2 to 38 cm^2 /9.2 m^2 surface

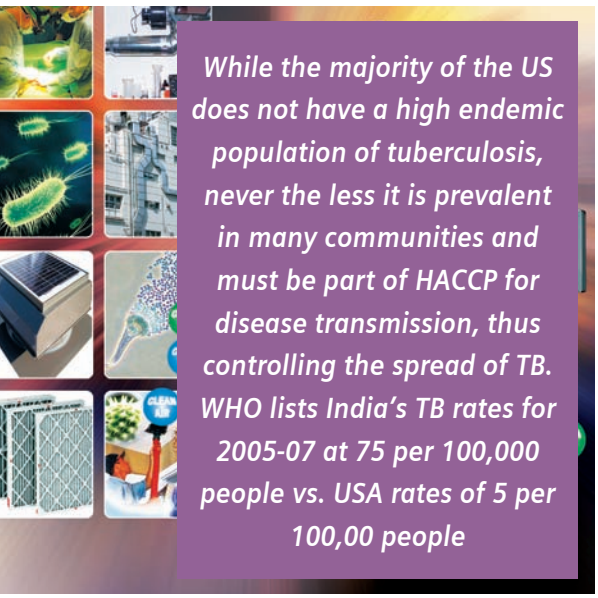
Ventilation also is depended upon for control of potential discomfort from too much or too little heat. Humidity control, also, is important for control of comfort as well as prevention of mold growth in the health care environment. Control of airflow direction with pressure differential is designed to move particles in a direction that should mitigate a patient hazard such as tuberculosis. We design hospitals with a variety of environments and dictate through specification the air exchange rates, filtration and pressure for special ventilation managed spaces. While the degree of hazard varies for airborne infectious agents such as tuberculosis, this world wide persistent disease (TB) is part of work place safety requirements promulgated by the Occupational Safety and Health Administration (OSHA). This means we always have an obligation for TB risk mitigation and a TB mitigation process based on exposure potential in the various endemic regions of the U.S. and the world. Some countries have more exposure potential than others.

In the compromised patient protective environment (PE), facility managers also are aware of the control requirements of the patient care setting for operating rooms and bone marrow transplant rooms. These spaces have set minimums for the pressure >2.5 Pascal's, air exchanges from 12 to 20 per hour, and filtration at or better than 90% efficient (>Minimum Efficiency Rating Value 14). The validation of

these parameters should be part of specified ventilation control assurances. Validation of airflow direction using a smoke pencil has been part of regulation that demonstrates objectively which way the air is flowing. This test does not demonstrate the intensity of the airflow velocity. A pressure gauge is used to demonstrate pressure intensity. Pressure management is infection control. If we can dictate the airflow direction and intensity, we should be able to keep infectious particles away from susceptible hosts-patients and employees.

Existing Conditions

The challenge of knowing what the ventilation system is actually delivering requires an investigation. The original design should provide specification for optimizing an area to provide comfort and control of the patient care environment. But, an aging building will bring about functional problems for the mechanical ventilation. Specified airflow will decrease (fan belt slippage), cooling coils will begin to plug, filters will become dysfunctional, and deferred maintenance will result in ventilation system malfunction. Existing conditions are the functional parameters observed after the initial air balance report. Once the initial baseline values have been established, health care facility managers by using a process of "continuous quality improvement" will be able to not only monitor, but also take corrective action, when the ventilation system has been compromised in any way. There can be significant differences between the system as designed and the system as it is actually functioning. Thus, early detection of system impairments allows the facility management to know when to schedule routine maintenance procedures as well as replace any malfunctioning equipment. This is especially important in assuring patients are protected from common airborne fungal infections while convalescing from severe disease processes confronted during transplantation procedures.



While the majority of the US does not have a high endemic population of tuberculosis, never the less it is prevalent in many communities and must be part of HACCP for disease transmission, thus controlling the spread of TB. WHO lists India's TB rates for 2005-07 at 75 per 100,000 people vs. USA rates of 5 per 100,00 people

Likewise, knowing the ventilation condition of the special ventilation rooms for patients admitted for "rule-out" tuberculosis screening is important for Health Care Workers (HCW) because of the conditions working with potentially hazardous patients if they, in fact, have tuberculosis. While the majority of the United States does not have a high endemic population of tuberculosis, never the less it is prevalent in many communities and must be part of hazard analysis for critical control points (HACCP) for disease transmission, thus controlling the spread of TB. World Health Organization (WHO) lists India's TB rates for 2005-07 at 75 per 100,000 people [vs. USA rates of 5 per 100,00 people]

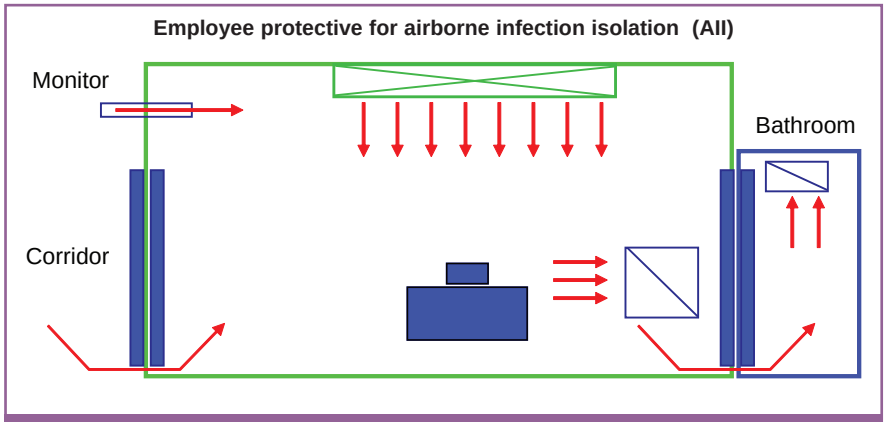


Figure 1. Example of Negative-pressure Room (greater exhaust than supply air volume)

Maintenance/Sustainability

While hospitals are considered an environment of controlled hazards, the roles and responsibilities of infectious disease control managers are essential for solving problems and establishing infection prevention protocols within the HCF. Continuous validation of air handling systems is essential for quality assurance.

Risk, to a certain extent, is variable among health care facilities especially as endemic rates of various infectious diseases change seasonally and geographically. That is why the infection control risk assessment is crucial when evaluating the status of a specific risk, the state of our knowledge concerning the specific diseases, and possible mitigation options. For example, relatively few healthcare institutions will have bone marrow transplant capabilities (with their attendant disease control issues) while all healthcare institutions will have backed up sewers from time to time creating mold growth conditions. How we mitigate the hazard requires conducting a risk assessment for the occupants? Part of that is how we validate ventilation, a key factor for infection prevention regardless of facility. It is important to understand the relative risk in each HCF.

Ventilation validation requires defined specification and construction guidance to accomplish a performance evaluated by functional testing. Saravia, S. University of Minnesota has shown that often

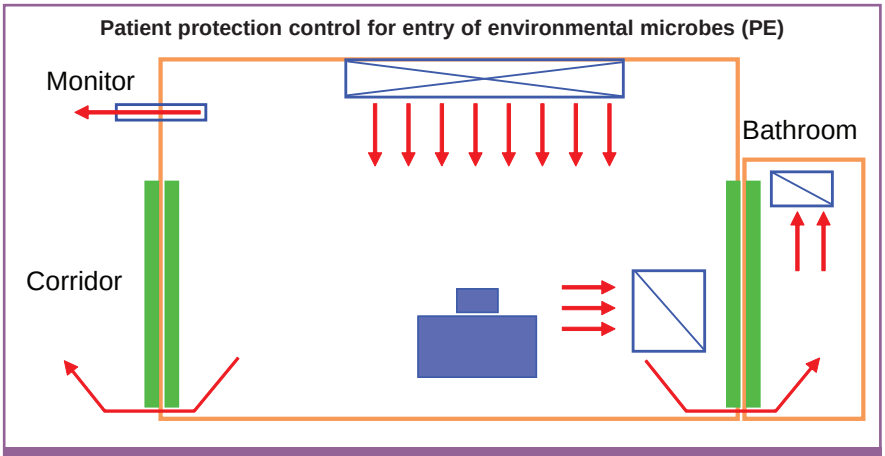


Fig 2. Example of Positive-pressure Room (greater supply than exhaust air volume)

rooms needed for special Airborne Infection Isolation (AII) ventilation do not perform as specified. The negative pressure condition for Airborne Infection Isolation Rooms is mandated by tuberculosis prevention regulations.

The Protective Environment is used for Operating Room (OR) patient protection best practice without regulation other than the codified design guidelines. AIA and ASHRAE provide the information for design. Currently minor discrepancies between these two design guides are found that need reconciliation (for example, formulas for calculating room surface air leakage in sealed rooms). Some countries/states/ provinces/ regions have their own regulations that can feature additional guideline discrepancies to those listed. For example, humidity control is an important climate related consideration for humid tropical versus cold climate healthcare facilities. All in all, intelligent design is needed for a consistent means of functional testing of validating ventilation parameters.

In the US a voluntary inspection of healthcare facilities is performed by The Joint Commission in part to determine appropriate clinical and environmental conditions for safe patient care. It is imperative in the Environment of Care section of the guidance 7.3 of the manual regarding the Infection Control Systems that there are assurances of safe ventilation practice.

Does that mean the air handling pressures should be checked for hazard control? Air exchanges evaluated for dilution ventilation? Particle removal from highly filtered areas ambient air? Yes, this is a safety goal. The first two issues for pressure and air exchanges are relatively easy to define. Because pressure is easy to ascertain with the room door closed using a pressure gauge. Room air exchanges can be difficult to determine if TV's, curtain rods or other ceiling fixtures do not allow for balance testing hood access to the extractor grill. Also in operating rooms with multiple diffusers that, too, can be cumbersome especially with high ceilings.

Regardless of the testing, the important thing to remember is that not testing reveals nothing! Finding a deficiency during a cluster of infections related to airborne spread disease is too late. It is too late when the infected patient walks in and the facility is not ready.

Table 3. Approximate Air Velocity compared Pressure Differential

Pascals	Meters Per Second
0.25	0.6
2.5	2.0
25	6.5

Therefore should we assume that a air duct traverse reading in the supply ducts to operating rooms is sufficient information to assume air exchanges are appropriate and evenly distributed among the diffusers? We need to note that the particle removal becomes something more difficult to judge. The basis of interpretation is particle removal across the respective filter. Therefore the efficiency is measured in a lab by defined criteria of particle removal of various sized test particles. Atmospheric dust can be used for filter efficiency once installed, but there are no criteria for testing installed filters. But once the filters are installed, the fittings to the filter bank and the microclimate conditions in the fans can cause leaks around the housing of the filters.

The interpretation of particles should be based on orders of magnitude reduction. And using a optical particle counter, the reduction of the >0.5µm particles per cubic meter should be about 90 %. International Standards also require demonstration of particle removal based on log reduction for respective class-rooms. In patient care this is more difficult due to healthcare workers and other occupants. Testing before occupancy will allow baseline analysis to demonstrate such reductions showing rank order from clean to cleanest.

Regardless of the testing, the important thing to remember is that not testing reveals nothing! Finding a deficiency during a cluster of infections related to airborne spread disease is too late. It is too late when the infected patient walks in and the facility is not ready. The essence of infection prevention is to mitigate the risk through administrative, engineering and

personal protective controls. Understanding the specification for ventilation control and verification of the air exchanges, room pressure and validation of filtration will help rule out the patient room as a potential source of infection. This demonstration of control is the essence of preparedness. This is difficult especially if we consider the ever-present mold spore in most climates. While we protect occupants from airborne spread infectious disease patients we must consider how to protect patients from airborne spread common opportunistic infectious organisms such as fungal spores from Aspergillous fumigatus. Susceptible patients to this disease are becoming more common especially since the ubiquitous presence of the Aspergillous species is indicative of the need to validate and assure that the health care facility is protecting the specific at risk occupants. In U.S. Aspergillosis has increased significantly since 1970.

In Europe "significant proportions of patients undergoing lung or allogeneic bone marrow transplantation and patients with leukemia will develop invasive mycosis....which, mostly become the cause of death". In developing world regions advancing the medical technology for treating deadly malignant diseases and organ failure the opportunistic fungal infections will also increase. Therefore, understanding the mitigation process for controlling these infections will improve outcomes.

In developing world regions advancing the medical technology for treating deadly malignant diseases and organ failure the opportunistic fungal infections will also increase. Therefore, understanding the mitigation process for controlling these infections will improve outcomes

Demonstrate pressure by taking pressure readings under the door. The use of a digital pressure gauges wall mounted or hand held will show pressure relationships. Pressure controls particle movement in and out of patient rooms. The airflow escaping or being sucked into the patient room should be checked for pressure differential and airflow direction. The pressure in inches water column or Pascal's represents air velocity. The pressure differential and air velocity table shows that when 2.5 Pascal's is compared with airflow the air velocity is about 2 m/s. This velocity pushes air out of the room and leakage areas to prevent airborne spores from entering the patient Protective Environment room. The table below approximates the velocity of air escaping but this is contingent on the shape of the opening.

Likewise if we wish to pull or suck air into the room, the airflow and pressure also is a consideration except it seems to be more difficult to manage a depressurized room. This is because air can be pulled into the room by cracks or leaks independent of the ventilation system. The cracks and leaks provide unwanted additional air volume that makes the desired pressure more difficult to attain. Without a leakage standard for health care we need to over exhaust an area in order to achieve the desired pressure. That means wasted air because the air from Airborne Infection Isolation rooms needs to be exhausted and not

Hospital areas with special-ventilation considerations Best Practice			
At-Risk Area	Equipment	Planning	Routine Evaluation
Bone-marrow transplant	Air-handling system:	• Preventative maintenance	• Air changes per hr
	• Filtration	• Air-quality certification	• Pressure differential
	• Air exchanges	• Emergency planning	• Filtration analysis
	• Positive pressure	• Training	• Vibration check
	• Emergency power	• Outage notification	• Room leak testing
	• Redundant equipment	• Spare parts	
Operating room	Air-handling system:	• Preventative maintenance	• Air changes per hr
	• Filtration	• Air-quality certification	• Pressure differential
	• Air exchanges	• Emergency planning	• Filtration analysis
	• Positive pressure	• Training	
	• Emergency power	• Outage notification	
		• Spare parts	
Airborne-infection isolation	Air-handling system:	• Preventative maintenance	• Air changes per hr
	• Negative pressure	• Outage notification	• Pressure differential
	• Emergency power	• Training	• Room leak testing
	• Exhaust systems	• Label exhaust fan	
Local exhaust areas	Local vacuum system:	• Training of operators	• Filter changes
	• Filters	• Preventative maintenance	• Air velocity and/or room-air changes
	• Hose attachments	• Outage notification	• PPE
	• Air-flow velocity	• Label exhaust fan	
	• Discharge location		

reused. The proposed standard is for the room to have between 18 cm cm^2 to 38 cm^2 /9.2 m^2 surface square feet area except for the slab surface. The housing industry

has a similar standard of 18 cm cm^2 /9.2 m^2 surface feet for a weather tight house in the US. This number can be achieving by using a blower door on a room and pressurizing it. Excess pressure can then be utilized with a smoke stick to find and caulk the room to achieve the specification. Some institutions caulk then test but if the air balance is assured and extreme offset can be accomplished by blocking the return or exhaust then using the smoke stick to find the leakage and seal. Recently this method was used to seal rooms in a hospital ICU preparing to upgrade to BMT status.

Indoor Air Quality (IAQ) Tool Kit

- A particle counter for measuring particles per unit volume.
- A pressure-testing device for measuring air-flow pressure.
- An air sampler for collecting airborne particles capable of growing on growth media.
- A smoke stick for demonstrating air-flow direction.

Validation is essential to assure a safe standard of care. The persistence of airborne infectious diseases like tuberculosis and the emergence of opportunistic fungal spores on compromised patients adds to the need for assuring appropriate ventilation for safe indoor air quality for patients and health care workers. This means demonstration that the ventilation is working as designed is a best practice quality management.

Acknowledgment

Author wish to thank Allen Gronhovd, M.Ed., for his technical assistance.

Andrew J. Streifel is a Hospital Environment Specialist with the Department of Environmental Health & Safety at the University of Minnesota. Mr. Streifel has written articles on design and construction management in health care facilities. He serves on the committee for development of the FGI Guidelines for Design and Construction of Health Care Facilities since 1996. He has consulted with over 400 hospitals world wide on issues relating to hospital air quality, water microbial contamination and environmental infectious agents.