Hospital Pollution Problems, Relevant Regulations, and Control Methods

ENV4121/ENV6126 Air Pollution Control Design

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Abstract

Indoor air quality is of great concern in hospitals as pollutants can pose a serious threat to patients who may already have compromised immune systems.[1] Bioaerosols, like fungal, bacterial, and mold spores, are the most important pollutants monitored for hospital air quality.[3,4] Infections from fungal spores are a serious threat to hospital health as they are more difficult to treat than bacterial infections.[1] Hospital air quality problems are generally caused by poor ventilation or exposure to a contaminant source in buildings; thus, ventilation systems, among other controls like pressure, temperature, and gas scavenging systems, and appropriate regulations and standards are important controls for hospital contaminants and must be continually improved upon.[2,5]

Objective

The objective of this study is to research major air pollution problems in hospitals, the regulations applicable to these issues, and the methods used to remediate them. Furthermore, improvements to these air pollution control systems will be investigated with new, possible innovative treatments assessed.

Background

Adequate indoor air quality (IAQ) is beneficial for human health, especially in hospitals. Due to a hospital's complex environment, IAQ must be regulated to protect patients, healthcare workers, and visitors from hospital-acquired (nosocomial) infections.[6]

The control of IAQ in hospitals prevents infecting hospital staff, visitors, and patients. Immunosuppressed and immunocompromised patients have a higher risk of infection by airborne vectors than other patients.[7,8,9] According to the Centers for Disease Control and Prevention (CDC) an estimated 2 million patients acquire infections in US hospitals while hospitalized for initial health problems, and 88,000 die as a result.[2] In order to minimize nosocomial infections, air pollution control devices, such as HVAC systems, must be installed.

Hospital indoor air pollutants originate from both indoor and outdoor sources. Outdoor sources include vehicle emissions, smoking, and industrial and construction activities.[10] Microorganisms are also present in soil, water, dust, and decaying matter.[7] When disturbed, these microorganisms become volatilized and have the possibility of entering the hospital and causing infections.[7] Studies have indicated a correlation between the presence of pathogens in the hospital air to nosocomial infections.[11]

The major sources of indoor airborne hospital pollution problems are bioaerosols and inhalation of harsh chemicals used in the hospital setting.[7,8] Bioaerosols include bacteria, fungi and viruses which travel inside buildings by floating inside, landing on material brought inside, or infecting a person who then comes inside the hospital.[7,8] Fungus is also able to float through the cracks in the outer walls of hospitals.[12] Condensation formed by the warm outside air meeting the cooler inside air creates an ideal environment for the fungus to proliferate in the wall.[12] To keep mold from entering the hospital, the indoor air pressure is slightly greater than outdoor air pressure (or positive pressure).[12]

Both indoor and outdoor sources release particulate matter (PM) which has the ability to penetrate the lungs into the alveoli. As a result, hospitals regulate PM concentrations and potentially hazardous pollutants such as nitrogen dioxide (NO_2), volatile organic compounds (VOCs), respirable suspended particulates (RSPs), and latex allergens.[6] Hospital buildings are also affected by season, weather conditions, intrusion of moisture, number of occupants, visitors, and human activity.

Pathogens use human carriers as one of the most common routes to enter hospitals.[7,8] People inside the hospital, including patients and doctors, can be symptomatic or asymptomatic carriers of a pathogen. Symptomatic carriers show disease symptoms while asymptomatics do not show the signs of sickness but can still infect others.[7,8] Carriers can spread illness by sneezing, coughing, and, in extreme cases, just breathing.[7,8] Pathogens are then spread by respirable suspended particulates.[7,8] Most illnesses have the highest risk of spreading within three feet of the inflected person.[7,8] In extreme cases (like for tuberculosis or measles), the stream of particles hang in the air for a undetermined amount of time and can travel long distances by wind currents and diffusion.[7,8,9] If patients are known to carry these pathogens, they are placed in negative pressure rooms to avoid pathogen escape.[7,8,9,12]

Waste anesthetic gases (such as nitrous oxide and halogenated anesthetics) are another risk to both patients and hospital staff.[13] Exposure can occur through leaks in the anesthetic breathing and exhaling system or during the transition from one patient to the next.[13] Acute exposure, which generally affects patients, has risks including headache, fatigue, nausea, liver and kidney disease.[13] Chronic exposure risks, which affect the staff, are genetic damage, cancer, birth defects, and miscarriages.[13]

Inhalation of the harsh chemicals used to disinfect, treat, or diagnose illness is another possible risk in hospitals. Mercury can be found in medical equipment and in cleaning solutions.[14] The risks of using mercury in medical equipment comes from the exposure of liquid mercury to the air when an item containing it is broken.[14] Other chemicals used for cleaning in a hospital setting are ethylene oxide and glutaraldehyde.[15] These are high-level disinfectants that when inhaled can cause nausea, vomiting, throat and lung irritation, and neurological disorders.[15]

Regulations, Standards, and Design Recommendations

A few entities play a role in reducing the amount of airborne pollutants within a hospital: the U.S. Environmental Protection Agency (EPA), the Occupational Safety and Health Administration (OSHA), the National Institute of Occupational Safety and Health (NIOSH), and the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). It is important to note that the EPA and OSHA are regulatory authorities while the NIOSH and ASHRAE are recommendatory agencies. This means that the recommendations and standards proposed by NIOSH and ASHRAE are not legally enforceable unless they are specifically referenced in promulgated regulations.

The EPA's most notable regulation that applies to the air quality of hospitals is the Clean Air Act (CAA). The CAA regulates emissions from stationary sources such as factories, power plants, and, for this report, hospitals, and also covers emissions from mobile sources such as vehicle exhausts.[16] A primary goal of the CAA is to meet National Ambient Air Quality Standards (NAAQS) for specific air pollutants nationwide. The air pollutants regulated by NAAQS are carbon monoxide (CO), lead (Pb), nitrogen dioxide (NO_2), ozone, particulate matter (PM), mercury, and sulfur dioxide (SO_2). If a hospital exceeds NAAQS at any time, the facility will be labeled as not attaining the standards. The CAA also regulates air pollutants classified as hazardous (HAPs).[16] These HAPs are discussed in Section 112 of the CAA. Section 112 requires that HAPs generated by sources are reduced using maximum achievable control technology (MACT) standards. Under the CAA, National Emission Standards for Hazardous Air Pollutants, or NESHAPs, have been established to set limits on allowable amounts of HAPs that can be emitted into the atmosphere.

An HAP of particular concern in hospitals is mercury, as it is a widely used metal in numerous medical equipment such as thermometers, sphygmomanometers (blood pressure monitors), gastroenterology instruments, and cleaning solutions.[14] If these instruments break and release mercury, it can volatilize and cause elevated levels of airborne mercury.[14] Under 29 CFR 1910, OSHA has set an allowable exposure limit for airborne mercury of 1 mg/10m.[17]

Although cleaning sterilizers are used to protect patients and staff from infectious pathogens, they also represent a potential indoor air quality issue. Most notably, the sterilizer ethylene oxide (EtO) is a chemical that at certain airborne concentrations causes very serious health problems. EtO is typically used at hospitals to prevent infections by sterilizing medical equipment. However, EtO is classified as an HAP by 40 CFR 63 NESHAP Subpart WWWWW and requires that sterilization using EtO is done under full loads in which all equipment has the same disinfection time requirement.[18] Under 29 CFR 1910:1047, OSHA defines the maximum exposure of EtO as 1 part per million parts of air (ppm) for an 8 hour time-weighted average or 5 ppm in a 15 minute interval.[19] Due to its toxicity, EtO is being slowly phased out in hospital use.

Another commonly used sterilizer is glutaraldehyde. Although it is not regulated, the NIOSH has established suggestions for its handling and usage. Glutaraldehyde recommendations are given in NIOSH Publication Number 2001-115 and are listed in Table 1 of Appendix A.[20]

For the HVAC systems in hospitals, ASHRAE guidelines are a standard in the United States and in many other parts of the world. ASHRAE Standard 62, Ventilation for Acceptable Indoor Air Quality, provides the guidelines that set the standards for providing acceptable indoor air quality in hospitals and may also be mandated if referenced in regulations. General HVAC systems have specifications described in Table 2 in Appendix A.[21] Furthermore, there are ASHRAE specifications for positive and negative pressure isolation rooms along with operating rooms which are given in Tables 3 and 4 within Appendix A, respectively.[21]

As for waste anesthetic gases (WAGs), NIOSH has recommendations to limit exposure to these gases. NIOSH Publication Number 75-137 encourages gas scavenging, or collection of gases and vapors from the anesthetic breathing systems, reducing gas leakage into the operating room by proper administration of anesthetics and maintenance of equipment, and air monitoring to achieve nitrous oxide (N_2O) levels of less than 30 ppm and halothane levels of less than 0.5 ppm.[22] NIOSH Publication Number 96-107 applies directly to N_2O control specifying several requirements. These requirements include having the anesthetic delivery system maintained to prevent N_2O leakage, making sure scavenging systems remove N_2O from a patient's mask at an airflow rate of 45 liters per minute and venting that exhaust outdoors, rooms consisting of 100% clean outdoor air, and using an auxiliary exhaust ventilation to catch excess N_2O from patient breathing.[23] Also, appropriate work practices should be used such as proper mask sizing to fit patients, avoiding unnecessary N_2O dosing, and air monitoring.[23]

Heating, Ventilation, Air Conditioning Systems (HVAC)

Fundamentals of HVAC Systems

The most common air pollution control system for hospitals is the HVAC system. HVAC stands for heating, ventilation, and air conditioning.[24] HVACs are able to remove pollutants such as viruses, bacteria, and cleaner chemicals. In order to understand the overall process of an HVAC, it is useful to think of it as a manufacturing process where there is an input to the system which then generates a final product.[24] In this case, the input is dirty air and the product is clean air emitted into the hospital.

Air that enters an HVAC system comes from two sources: outside air or recycled air from the building.[24] The first step in the cleaning of this air is to mix the air and pass it through an initial filter.[24] This allows relatively large particulate matter to be removed before entering the rest of the HVAC system, helping to avoid issues later on in the process.

The initially filtered air then passes through a heating coil. Temperature is usually raised through steam or water treated with antifreeze.[24] This step is only necessary for HVAC systems in climates where the temperature drops below freezing levels. The heating of the air prevents the subsequent components of the HVAC from freezing.[24]

In order to remove the finer particulate matter, the air then passes through a variety of filters. The most efficient way to remove small particles in an HVAC is to have each subsequent filter smaller than the previous filter.[24] This allows smaller particles to be collected and helps prevent the filters from getting clogged.

The next few steps of the HVAC system allow the cleaned air to be brought to the target characteristics. This includes temperature, humidity, and pressure. Remembering that the air was heated to avoid freezing, it must now be cooled to the desired air temperature of the facility. This is done by passing the air through a cooling coil which will decrease the air to the desired temperature. As this happens, the air will become saturated and some water will precipitate out of the air.[24] Air then passes through a fan which enables the air to reach the target pressure and also causes the air to reach its dew point.[24] This is the section of the HVAC where the desired humidity of the air is produced. In the colder seasons when there is less moisture in the air, a humidifier is needed to inject moisture into the air in order to reach the desired humidity.[24]

The final components of the HVAC system deal with the distribution of the clean air throughout the facility. Ductwork supplies the different sections of the facility with clean air. There may be extra coils and filters for more temperature regulation or particulate matter removal.[24] This would be particularly useful if certain areas of the facility needed to have cleaner air than the rest. The ductwork may also contain devices such as smoke detectors for fire prevention and for the general safety of the HVAC.[24] All HVAC components discussed can be seen in Figure 1 in Appendix A.[24]

<u>Addition of UV Irradiation to HVAC Systems</u>

As discussed previously, one of the more serious issues in hospitals is the ability to acquire infections through the air of the hospital. In a study done in the Northeastern part of the United States, 65 separate cultures were taken from 13 different HVAC systems in different hospitals. From these samples, 100% of them tested positive for bacteria with the ability to cause infection.[25] This is problematic because bacteria have the ability to spread throughout a hospital. The next step in this study was to install ultraviolet (UV) radiation into the HVAC systems. UV lamps were installed in multiple rows on the effluent side of the cooling coils in the HVAC system (Figure 2 in Appendix A).[25] In just 90 days, there was a 99.999% reduction in the colony forming units of the Gram negative bacteria.[25] This study clearly shows that the use of UV irradiation in HVAC systems is beneficial to curb the growth of bacteria.

In general, UV irradiation systems are placed in the HVAC unit after the fan and cooling coils.[25] This placement is done to avoid the bacterial growth on the coils rather than the bacteria in the air moving through the unit. However, in other systems, UV lamps may be placed in the ducts to allow one last disinfection before being blown out into the hospital.[24]

Making HVAC More Efficient

While HVAC systems are the tried and true method of hospital air pollution control, there are some disadvantages to the system. The largest disadvantage is that running an HVAC system is extremely energy intensive, which also means it is costly. It is estimated that hospitals represent about 6% of the total energy consumption in the utility buildings sector with HVAC systems using 60% of the energy required by the hospital.[26]

Generally, it is beneficial to the hospital if the components of the HVAC system are replaced with the most energy efficient models.[26] Since it is not feasible to replace entire systems at once, when a component wears out, it should be replaced with a more efficient model. While upfront costs of replacing components are high, there is usually a payback within a few years.[26]

There are also some simple things that can be done to maximize energy efficiency. One such example is to ensure that there are no leaks in the HVAC system.[26] Leaks will cause the system to expend more energy to get the same result. Maintenance of the system is also important to ensure that everything is clean and working properly.[26] Finally, the placement of objects in the hospital is important to the energy efficiency of the HVAC.[26] If there are things blocking air vents, the system will use more energy to make the room reach the proper conditions. All vents should be clear of dust and have any objects in front of them removed.

UF Shands Hospital HVAC Air Handling Unit

The main way that Shands hospital deals with air pollution control is through an HVAC system. One of the most challenging parts of air pollution control in hospitals is that there are different pressure, particle, and humidity requirements for different rooms. This means that the air pollution control method must be able to handle this wide variety of air conditions.

In Shands, there are 52 air handling units that compose the HVAC system.[12] Each unit is designed to provide air with the specific requirements of the rooms. This means that one unit will provide only air for sterile rooms and another will provide air specific to the general hospital. The two air handling units toured provided air for only a small section of 3 floors of the hospital![12] By the sheer number of units required, it can be quickly understood why HVAC systems use much of a hospital's energy.

The air handling unit begins by drawing in air, 10% of which is drawn from the outside while the rest is recycled. The use of fresh air avoids the development of sick building syndrome and keeps carbon dioxide levels low.[12] Fans are used to blow the air through a pre-filter and then through the heating and cooling coils. The system has a pressure gauge before and after the coil in order to note the pressure drop.[12] The fans are controlled by a variable frequency drive that automatically adjusts the power of the fan in order to achieve the optimum pressure drop.[12] These pressure gauges are also used to determine when the coils need to be cleaned in order to increase efficiency. The air then passes through final filters before entering the ductwork.

In the newer air handling units, UV lamps have been added to deter the growth of bacteria on the coils. Since the air is moving so fast, the UV does not actually disinfect the air.[12] However, by decreasing the amount of bacteria on the coils, the likelihood of bacteria being transported throughout the system decreases.

In order to ensure that the air is being treated properly, the HVAC system is maintained properly and consistently. The pre-filters are changed on a quarterly basis, and the final filters are changed on either an annual or semi-annual basis depending on the type of air being produced by the unit.[12] Shands spends about $200,000 a year on filters alone.[12] Since each room in the hospital is so different, it is also important to ensure that the room air has the proper characteristics. Each room is checked on an annual basis.[12] The other components of the HVAC system are monitored and replaced when they need to be replaced. Shands spends approximately $5,000 year for replacing the various fans in the HVAC system.[12]

While Shands may not have all of the "up and coming" technology in their HVAC system, they are still providing high quality air to the hospital. Shands hospital adopts new technology that makes sense.[12] When a technology comes out that makes sense to adopt based on financial and technological reasons, like the addition of UV, they add it to the system. Doing this allows them to avoid problems that may arise from adopting new technology too quickly.

Additional Control Technologies

High efficiency particulate air (HEPA) filters are found in every aseptic environment, like hospitals, because they reduce the intrusion and spread of airborne pathogens.[27] They are filters designed to remove particulates from dry air with an efficiency of 99.97% or better at 0.3 microns. HEPA filters clean air using the sieve effect, inertial impaction, interception, and diffusion.[28] These filters are used in room recirculation units often found in isolation rooms, and also to filter incoming outdoor air and exhaust air in the HVAC system.[27] HEPA filters do not remove all microbes but the penetration occurs in such small number that this is not an issue unless there is a high inlet concentration of microbes.[27] HEPA filters may also be used in facemasks and respirators that might be required for handling certain tasks within the hospital.[27] Efficiency tends to be inaccurate for these masks, since microbes can leak around the face seal, however, new designs are working with fitted masks to reduce this type of infiltration.[29] In isolation rooms where air is recirculated, HEPA filters are used, but air is passed through multiple times in order to increase the effective filtration rate.[27]

Portable filtration units may also be utilized, especially in hospitals under construction and renovation where invasive fungal spores may be released. One study conducted with 48 units for 2.5 years found a 51% reduction in incidence of Aspergillus, and other retrospective studies show that HEPA filters significantly reduce the concentration of environmental fungal spores.[30] HEPA filters may also be combined with ultraviolet germicidal irradiation (UVGI) to increase efficiency of the filter and the UV system to remove even more infectious particles.

Monitoring filters is important to ensure efficiency. Damage to the filter, a break in the protective seal, clogging, or caking from high humidity air could reduce the efficiency of the system. Pressure drop across the filters must be monitored; particle counts upstream and downstream from filters are also employed to ensure functionality.[28] The filters do not act as a growth medium for trapped microorganisms, as studies show bacteria tend to die rapidly from dehydration.[28] However, some filters still use a self-cleaning method to sterilize the filter, such as UVGI. This further protects those in charge of filter maintenance from exposure.[31]

Waste anesthetic gases (WAGs) are considered to be a severe health hazard to operating room staff, who may be chronically exposed. For this reason, multiple technologies may be used in surgical theaters to ensure the safety of the staff as well as sterility of the environment to reduce risk of infection for the patient.[32] To do this, technologies including filters, pressure ventilation systems, and waste anesthetic scavenging systems may be used.[32]

Gas scavenging systems may be active or passive. Passive systems use a positive pressure differential between the outside exhaust and the higher pressure produced by the patient's breathing or a ventilator. This drives gases through the system and to the exhaust. Active systems use a remote air pump and a negative pressure differential as the driving force for gases to be collected in a reservoir bag.[33] Active systems require high and low pressure relief valves to protect the patient from excessive negative or positive pressures during use.[34] Emerging technology includes a unique gas scavenging hood that fits loosely over the patient's head. An uncuffed endotracheal tube enters through a port in the bag. A suction tube emerges from the top of the bag and connects to a standard suction source, which vents the waste gases out of the building.[35] All three systems have been found to reduce WAGs below the regulated level.

Monitoring the gas scavenging system is very important to ensure there are no leaks or no malfunctions that may put the patient's life in danger. Leaks could nullify the purpose of the gas scavenging system, while malfunctioning pressure valves could cause barotrauma to the patient.[34]

UVGI air disinfection systems designed to disinfect air include in-duct UV systems, stand-alone recirculation units, upper-room systems, and UV barrier systems.[36] UV disinfection systems remove airborne bacteria, viruses, and fungi using ultraviolet radiation from mercury lamps. These systems, especially the in-duct and recirculation UV units may also use filters to reduce contamination since filters remove microbes that tend to be resistant to UV. UV disinfection is not a singular air pollution solution in hospitals, but in combination with other controls it can reduce infection rates.[27]

In-duct systems use UVGI to disinfect the airstream using UV lamp fixtures in the ductwork and filters to keep the lamps clean.[27] Recirculating units contain UV lamps and filters in a housing containing a fan. They are generally portable and used in isolation rooms. Recirculation delivers multiple UV doses, which enhances efficiency.[27] Upper-room systems consist of UV lamps hung from the ceiling. They are designed to provide maximum irradiance in the upper portion of the room, while minimizing UV levels below to protect room occupants from UV exposure.[27] Air that passes through the upper zone is disinfected and remixes with the lower air. The system may run continuously and is safe for patients. They are most often used in tuberculosis (TB) wards and clinics.[35] Continuous air mixing, low relative humidity (below 60%), and temperatures between 68 and 75°F are optimal conditions for upper-room systems, which are also in the range of recommended conditions for patient care areas.[37] UV barrier systems are mounted on doorways with the intention to disinfect air that passes between rooms. Though not commonly used, they have been proven to reduce the spread of airborne illnesses.[27] Making sure the mercury lamps are functional and that the lamps are free of dust are the common ways to monitor the UV efficiency. For upper-room systems, good air mixing is the most important parameter to ensure.[37]

Technology is constantly emerging for improved air quality, especially for those who may be immunocompromised and sensitive to air quality issues. One emerging technique is real time air quality monitoring. The Weiss Mediclean continuous particle monitoring system is designed for operating theaters. The system uses real time particulate monitoring to ensure the particle pollution around the critical zone, or the area surrounding the patient that must remain sterile, is clean. The system uses red, yellow and green light indicators to establish the quality of the surrounding air, and will increase the clean air flow if the air is insufficient until the values have dropped back to optimal levels.[38] This system can further reduce the risk of infection for the patient. It can also dilute WAGs if they are present due to a scavenging system failure and surgical flue gases (mixtures of gas, steam and particles from cutting tissue and bone) to protect hospital staff.[27] Another air disinfection technology in development includes ozonation, which has yet to perfected or proven if the effectiveness outweighs the potential risks of ozone generation indoors. Plasma and corona technologies may also be employed, as well as antimicrobial coatings to reduce the spread of infection in hospitals.[27]

Conclusions

Since hospitals are a place where citizens go to remedy their health problems, they have an obligation to provide the best care to its patients and visitors through superb care and air free of harmful pollutants. For Shands and many other facilities, this concern is at the top of their lists and they continuously improve upon their current installations to find configurations that provide the highest air quality. Meanwhile, they also utilize new technology based on its scientific merit rather than its modernity. These actions allow Shands and other top hospitals to provide outstanding care to its patients and reduce the incidence of many of these air quality problems previously discussed. In the future, advances in air quality control will allow for new technologies to further protect people from these air quality issues and also allow for more stringent regulations to be implemented. Ideally, these new technologies will be able to be utilized globally to further provide everyone with safe, high quality medical care.

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Appendix A: Tables and Figures

Table 1: Glutaraldehyde Recommendations by the NIOSH. Credit: Glutaraldehyde – Occupational Hazards in Hospitals; National Institute for Occupational Safety and Health; http://www.cdc.gov/niosh/docs/2001-115/.

Glutaraldehyde Recommendations by NIOSH
Handling in areas where ventilation has a capture velocity of 100 feet per minute or greater and is able to perform 10 or more air exchanges per hour.
Keep substance under fume hoods when baths containing the chemical are made.
Store in covered containers when the chemical is not being used.
Use minimally during the sterilization process.
Handle using protective equipment (gloves, face shields, etc.).

Table 2: General HVAC Standards. Credit: *Infection Control In Hospitals*; American Society of Heating, Refrigerating and Air-Conditioning Engineers: Atlanta, GA, **2006**; 20091215_ashraed2830120060711.pdf.

General HVAC Standards
80% or less relative humidity within the air ducts.
Positive pressure in patient areas.
Minimum outside air rate of 2 $L/s/m^2$ (0.4 cfm/ft^2) within treatment or ward areas, which can be higher if mandated by code requirements.
Allows and facilitates proper maintenance of air-handling units.
HEPA filters for operating rooms and critical care areas.

Table 3: Isolation Room HVAC Standards. Credit: *Infection Control In Hospitals*; American Society of Heating, Refrigerating and Air-Conditioning Engineers: Atlanta, GA, **2006**; 20091215_ashraed2830120060711.pdf.

Isolation Room HVAC Standards	
Positive Pressure	**Negative Pressure**
10% excess air from dedicated air-handling device.	10% excess exhaust air flow with dedicated air handle per room.
A visual pressure difference gauge and warning system in case positive pressure is lost.	Must have all outside air single-pass air systems.
Minimum of 12 air changes per hour on supply air with recirculation and minimum outside air rate allowed by code.	Warning system in place in case negative pressure is lost.
	Minimum of 12 air exchanges per hour on supply air.
	Exhaust systems only need to be filtered if the hospital requires it.

Table 4: Operating Room HVAC Standards. Credit: *Infection Control In Hospitals*; American Society of Heating, Refrigerating and Air-Conditioning Engineers: Atlanta, GA, **2006**; 20091215_ashraed2830120060711.pdf.

Operating Room HVAC Standards
HEPA units are arranged on the ceiling in a square layout.
Returned air is split with 50% of it returning warm air to the ceiling and the other 50% at low level exhaust for particulate collection.
Air flow rate of 1,700 L/s or 3,600 cfm or at least 20 air exchanges per hour.

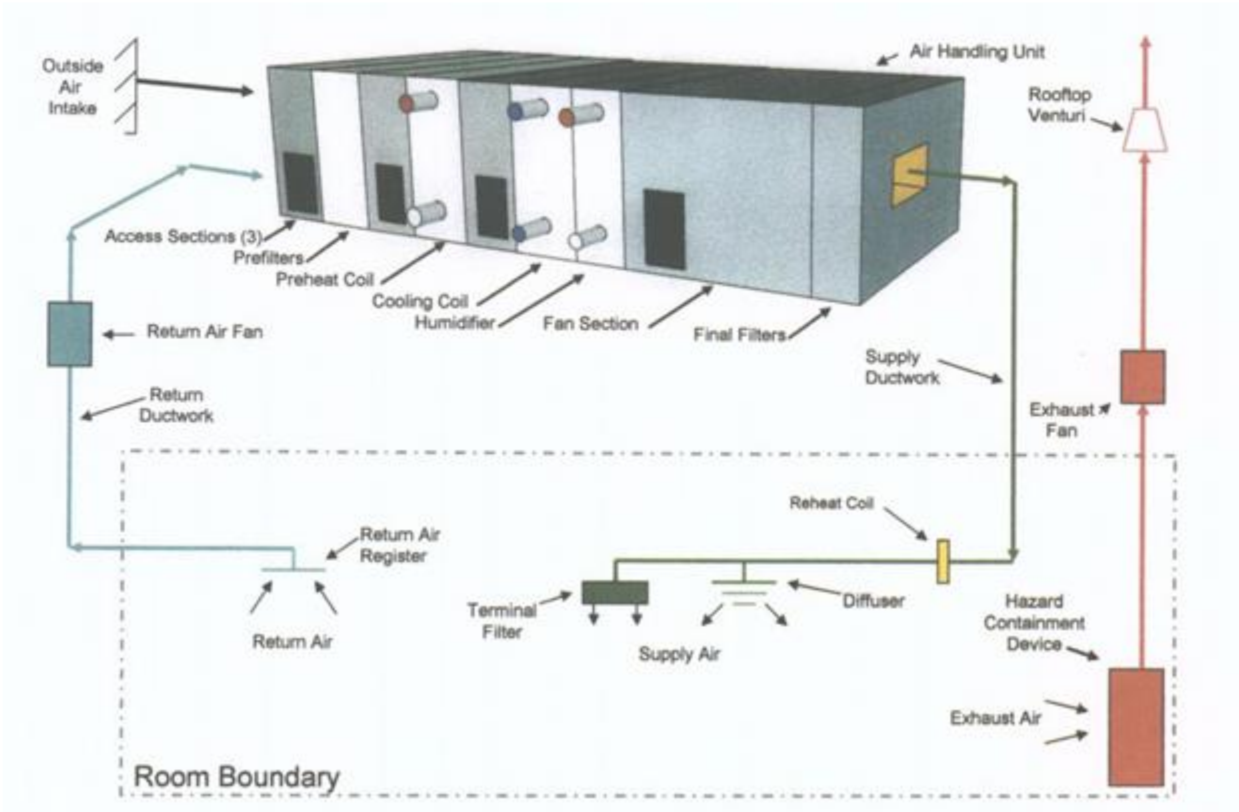

Figure 1: Common Components of an HVAC System. Credit: Paoli, A. D.; The HVAC Process. *Journal of Validation Technology* **2011**, Autumn, 20-27.

This figure shows the most common components of an HVAC system. Starting from the left of the diagram, air is drawn into the system then passes through a series of filters and coils. The ducts to and from the hospital are shown as well.

Figure 2: UV Irradiation Lamps of an HVAC System. Credit: Leach, T.; Scheir, R.; Ultraviolet Germicidal Irradiation (UVGI) in Hospital HVAC Decreases Ventilator Associated Pneumonia. *ASHRAE* **2014**.

Seen here is the addition of UV irradiation lamps to the coils of an HVAC. UV irradiation kills bacteria on the coils and prevents new growth. This helps stop the spread of bacteria through the air system.

Appendix B: Group Member Responsibilities

Each individual’s responsibilities and contributions are listed below:

- Carolina Bryan – Background; Scheduled Shands tour
- Anjali Modi – HVAC Air Pollution Control Device
- Taylor Murphy – Additional Control Technologies
- Chad Spreadbury – Regulations, Standards, and Recommendations; Webmaster
- Bridget Wlosek – Background; Compiled YouTube video
- All – Abstract, Objective, and Conclusions