AN EVALUATION OF ULTRAVIOLET GERMICIDAL IRRADIATION (UVGI) TECHNOLOGY IN HEALTH CARE FACILITIES

by

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Abstract

Health care facilities are responsible for treating highly infected and contagious patients at the same time as patients who are most susceptible to disease. Therefore, it is important that every available technology and application to be strategically applied to protect each and every occupant. In particular, ultraviolet germicidal irradiation (UVGI) technologies are being used in today's industry as infection control devices, primarily in health care facilities. This paper addresses the effectiveness and economic impact of applying UVGI to remove harmful airborne pathogens and outlines background information on infectious airborne pathogens such as viruses, bacteria, and fungi. Besides UVGI, other engineering control methods covered in this paper include mechanical ventilation and air distribution, filtration, and differential pressure control. Consequently, an economic evaluation of a diagnostic and treatment area was created to compare UVGI technologies and other control methods. The evaluation consists of a baseline system designed to meet code requirements; an upper-room UVGI system; a heating, ventilating, and air-conditioning (HVAC) system with an increased air changes per hour (ACH); and a UVGI system in an AHU. First costs, energy costs, and maintenance costs were the basis of economic comparison. The predicted effectiveness of all the alternatives was held constant and the time required to achieve the desired effectiveness was determined. As a result, the upper-room UVGI system and HVAC system with an increased ACH yielded much higher comparative annual costs as well as significantly better room disinfection effectiveness. The UVGI system in the AHU resulted in a lower comparative annual cost than the baseline system with the same room disinfection effectiveness. By designing infection control systems with UVGI, HVAC engineers will be more capable and successful in providing the optimal control system to these critical facilities.

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Dedication

For my parents, Joel and Melinda Dreiling. The dignity, passion, and perseverance they have bestowed upon me have been instrumental in my personal development through the years.

CHAPTER 1 - Introduction

The purpose of this paper is to inform HVAC engineers of the effectiveness and economic impact of applying ultraviolet germicidal irradiation (UVGI) technologies in health care facilities to remove harmful airborne *pathogens*. Any patient or health care professional may receive a *nosocomial infection*, a hospital-acquired infection, due to these airborne *pathogens*. Prevention of *nosocomial infections* will be the focus of this paper through effective engineering control methods. The engineering control methods covered include mechanical ventilation and air distribution, filtration, differential pressure control, and UVGI. As UVGI becomes more prevalent in the industry as a means of reducing *nosocomial infections*, it is important for HVAC engineers to critically analyze its effectiveness and economic impact.

This paper is intended for HVAC engineers designing health care facilities who may not have been exposed to all the UVGI applications or who wish to pursue further understanding of the technology. Both surface and air disinfection can be performed with UVGI; however, this paper will stress the air disinfection methods. Engineers are encouraged to read Chapter 2 to gain an understanding of the characteristics of airborne *pathogens* and the importance of removing them from the building. Chapter 3 describes the standard engineering control methods applied in health care and may be of particular interest to engineers new to the industry. The applications, advantages, disadvantages, and effectiveness of UVGI in Chapter 4 provide a fundamental background on the subject matter. HVAC engineers can use this information to communicate with owners and product manufacturers when looking to apply UVGI to their projects. The economic study presented in Chapter 4 compares UVGI technologies to the effectiveness of traditional engineering control methods in removing airborne *pathogens*. With this data, HVAC engineers will better understand the costs associated with UVGI and be able to determine its feasibility for specific health care projects. Due to the nature of the topic, some words may not be familiar to the reader; accordingly, words which are italicized throughout the paper are defined in the glossary, Appendix A.

Health care facilities exist to administer medical care to patients in need. Unfortunately, health care facilities house *contagious* patients with weak immune systems who must battle not only their infection, but any disease or infection to which they are exposed while in the facility.

"Patients who have the worst infections wind up at a hospital. Patients who have the most drug-resistant organisms wind up at the hospital. Infected patients without regular medical care wind up in hospital emergency rooms (and waiting rooms) after they have put off seeking help as long as possible. A community's worst and most drug-resistant infections are, therefore, concentrated in a single community location—the hospital where we take our most vulnerable and susceptible loved ones. It is incumbent upon us as citizens, hospital workers, architects, and engineers to do our utmost to prevent the spread and proliferation of infection" (Geshwiler, Howard, & Helms, 2003, 217).

A number of guidelines, codes, and standards outline specific requirements of the engineering control methods for health care facilities. By applying these resources and the data compiled in this paper, HVAC engineers will be more equipped to successfully design infection control systems. One of the newer technologies being applied to the health care industry for control of *pathogens* is UVGI. Of all UVGI installations, approximately 60% of UVGI air-disinfection systems are installed in health care facilities (41% in hospitals and 19% in clinics) (W. J. Kowalski & Bahnfleth, 2000b). This paper addresses the implementation of UVGI technology and discusses the advantages and disadvantages, as well as the economics.

CHAPTER 2 - Concern of Infection Control in Health Care

The following sections introduce the infectious *pathogens* to be addressed by HVAC engineers. The potential impact on patients, health care workers, and visitors is discussed along with the sources of infectious *pathogens*.

2.1 Infectious Pathogens

Airborne *pathogens* are classified in three groups: *viruses*, *bacteria*, and *fungi*. These *pathogens*, also called *bioaerosols* or *microorganisms*, vary in their characteristics. It is important to understand both the physical and biological properties of the *pathogens*. According to 2005 ASHRAE Fundamentals, "For a *microorganism* to cause illness in building occupants, it must be transported in sufficient dose to a susceptible occupant. Airborne infectious particles behave physically in the same way as any other aerosol-containing particles with similar size, density, and electrostatic charge. The major difference is that *bioaerosols* may cause disease by several mechanisms (infection, allergic reaction, toxicosis), depending on the organism, dose, and the susceptibility of the exposed population" (*2005 ASHRAE Handbook - fundamentals*, 9.7). For HVAC engineers, the most important characteristic is size. Knowing the size of potential contaminants in the building allows engineers to install the most efficient and effective infection control system, beginning with filtration (W. J. Kowalski & Bahnfleth, 1998). Figure 2.1 shows the size ranges for common air contaminants on a logarithmic scale. *Viruses*, *bacteria*, and fungal spores (*fungi*) are displayed along with many common contaminants, not discussed in this paper, to give a relative size comparison.

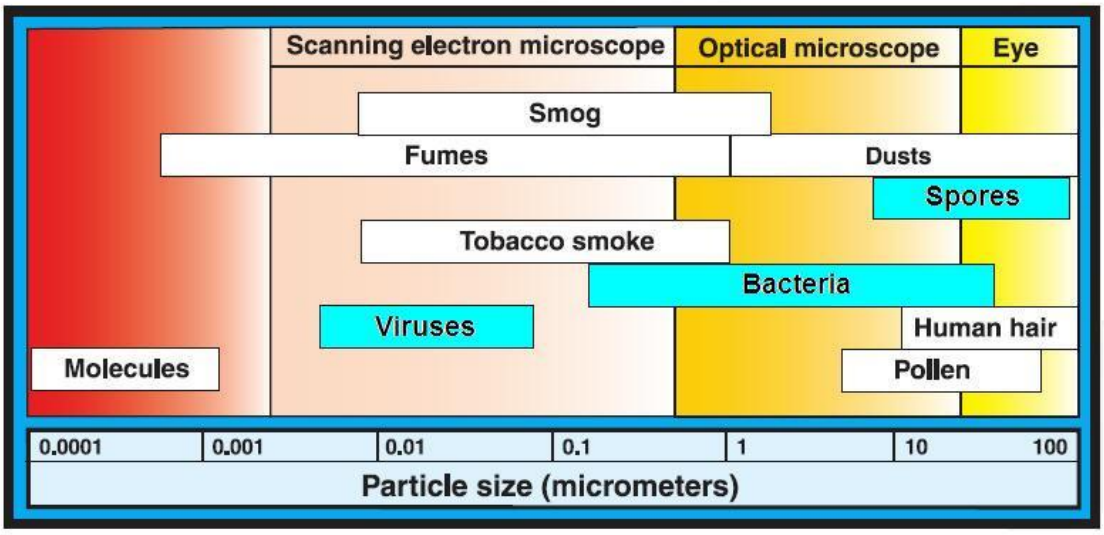


Figure 2.1 Air Contaminant Sizes

(National Institute for Occupational Safety and Health, 2003)

Engineers must also take into consideration the difference between communicable and non-communicable *pathogens*. Communicable *pathogens*, such as *bacteria* and *viruses*, are *contagious pathogens* originating from humans. Non-communicable *pathogens*, consisting primarily of spores, originate from the environment and are not *contagious* between humans. Healthy humans will not be harmed by non-communicable diseases, whereas *immunocompromised* patients may be harmed by the disease as a *nosocomial infection* (W. J. Kowalski & Bahnfleth, 1998).

Viruses are the smallest and most infectious *pathogens*. Individual *viruses* range from 0.003 to 0.06 micrometers (μm), yet they commonly occur as aggregates and are therefore much larger in size (*2005 ASHRAE Handbook - fundamentals*). Due to their size, *viruses* are transported primarily by airborne route and can remain airborne for extended periods of time presenting even greater risks to occupants. Some common *viruses* include measles, influenza, smallpox, and AIDS.

The next largest *pathogens* in size are *bacteria*. *Bacteria* cause many different types of diseases and follow many infectious pathways (W. J. Kowalski, 2006). Individual *bacteria* range from 0.4 and 5 μm, but may occur in larger forms as aggregates (*2005 ASHRAE Handbook - fundamentals*). *Bacteria* originate from both the environment and humans or animals. Common *bacteria* include tuberculosis (TB), anthrax, pneumonia, and strep throat. The

pathogenic form of *bacteria* primarily comes from humans or animals and some *bacteria* produce spores that are transmitted by airborne route (W. J. Kowalski, 2006).

Fungi, or fungal spores, are the largest airborne *pathogens*. Fungal spores primarily originate in the environment and range from 2 to 10 μm (*2005 ASHRAE Handbook - fundamentals*). HVAC engineers must consider the potential growth characteristics of *fungi*. In addition, engineers must consider the increased resistance of *fungi* to factors that destroy *viruses* and *bacteria* (W. J. Kowalski & Bahnfleth, 1998). Respiratory infections, allergies, and toxic reactions can be caused by fungal spores, but not *contagious* diseases (Howard & Howard, 1983). Common *fungi* include ringworm and yeast infection.

As seen from the above discussions, *viruses*, *bacteria*, and *fungi* vary significantly in size. HVAC engineers will use the size information when designing engineering control methods aimed at removing the *pathogens*. Table 2.1 lists common examples of these *pathogens* as well as their corresponding size ranges. *Bacteria* and *fungi* larger than the sizes listed are primarily surface contaminants, not airborne *pathogens*.

Table 2.1 Pathogen Reference

Pathogen	Individual Sizes (μm)	Common Examples
Viruses	0.003 to 0.06	Measles, Influenza, Smallpox, and AIDS
Bacteria	0.4 to 5	Tuberculosis (TB), Anthrax, Pneumonia, and Strep Throat
Fungi	2 to 10	Ringworm and Yeast Infection

2.2 Importance of Nosocomial Infections

The indoor air quality of the health care facility is vital to improving the health of patients and protecting the health of visitors and staff. If *viruses*, *bacteria*, or fungal spores reside in the facility, all occupants may be in danger of receiving an infectious disease. Likewise, any patient or staff worker may develop a *nosocomial infection*, a hospital-acquired infection, due to these airborne *pathogens* not being properly reduced and eliminated. *Nosocomial infections* are infections that a patient contracts directly from being in the health care facility unrelated to any initial disease or infection the patient may already have upon entering the facility.

Knowledge of the extent and implications of *nosocomial infections* is important to the HVAC engineer in understanding the impact the HVAC system has in reducing this tremendous risk to thousands of occupants. The data on *nosocomial infections* is quite dramatic in the United States alone. "Various sources estimate that between 2 million and 4 million *nosocomial infections* occur annually, resulting in 20,000 to 80,000 fatalities. The cost of *nosocomial infections* in the United States is estimated to be about $4 billion to $5 billion annually" (W. J. Kowalski, 2007, 30). By applying specific technologies and design strategies, an HVAC engineer may reduce the astonishing risk imposed on staff, patients, and visitors. These technologies are further discussed in Chapter 3.

2.3 Occupants Affected

Health care facilities have a diverse group of occupants. Health care professionals, patients, and visitors routinely occupy the same common spaces of the facility. Therefore, *nosocomial infections* can occur in any occupant given the susceptibility to an endless degree of airborne contaminants. Figure 2.2 shows the major pathways of *nosocomial infections* in patients and health-care workers (W. J. Kowalski, 2007). "Only the first- and second-order pathways are shown, although it is possible for a microbe to become reaerosolized several times or pass from person to person before causing an infection" (W. J. Kowalski, 2006, 536).

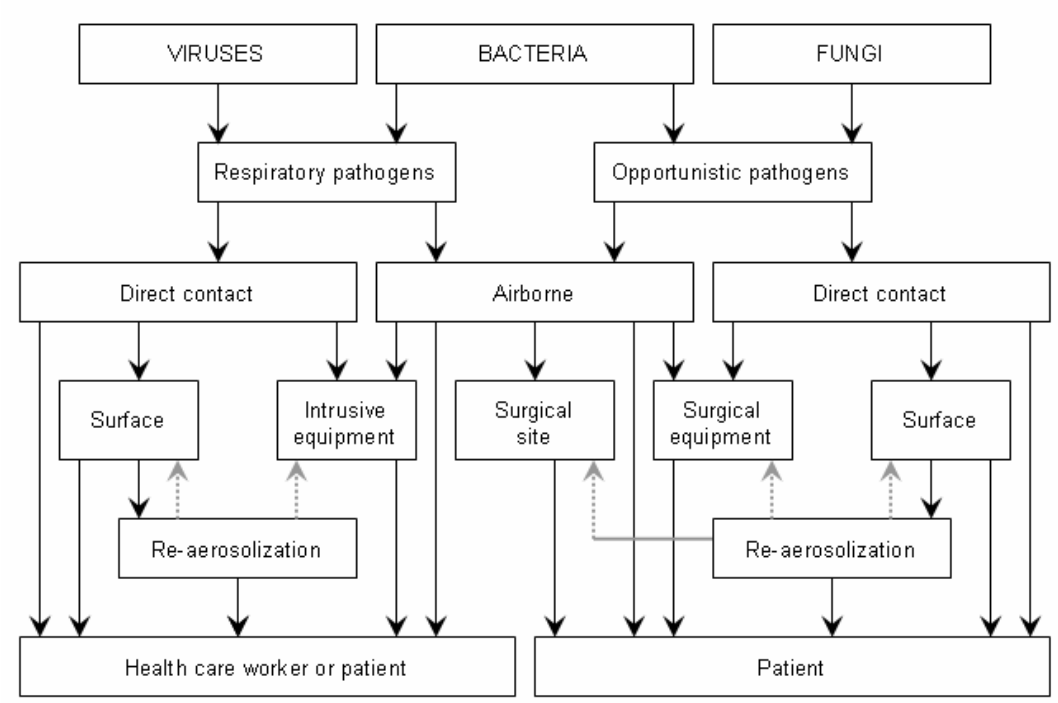


Figure 2.2 Pathways of Airborne Nosocomial Pathogens

* Figure modified from "Air-Treatment Systems for Controlling Hospital-Acquired Infections" by Kowalski, W.J.

Patients are most susceptible to acquiring *nosocomial infections*. "An organism that has no adverse effect on a healthy individual may be life-threatening to an ill patient suffering with a suppressed immune system due to a preexisting medical condition or medical treatment. Likewise, during surgery the procedures expose areas of the body, normally protected, to attack from multiple sources of infection" (Drake, 2006, H13).

Health care professionals and visitors are also at risk for *nosocomial infections*, which have led to fatalities (W. J. Kowalski, 2007). TB and influenza are examples of *contagious* respiratory infections which may routinely expose risk to health care professionals. The primary cause for respiratory infections among health care professionals is inadequate local ventilation or systems and equipment not working properly (Castle & Ajemian, 1987). Health care professionals thus are exposed to an environment that can be very harmful even after the infectious patient as left the space. Contaminants may remain in the environment until a cleaning procedure effectively removes them.

2.4 How Contaminants are Introduced into the Health Care Facility

Airborne contaminants may be introduced into a health care facility by occupants or the environment. HVAC engineers design infection control systems that address the numerous ways contaminants are transported into the building or are released from a *contagious* source. This paper concentrates on internally released *pathogens*.

Occupants are responsible for introducing *pathogens* into the health care facility by two methods. First, occupants transport *pathogens* into the building on their skin or clothes. Due to the movement and activities of the occupants, the *pathogens* that are transported in on clothing or skin may enter the space's air. Second, occupants release internally-contained *pathogens* into the space. High concentrations of contaminants may be introduced into spaces by an infected patient through coughing or sneezing or simply talking. The number of droplets liberated when talking ranges from 0-200; when coughing ranges from 0-3,500; and when sneezing ranges from 4,500-1,000,000 (F. Keikavousi et al.). The fate of the droplets released from sneezing and coughing will vary. Large droplets settle to the ground near the patient, while *droplet nuclei* will remain airborne on small air currents and can remain suspended for hours resulting in potential spread (F. Keikavousi et al.). Furthermore, health care professionals release contaminants that escape their protective clothing and facemasks. Figure 2.3 shows the various ways *pathogens* are released by a health care professional. It is possible for the health care professional to release between 3,000 and 50,000 *microorganisms* per minute, depending on activity level and clothing effectiveness (W. J. Kowalski, 2007). By understanding the various ways contaminants may enter the space, HVAC engineers will be better equipped to provide systems that minimize concentrations of contaminants when introduced in the space.

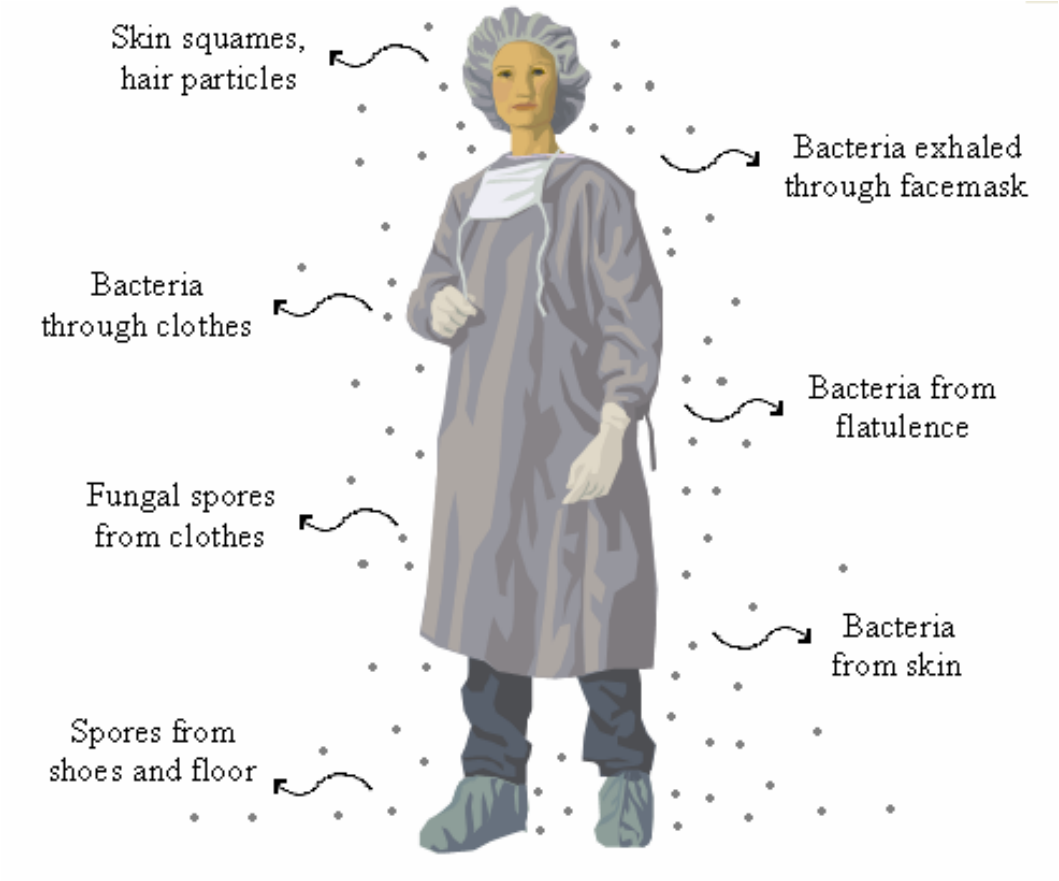


Figure 2.3 Release of Pathogens by Health Care Professionals

* Figure modified from "Air-Treatment Systems for Controlling Hospital-Acquired Infections" by Kowalski, W.J.

Environmental factors also account for *pathogens* being introduced into the health care facility in two ways. First, health care facilities draw in outdoor air to dilute the contaminated air within the building. Consequently, natural environmental *microorganisms* such as *fungi* and *bacteria* are introduced indoors. Once in the indoor environment, these *pathogens*, which had low concentrations outdoors, may quickly increase to harmful levels due to growth at amplification sites (W. J. Kowalski, 2007). These amplification sites lead to the second method of introducing *pathogens* into the space. *Fungi* will grow in the suitable conditions often provided within a health care facility and release spores into the air-stream, further polluting the building with *pathogens*. Therefore, it is highly important for the HVAC engineer to address potential contaminants immediately upon entering the building at the outdoor air intake. Proper operation and maintenance of the HVAC system will reduce the occurrence of contaminants being circulated throughout the building and initially brought into the facility. "Decreased

performance of health care facility HVAC systems, filter efficiencies, improper installation, and poor maintenance can contribute to the spread of health care-associated airborne infections" (Sehulster & Chinn, 2003, 13).

CHAPTER 3 - Engineering Control Methods

HVAC systems can distribute infectious contaminants through a health care facility because of the circulation of air for heating, cooling, and ventilation purposes. Recognizing this fact, HVAC engineers must take measures to minimize the transmission of infectious contaminants. The engineering control methods, also referred to as environmental controls, addressed in the following sections include mechanical ventilation, filtration, and differential pressure control. In many health care applications, these methods are implemented simultaneously to create the most effective and efficient infection control system (Geshwiler et al., 2003).

Prevention and removal of airborne contaminants are of primary concern in health care facilities. Therefore, health care HVAC systems are crucial in removing any contaminants that may have entered the building by environmental means or released by infected occupants. For instance, preventing outdoor contaminants from entering through ventilation or infiltration eliminates the environmental source. Also, since ccupants may spread millions of airborne contaminants by sneezing and coughing, unless these contaminants are removed by the HVAC system, they will remain a hazard until they naturally decay. Typically, airborne *pathogens* decay slowly over time due to the absence of a growth source while suspended in the air. However, within buildings, natural decay is usually too slow to prevent secondary infections to building occupants (W. J. Kowalski, 1997). In addition to eliminating or minimizing transfer, the HVAC system must also prevent the amplification of infection sources. Cooling coil drip pans are examples of a component in an HVAC system where microbial growth may increase until aerosolized into the air-stream where it reaches occupants.

3.1 Mechanical Ventilation and Air Distribution

The first engineering method to prevent airborne infection is mechanical ventilation and air distribution. Buildings are typically either naturally ventilated or mechanically ventilated. Due to the strict ventilation requirements and space pressurization relationships, health care facilities are almost always ventilated by mechanical means. Therefore, only mechanical

ventilation will be covered in this paper, as will proper air distribution techniques, which further reduce the potential of airborne infections by controlling the air paths of contaminants.

Mechanical ventilation prevents airborne infection among occupants by diluting contaminated air within the space. Due to the energy requirements to condition outside air, re-circulated air that has been filtered by the system is used in conjunction with outside air. This combination of outside air and filtered re-circulated air will wash out the contaminated air within a space by a rate expressed as air changes per hour (ACH) (First, Nardell, Chaisson, & Riley, 1999a). As a certain volume of supply air is introduced into the space at a fixed rate, the equivalent volume of air, containing room contaminants, is removed from the space. In this process, approximately 37% of the contamination will remain after one air change assuming perfect mixing of the air, which seldom happens except in research settings (First, Nardell, Chaisson, & Riley, 1999a). With 37% of the contaminants remaining, 63% of the contaminants are effectively removed from the space. This effectiveness is a nominal representation for each air change and does not represent the desired effectiveness for the system.

The effectiveness of dilution by supply air is reasonably predictable and successful for any type of contaminant with increasing air changes. *Viruses*, *bacteria* and fungal spores are all transported in the air; therefore, they may also be removed from the space through dilution with supply air containing the combination of fresh air and re-circulated air as discussed above. The removal efficiencies of airborne contaminants for incremental ACH rates are listed in Table 3.1. The efficiencies given represent perfect mixing conditions, and thus actual performance will be lower than these projected values. "For most purposes, 6 ACH may be considered equivalent to approximately a 99% clearance rate in one hour" (First, Nardell, Chaisson, & Riley, 1999a, 4). A removal effectiveness of 99% within the space represents a highly effective value, which can be efficiently attained by engineering control methods.

Table 3.1 Contaminant Removal Efficiency by ACH

(Centers for Disease Control and Prevention, 1994)

ACH	Minutes required for a removal efficiency of:		
	90%	99%	99.90%
1	138	276	414
2	69	138	207
3	46	92	138
4	35	69	104
5	28	55	83
6	23	46	69
7	20	39	59
8	17	35	52
9	15	31	46
10	14	28	41
11	13	25	38
12	12	23	35
13	11	21	32
14	10	20	30
15	9	18	28
16	9	17	26
17	8	16	24
18	8	15	23
19	7	15	22
20	7	14	21
25	6	11	17
30	5	9	14
35	4	8	12
40	3	7	10
45	3	6	9
50	3	6	8

***** This table has been adapted from the formula for the rate of purging airborne contaminants. Values have been derived from the formula $t_1=[\ln(C_2+C_1)+(Q+V)]x60$, with $T_1=0$ and C_2+C_1-(removal efficiency+100), and where:

t_1 = initial timepoint

C_1 = initial concentration of contaminants

C_2 = final concentration of contaminants

Q = air flow rate (cubic feet per hour)

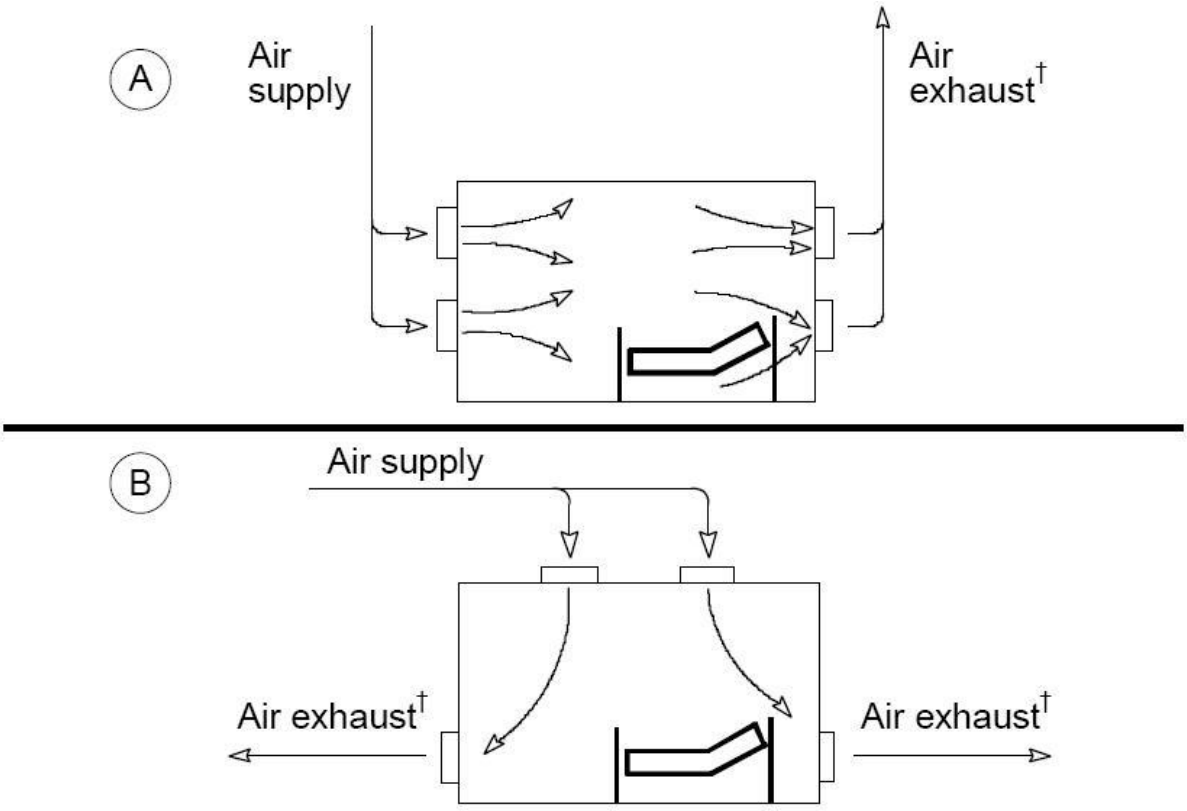
V = room volume (cubic feet)

Q + V = ACH

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) and The American Institute of Architects (AIA) outline the minimum ACH rates for ventilation and total supply air by the space classification within health care facilities. Therefore, HVAC engineers are guided by these resources to design a system that will create a reasonably safe and healthy environment for the occupants. Yet, these recommendations are only baseline values that HVAC engineers may design above to further improve the space conditions. Appendix B, lists the guidelines for all health care function spaces compared between the ASHRAE HVAC Design Manual for Hospitals and Clinics, ASHRAE Handbook, and AIA Guidelines. The recommended ACH rates and design criteria vary slightly among the different resources. Therefore, HVAC engineers are encouraged to design around the most stringent recommendation for each specific space.

Beyond introducing ventilation air into the space for dilution, HVAC engineers must design for air to move through the space in a manner that reduces the exposure of contaminants to health care workers. Thus, HVAC engineers should locate the air supply and exhaust to provide controlled airflow patterns of clean air first to areas where the health care professional is working and then to the patient location. As with every air distribution system design, the layout of the system should also prevent air stagnation and short-circuiting of air (Jensen, Lambert, Iademarco, & Ridzon, 2005).

In spaces where the likelihood of exposure is likely to be high, the following design practice should be implemented per the recommendations of the Centers for Disease Control and Prevention (CDCP). "Airflow should ideally be laminar, with supply diffusers located in a wall opposite to the patient, and the exhaust located in a wall near the patient. Alternatively a ceiling supply can be used with the exhaust located at low level in the walls" (Beggs et al., 2000, 22). These air distribution recommendations are shown in Figure 3.1 as A and B, respectively.



† Air should be exhausted to the outside (or through high-efficiency particulate air [HEPA] filters, if recirculated).

Figure 3.1 Air Distribution Methods

(W. J. Kowalski, 2003)

Mechanical ventilation using the ACH rate method has disadvantages that ought to be considered by HVAC engineers. Although beneficial, it is a slow process that requires time to reach the desired level of effectiveness. Prior to contaminants being properly diluted and removed, additional patients and health care professionals may enter the room increasing the potential for *nosocomial infections*. To decrease the time required to achieve a set level of effectiveness, a higher ACH rate could be supplied, but a larger mechanical system would be required, increasing operating costs without addressing all critical issues. "*Dilution ventilation* can provide a considerable degree of control over the aerobiology of the indoor air, but it cannot, by itself, provide a complete solution because of the outdoor microbes that are brought into the system. At the very least, some level of filtration is needed to control the number of ambient environmental microbes that enter the indoor environment" (W. J. Kowalski, 2006, 191).

Another disadvantage is the possibility of contaminants in one space being circulated throughout all the rooms served by the system. Therefore, another engineering control method, such as filtration, is needed to reduce the distribution of contaminants beyond the mechanical supply unit.

3.2 Filtration

Filtration is the second engineering method applied to reduce airborne infections. This section covers the filtration selection and design criteria important to HVAC engineers for health care facilities. Filtration selection is based on the following factors: "(1) degree of air cleanliness required, (2) specific particle size range or aerosols that require filtration, (3) aerosol concentration, (4) resistance to airflow through the filter, and (5) design face velocity to achieve published performance" (*2004 ASHRAE Handbook - systems and equipment*, 24.2). HVAC engineers need to understand the types and properties of filters to design the most effective and economic system in reducing airborne contaminants.

Filtration is used in HVAC systems for multiple purposes. Most important to occupants is the protection it provides from airborne contaminants circulating in the building. Without filtration, any number of *viruses*, *bacteria*, or spores would be distributed to all the spaces of the building supplied by the HVAC system. Filtration also serves to protect the coils, ducts, and distribution system from dust buildup and microbial growth. Coil performance is maintained and operates more efficiently when filters prevent buildup from clogging the coils. In addition, filtration reduces the cleaning and maintenance required at the AHU and throughout the system (Wang, 2001).

Air filtration is broken down into two classifications, mechanical filters and electrostatic filters. In health care applications, mechanical filters are the most commonly used because of their continuous collection efficiency, covered later in the section. Electrostatic filters rely on an electrostatic force, which will weaken over time and therefore compromise their collection efficiency (National Institute for Occupational Safety and Health, 2003). For this reason, this paper will discuss only mechanical filtration.

Mechanical air filters are classified as panel filters, pleated-medium filters, bag filters, rigid cartridge filters, or roll filters. These typical filter configurations are pictured in Figure 3.2

for reference. Panel filters are low efficiency filters that offer protection against larger particles in the air-stream and have little airflow resistance. Pleated-medium filters are denser than panel filters and are constructed in a zig-zag manner to increase the surface area of the filtration medium. Bag filters consist of large areas of filtration medium formed into tubes or pockets that extend when units are operating. Rigid cartridge filters are similar to bag filters, yet they employ a rigid construction of pleated-medium within the fully-supporting frame. Roll filters are made of a compressible panel-type medium that rolls between two supports at its ends. Once the filter reaches a final pressure resistance due to buildup, a sensor will automatically drive the filter to roll until a new portion of the filter is covering the air-stream. Roll filters are not as common as the other configurations described (Grimm & Rosaler, 1997).

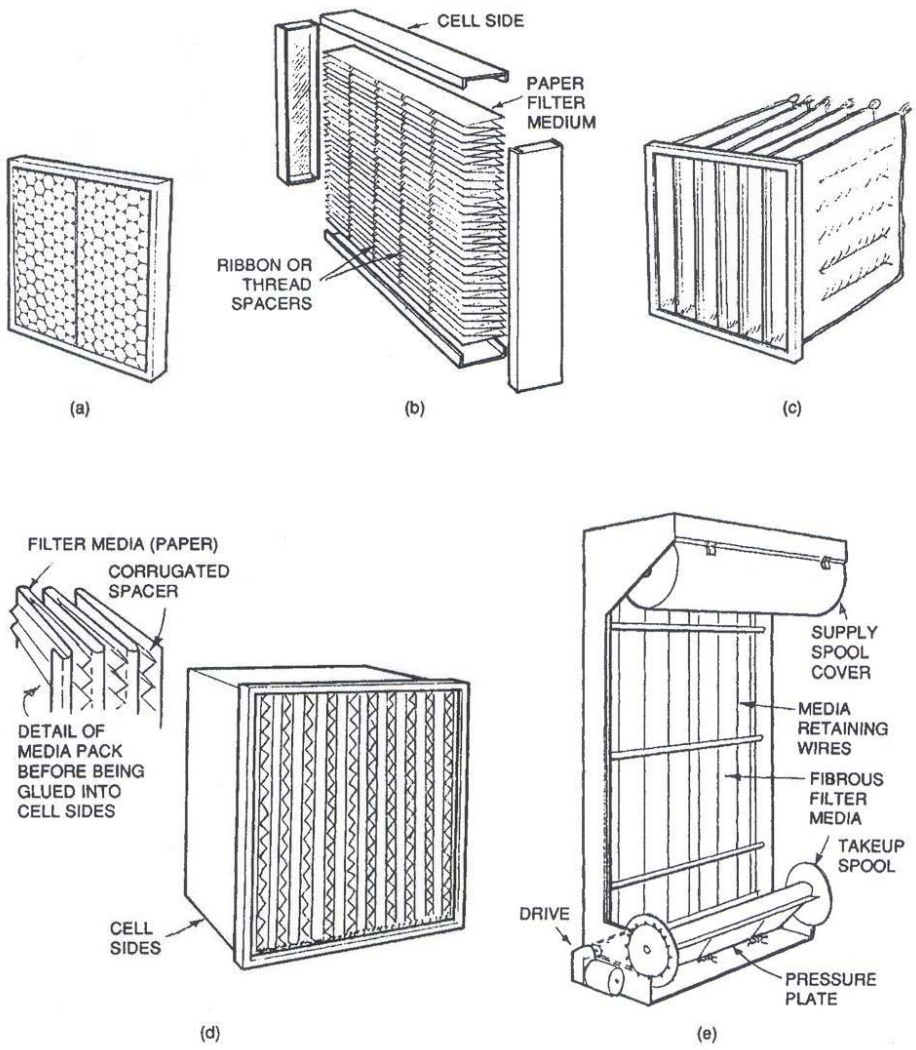


Figure 3.2 Air Filter Configurations: (a) panel filter; (b) pleated-medium filter; (c) "soft" cartridge bag filter; (d) rigid cartridge pleated-medium filter; and (e) roll filter.
(Grimm & Rosaler, 1997)

Of all these mechanical filter types, pleated-medium filters are preferred in health care settings. During normal maintenance, soft bag filters may collapse and release contaminants on the outer surface of the filter media into the air-stream. By their nature, rigid cartridge filters do not have this problem and will reduce the potential for spreading contaminants during maintenance (Geshwiler et al., 2003). Compared to panel filters, pleated-medium filters offer higher collection efficiency due to the increased surface area of the filter media.

The HVAC engineer's primary selection criteria are based on the degree of cleanliness that is to be achieved with filtration. The collection efficiencies, also called particle removal efficiencies, are established by ASHRAE Standard 52.2-1999, *Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size* to aid in the selection process (Persily et al., 2007). The rating method provided by ASHRAE Standard 52.2-1999 is referred to as the Minimum Efficiency Reporting Value (MERV). The MERV rating scale ranges from 1 to 20, with a higher value correlating to a higher removal rate. Table 3.2 lists the collection efficiencies based on particle size ranges as well as common applications. These applications are a broad classification included for reference with the MERV ratings. More detailed applications and requirements for health care filtration will follow in Table 3.3. In Table 3.2, hospital filtration is classified as primarily MERV 13-16, yet these facilities employ other MERV levels of filtration for specific spaces such as clean rooms and operating rooms or for prefilter applications. Figure 3.3 further develops the removal efficiencies of ASHRAE Standard 52.2-1999 graphically for each of the MERV ratings, showing continuous curves with increasing particle size. High-efficiency particulate air (HEPA) filters are classified as MERV 17 and higher with removal efficiencies expressed in the HEPA detailed view of Figure 3.3.

Table 3.2 MERV Rating and Collection Efficiency

(National Institute for Occupational Safety and Health, 2003)

ASHRAE 52.2				Particle size range, μm	Applications
	Particle size range				
MERV	3 to 10μm	1 to 3μm	.3 to 1μm		
1	< 20%	-	-	> 10	residential light pollen dust mites
2	< 20%	-	-		
3	< 20%	-	-		
4	< 20%	-	-		
5	20-35%	-	-	3.0 - 10	industrial, dust, molds, spores
6	35-50%	-	-		
7	50-70%	-	-		
8	>70%	-	-		
9	>85%	< 50%	-	1.0 - 3.0	industrial, Legionella, dust
10	>85%	50-65%	-		
11	>85%	65-80%	-		
12	90%	> 80%	-		
13	90%	> 90%	< 75%	0.3 - 1.0	hospitals, smoke removal, bacteria
14	90%	> 90%	75-85%		
15	90%	> 90%	85-95%		
16	>95%	> 95%	> 95%		
17	-	-	> 99.97%	< 0.3	clean rooms, surgery, chem-bio, viruses
18	-	-	≥ 99.99%		
19	-	-	≥ 99.999%		
20	-	-	≥ 99.9999%		

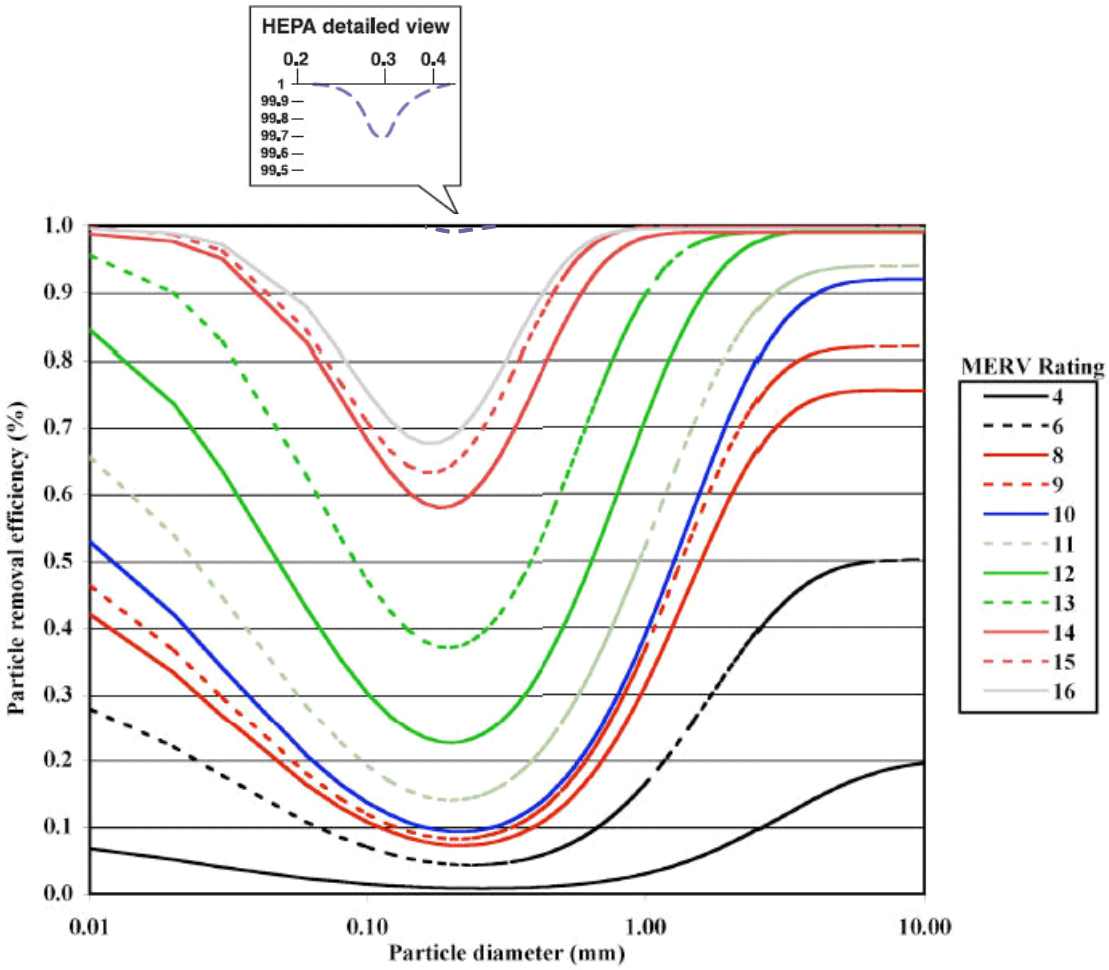


Figure 3.3 Particle Removal Efficiency Curves
(Persily et al., 2007)

For health care applications, a filtration system with multiple filters, namely a prefilter and final filter, is used to achieve the appropriate degree of cleanliness. A prefilter is installed upstream of the heating and cooling coils to prevent large particles, such as spores, from being deposited on the coils. In addition, the prefilter prolongs the life of the final filter downstream, resulting in cost-effective operation. Prefilters, which are very inexpensive, will remove large particles and prevent fast buildup on the final filter, which is a much more expense filter to replace. Reducing the frequency with which final filters need to be replaced will therefore lower the maintenance expense for filtration. AIA and ASHRAE recommend prefilters have a MERV 8 rating or higher. The final filters function to remove smaller particles, such as *bacteria* and *viruses*, prior to the air being dispersed throughout the HVAC system. Final filters should have a

MERV 14 rating or higher to collect a high percentage of fungal spores between 2-5 μm diameter and *bacteria* in colonies of 1 μm diameter or larger. Critical areas serving *immunocompromised* patients should employ HEPA filters (MERV 17 or higher) capable of removing 99.97% of particles smaller than 0.3 μm, such as unattached *viruses* (Leung & Chan, 2006). Filter efficiencies recommended by AIA and ASHRAE are summarized for health care facilities in Table 3.3.

Table 3.3 Health Care Filter Efficiencies

(*2007 ASHRAE Handbook - applications*)

Minimum Number of Filter Beds	Area designation	Filter Efficiencies, MERV[1]	
		Filter bed	
		No. 1	No. 2
2	Orthopedic operating room Bone marrow transplant operating room Organ transplant operating room	8	17 [2]
2	General procedure operating rooms Delivery rooms Nurseries Intensive care units Patient care rooms Treatment rooms Diagnostic and related areas	8	14
1	Laboratories Sterile storage	13	-
1	Food preparation areas Laundries Administrative areas Bulk Storage Soiled holding areas	8	-

Notes

1. MERV = minimum efficiency rating value based on ASHRAE 52.2-1999.
2. HEPA filters at air outlets

When selecting filtration devices, HVAC engineers must take into consideration the airflow resistance placed on the HVAC system due to the filter, termed the pressure drop. The pressure drop, measured in inches of water gauge, is expressed as a function of the average face

velocity across the air filter, calculated as the airflow divided by the filter's face area (Grimm & Rosaler, 1997). The pressure drop increases over the life of the filter until it reaches a final dirty pressure drop when the filter is to be replaced. Lower efficiency filters, such as MERV 8, begin with an initial pressure drop of 0.10 in. of water gauge and increase to a final pressure drop in the range of 0.5 to 1.0 in. water gauge. The initial pressure drop of HEPA filters may exceed 0.5 in. water gauge resulting in a final pressure drop higher than 1.5 in. water gauge (National Institute for Occupational Safety and Health, 2003). Although pressure drop affects the design of the HVAC system in the fan selection, it is equally important in maintaining proper operating conditions over the life of the system with regular replacement. "Filter replacement time must be a trade-off with the energy cost, which is associated with driving the air through the high-pressure drop filter. The higher the cost of energy, the more frequently the building operator should change out the higher-pressure drop filters" (National Institute for Occupational Safety and Health, 2003, 40). The pressure drop across the filter beds should be measured with a manometer or other pressure-sensing device to alert maintenance personnel when it is time to replace filters (National Institute for Occupational Safety and Health, 2003). Visual inspection of the filters is not an adequate or objective method in determining appropriate replacement needs. The replacement cost of filters must also be addressed in determining proper replacement. Camfil Farr Aeropleat MERV 8 prefilters measuring 24" by 24" cost approximately $5, while the same sized Camfil Farr XS Absolute HEPA filter (MERV 17) costs nearly $700 (Donahey, 3/25/2008). This overwhelming price difference is a major reason for implementing prefilters. It is much more economical to replace prefilters nearly every month, which prolongs the life of the HEPA filter, than to replace the HEPA filter on a frequent basis and incur a tremendous replacement cost. Table 3.4 provides a summary of the projected service life for each type of filter in reaching a loaded pressure drop. The typical change times provided in the table give replacement ranges that will vary depending on the energy rate to obtain the most economical operating conditions.

Table 3.4 Service Life of Filters

(Wang, 2001)

Filter type	Typical change time	Max. pressure drop across air filter, in. WC
Flat panel	30 to 60 days	0.5
2-in. pleated	3 to 6 months	0.9
4-in. pleated	10 to 14 months	0.9
6- to 12-in. cartridge	12 to 18 months*	1.5
21- to 36-in. bags	12 to 24 months*	1.5
HEPA	1 to 5 years*	2

* With prefilters

HVAC engineers must also ensure face velocities are within the rated values to achieve the most effective filtration system. The face velocity is defined as the air-stream velocity entering the filter (National Institute for Occupational Safety and Health, 2003). Pressure drop varies depending on the specific face velocity; as face velocity increases, the pressure drop also increases. HEPA filters are most susceptible to a decrease in collection efficiency at face velocities higher than the recommended levels. Figure 3.4 illustrates the large fluctuation of collection efficiency possible when amplifying the face velocity from 2 meters per second (395 feet per minute) to 5 meters per second (985 feet per minute). Clearly, maintaining a low face velocity at the filter will produce the most effective system, meeting the design goals of the HVAC engineer.

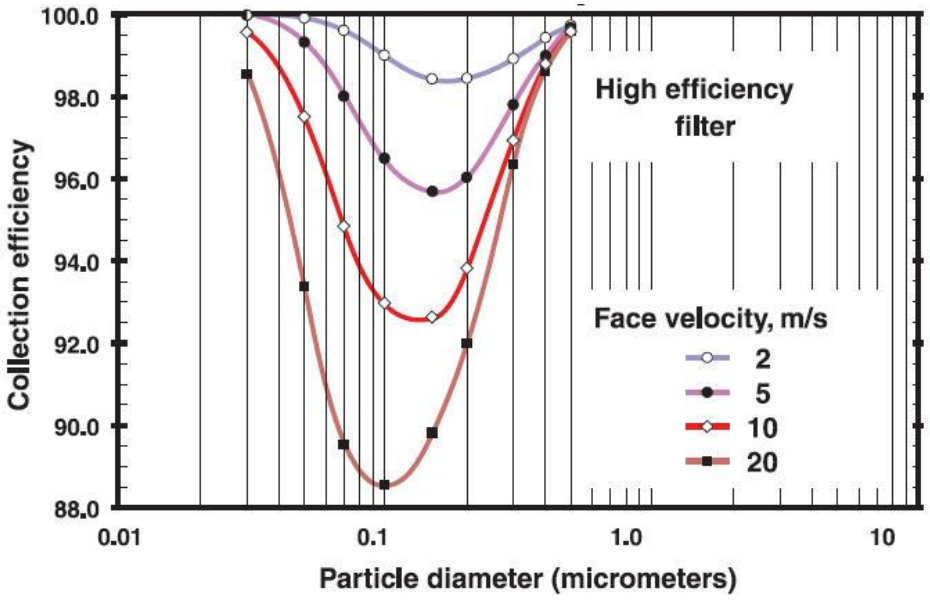


Figure 3.4 Effect of Face Velocity on Collection Efficiency
(National Institute for Occupational Safety and Health, 2003)

Limitations and disadvantages are apparent with filtration as an engineering control method. First, filters are only capable of removing contaminants that attempt to flow through them. "When a contaminant is released within the building, the location of that release relative to the occupants and the filter location becomes critical. If the occupants are very close to the release, filtration of the recirculation air may have little or no impact on their exposure" (Persily et al., 2007, 52). Therefore, patients or health care professionals are only protected by filtration when the contaminated air-stream has been circulated through the filter at the AHU. "A major potential source of fungal contamination in hospitals is filter bypass and maintenance problems" (W. J. Kowalski, 2007, 42). Filter bypass is another disadvantage of filtration due to air not passing through the filter media. Filter bypass occurs when filters are damaged or not properly installed so that a portion of the air will flow around the filter. In the event of filter bypass, airborne particulates will be circulated through the ventilation system without regard to the effectiveness of the filtration devices. HVAC engineers must ensure proper installation of filters initially as well as inform maintenance personnel of the importance of proper replacement to eliminate the possibility of filter bypass.

HVAC systems rely heavily on filtration devices to prevent the spread of infectious agents in health care facilities. Due to its successful removal of airborne *pathogens*, filtration is

required as a control method. However, filtration cannot exclusively eliminate all contaminants and protect each occupant in the building. Instead, filtration is an engineering control method that should be combined with other methods for an even greater effectiveness above that of filtration alone.

3.3 Differential Pressure Control

Another engineering control method closely related to mechanical ventilation is differential pressure control. "Air changes alone are not enough in controlling airborne infectious diseases and hazardous particles in health care facility environs; pressure management is key" (F. Keikavousi et al.). Differential pressure should be maintained to prevent the spread of contaminants between spaces within health care facilities. The pressure difference is vital to ensure airflow from clean spaces to less-clean spaces.

Pressure differentials are created between spaces by strategically designing the supply and return/exhaust airflow. "A generally accepted practice to ensure the achievement of directional airflow between spaces is the establishment of a minimum 75 CFM flow differential and/or 0.01 in. w.g. pressure differential" (Geshwiler et al., 2003, 30). This minimum requirement prevents the positive or negative nature of the space from changing when doors are opened and closed (The Facility Guidelines Institute & The American Institute of Architects Academy of Architecture for Health, 2006).

Differential pressure control is effective as long as the desired pressure difference is maintained in the spaces. However, over time, the filtration system will increase pressure drop, and, if not properly maintained, this pressure drop may exceed that used in the design. In this case, less airflow than initially designed will be delivered to the space. If substantial enough, the supply airflow may drop below the exhaust value creating a negative or neutrally pressurized room, relative to adjacent spaces, that was initially designed to be positive (Leung & Chan, 2006). The result is that the clean space will be contaminated by the less clean areas. This situation reinforces the importance of filter maintenance as discussed in the prior section.

3.4 Other Alternatives

In addition to the control methods listed above, engineers are being presented with more technologies to control airborne contaminants. Many of these alternatives have specific applications that limit their installation in all facilities. Dr. Wladyslaw Kowalski of The Pennsylvania State University outlines the airborne disease control technologies beyond the three discussed in this paper. Kowalski includes the additional technologies of *gas phase filtration*, *electrostatic filtration*, *photocatalytic oxidation*, *pulsed light*, *ionization*, *ozone*, *green technologies*, *thermal disinfection*, *cryogenics*, and *desiccation*, *antimicrobial coatings*, *microwaves*, and developmental technologies (W. J. Kowalski, 2006). Many of these alternatives are new and unproven beyond testing laboratories. Consequently, these technologies are not further explored in this paper because no test methods or rating systems are established for them.

CHAPTER 4 - Implementation of UVGI Technologies

This chapter introduces UVGI while discussing the applications available to HVAC engineers and the advantages and disadvantages of the technology. It is important to stress that all UVGI applications are implemented in addition to the other engineering control methods previously discussed and do not replace the other methods. Most importantly, the effectiveness in reducing airborne *pathogens*, as documented in case studies and research, is discussed in detail. This information was applied in developing an economic study that evaluates both upper-room UVGI and UVGI installed in an AHU. HVAC engineers can use this information to evaluate the feasibility of applying UVGI to their specific design projects.

4.1 Background

UVGI has been studied for many decades, yet it has not been widely applied in the industry because it is the least defined in practical application of the current approaches to air disinfection (Nardell, 1997). However, UVGI is gaining exposure and validity with the major concerns of indoor air quality (IAQ), specifically airborne *pathogens* in health care facilities causing *nosocomial infections* as discussed earlier in the paper.

UVGI systems for air-stream disinfection were first tested on airborne mycobacteria by William Firth Wells in the late 1930's (Wells, 1955). In 1946, the first design guidelines on the application of germicidal irradiation were developed by Mathew Luckiesh (Luckiesh, 1946). The studies by Luckiesh offered detailed experimental work on upper-room UVGI air disinfection and its interaction with room ventilation. "However, this was the same year that streptomycin, the first effective drug against TB, was discovered, and that enormous discovery, and the hope for TB eradication that it engendered, all but ended interest in UV air disinfection for TB control. Moreover it was assumed that vaccines would soon eliminate the common communicable viral illnesses" (Nardell, 1997, 28). Richard Riley and colleagues continued the work developed by Wells through the 1970s. Riley's research accounts for most of the developments and advancements made on the relative susceptibility of various mycobacteria to UVGI (Riley, Knight, & Middlebrook, 1976).

Some studies resulted in highly successful air disinfection by UVGI, while others had varied results. Unfortunately, the design studies that resulted in much lower disinfection effectiveness negatively impacted the advancement of the technology. The fluctuation in results was due to the abundance of factors that were being researched in the process. Improvements in UVGI effectiveness have been documented as more understanding of the correct application of devices has been developed. "It has only been in the past few years that new research in response to increased airborne diseases has begun to again advance this science, but mostly there are only older studies on which to base estimates of disease reduction" (W. J. Kowalski, 2006, 257). Further discussion of the effectiveness of UVGI based on varying factors is covered in Section 4.4.

With the advancements in research, UVGI found its way into practical environments such as hospitals, shelters, prisons, and clinics. These buildings are notorious for a transfer of diseases due to the large number of occupants who share the various spaces and frequently move from space to space. In addition, occupants are at an even higher risk of infection due to the nature of being located close to each other. As a result, UVGI air-disinfection systems are being installed the most in health care facilities, accounting for approximately 60% of all installations (W. J. Kowalski & Bahnfleth, 2000b).

4.2 How UVGI Works

The disinfecting ability of UVGI technology is based on the principle of ultraviolet radiation produced in the natural environment from the sun. Ultraviolet radiation is emitted from the sun affecting human health and the environment in three bands, based on wavelengths (UltraViolet Devices, 2008). UV-A are longwaves ranging from 320 nm to 400 nm, UV-B are mediumwaves ranging from 280 nm to 320 nm, and UV-C are shortwaves ranging from 100 nm to 280 nm (First, Nardell, Chaisson, & Riley, 1999a). Of all the radiation from the sun, 99% of the radiation that reaches the surface of Earth is UV-A radiation. Nearly all of the UV-C radiation is exhausted in the atmosphere, some of which accounts for the generation of ozone (UltraViolet Devices, 2008). UVGI lamps employ UV-C radiation because of its ability to inactivate *pathogens* with its short wavelengths. Compared to the other two ultraviolet classifications, UV-C characteristics are less harmful. "By comparison to outdoor exposure to

the more penetrating UV of sunlight, the added health hazard of less penetrating, low-intensity, indirect UV-C exposure is minimal" (Nardell, 1997, 29).

UV-C radiation has the highest energy of the three classifications of ultraviolet radiation, which accounts for its ability to inactivate *microorganisms*. UVGI lamps classified as low, medium, and high pressure mercury emit UV-C radiation but vary by output intensity for the wavelength spectrum. Low pressure mercury UVGI lamps are the most effective lamps because they emit an exceptionally high amount of radiation at a wavelength of 253.7 nm. Fortunately, *microorganisms* are highly vulnerable to light at or near 253.7 nm wavelengths because 260 nm is the maximum absorption wavelength of a DNA molecule. The germicidal irradiation changes the DNA structure as well as renders the cells non-infectious (Brickner et al., 2003). Therefore, by simply exposing *pathogens* to UVGI irradiation for periods of time, *pathogen* inactivation will occur. Without addressing the outside factors that alter the effectiveness, UVGI technology remains a promising application due to its innate ability to inactivate *pathogens* by lamp emission. Unlike low pressure mercury UVGI lamps, medium and high pressure mercury UVGI lamps emit a wide range of longer wavelengths, each at very low proportions of the UVGI energy (Free Patents Online, 2007). Therefore, these lamps are much less effective at providing the germicidal irradiation required to disinfect airborne *pathogens*. Figure 4.1 shows the large variation in output intensity for both low and high pressure UVGI lamps, suggesting the use of low pressure lamps to achieve high levels of germicidal effectiveness. These low pressure UVGI lamps appear similar to standard fluorescent lamps used for space lighting. The lamps are typically either linear fluorescent lamps or compact fluorescent lamps in a range of sizes (i.e. T5 and T8), UVGI output levels, and lengths (between 8" and 60") (Sylvania, 2006). Examples of the linear and compact fluorescent UVGI lamps are given in Figure 4.2.

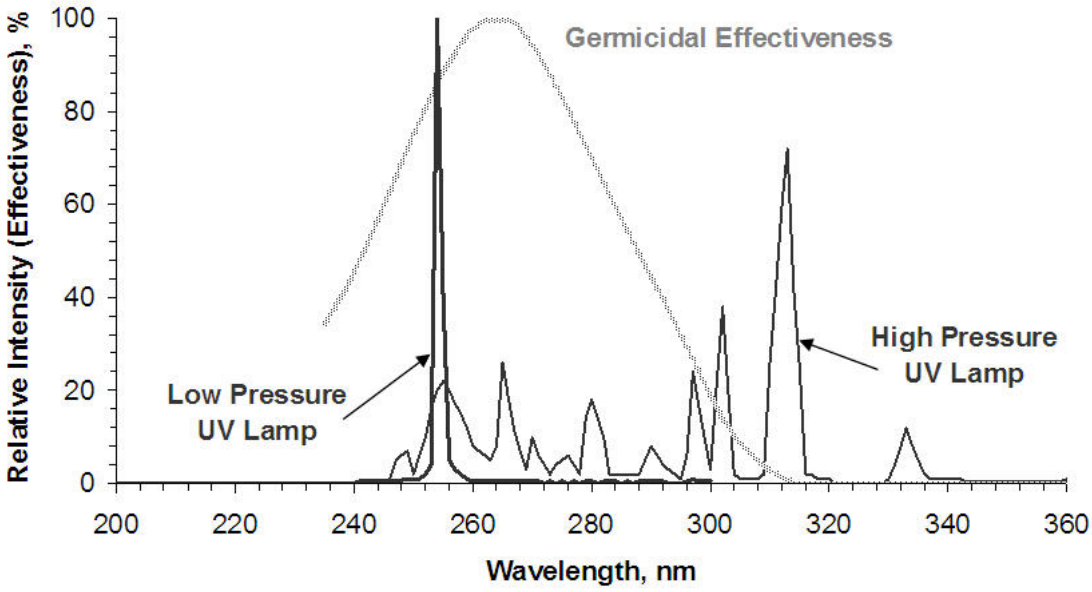


Figure 4.1 UVGI Lamp Spectrums and Effectiveness

(UV Air Treatment Steering Committee, 2005)

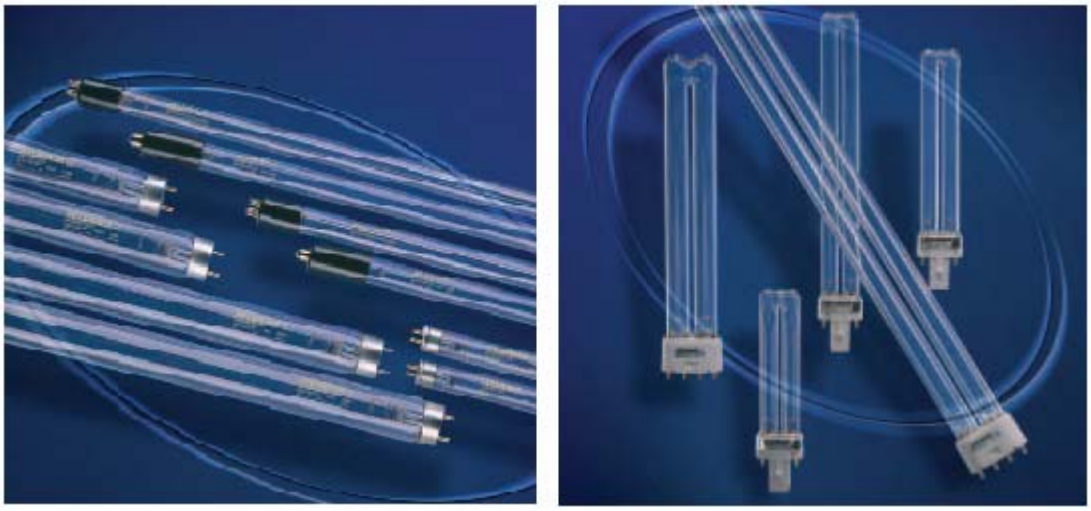


Figure 4.2 UVGI Lamps: Linear and Compact Fluorescent

(Sylvania, 2006)

Viruses, *bacteria*, and fungal spores are all vulnerable to UVGI exposure in different capacities. In particular, *viruses* and *bacteria* are more easily disinfected than spores because of their smaller size. Therefore, HVAC engineers must apply UVGI in the appropriate applications to utilize the technology's ability of disinfecting *pathogens* with UV-C radiation. The following

sections outline the applications of UVGI, and Section 4.4 expands on the effectiveness that is achieved for specific *pathogens* with various sizes and vulnerability.

4.3 Types of Applications

Due to the simplicity of UVGI technology, it lends itself to a wide variety of applications. For instance, UVGI lamps may be utilized in permanent mechanical equipment and upper-room fixtures or portable devices, new construction or renovation projects, and directly in rooms or at central HVAC locations. This multitude of general applications is categorized into either air-stream disinfection or surface disinfection. Accordingly, HVAC engineers must inform and guide owners of the benefits each of the applications will have in their facility. Selecting the most applicable UVGI application will be driven by the building size and layout as well as the functions of specific spaces. Additional factors driving the UVGI selection process will include target *pathogens*, HVAC system configuration, and the construction and operating budget.

4.3.1 Air-Stream Disinfection

Air-stream disinfection is the deactivation of airborne *pathogens* both suspended in a room and flowing in air currents. In health care facilities, infectious patients may spread airborne contaminants prior to being diagnosed with a *contagious* disease. Consequently, air-stream disinfection allows for installations within spaces to reduce the concentration of airborne particulates, thus preventing the spread of contaminants at the source. On the other hand, air-stream disinfection installed in the mechanical ventilation system or ductwork can treat large quantities of contaminated air before redistributing the contaminants to otherwise clean areas. The three configurations for UVGI air-stream disinfection include in-duct applications, upper-room air applications, and HEPA-UV ceiling units, and portable fans with UVGI.

4.3.1.1 In-Duct Applications

UVGI in-duct applications disinfect *microorganisms* that are passing through the HVAC system. The UVGI lamps are typically located either in the AHU near the coiling coil or in return air ducts. The effectiveness of in-duct applications in eliminating *pathogens* by the UVGI

system is based on the exposure time of the particulate to irradiance levels of the UVGI lamp. The air-stream velocity is a major environmental factor that impacts the UVGI lamp performance as it is directly related to the exposure time *pathogens* will have to the irradiation (Kujundzic, Hernandez, & Miller, 2007). Furthermore, the air velocity varies at different locations in the mechanical system; typically it is lowest at AHU coils and highest in the supply ductwork. Therefore, a given germicidal irradiance will be more effective at inactivating *pathogens* at the air handling coils than in the supply ductwork because of a longer exposure time. UVGI installations within the AHU are becoming the most popular application for a number of reasons. First, this method disinfects large quantities of air at one central location, which means maintaining and servicing one piece of equipment is much more economical than for individual room disinfection systems. Second, these applications present no risk to space occupants because the UVGI irradiation is isolated within the HVAC system. Therefore, UVGI intensity may be applied at a much higher level in mechanical systems than in the actual spaces with upper-room applications, described in the following section. Indeed, increasing the UVGI intensity will equate to a higher inactivation rate and a more effective system. In addition, these systems will simultaneously provide surface disinfection within the AHU as is discussed in Section 4.3.2.1. UVGI systems installed within AHUs consist of multiple UVGI lamps mounted on a structural frame adjacent to the cooling coil. Depending on the UVGI manufacturer and specific application, the UVGI lamps are spaced evenly and mounted either vertically or horizontally on the support frame. Figure 4.3 shows these various installation methods for an AHU.

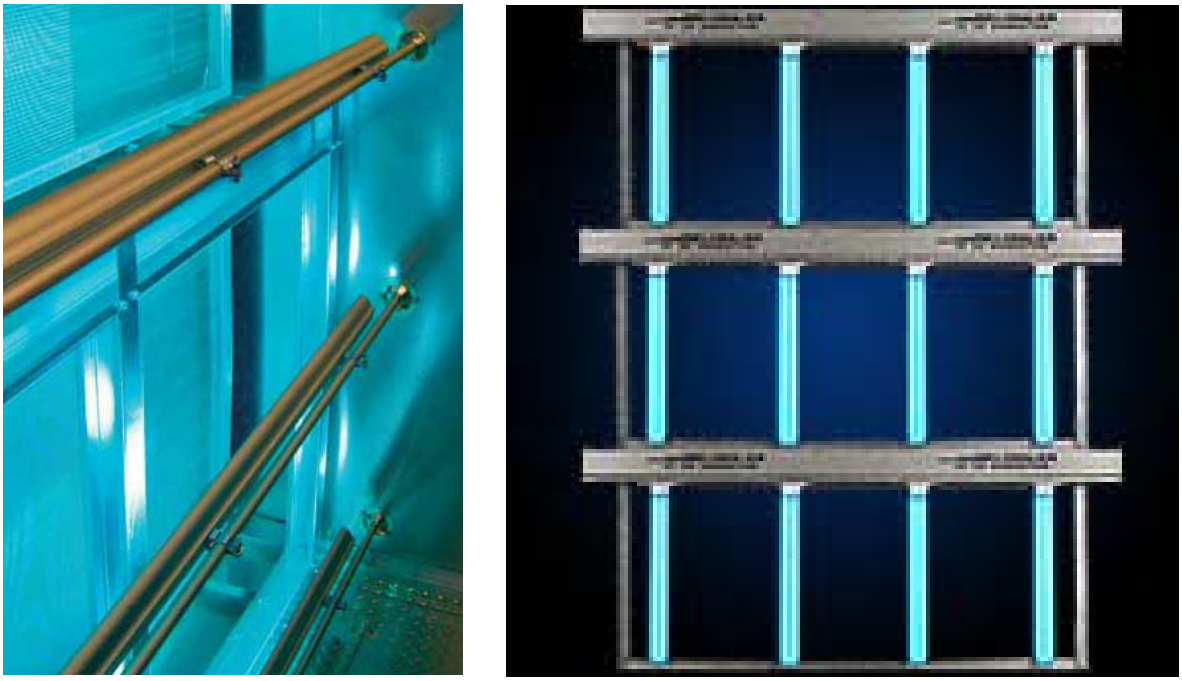


Figure 4.3 UVGI Lamp Systems in AHU: Horizontal and Vertical
(Sanuvox Technologies and Lumalier, Inc.)

Besides installation in AHUs, UVGI may be installed in return air ducts. This design method is best for areas where unsuspected diseases may be released by any number of occupants before being diagnosed (First, Nardell, Chaisson, & Riley, 1999a). This method is most applicable for systems with a high potential for concentrations of airborne *pathogens* from a limited number of rooms. In addition, fewer UVGI lamps are needed to effectively disinfect the smaller area of return ductwork than the entire cooling coil area. However, HVAC engineers need to ensure UVGI lamps in return air ducts are located far enough away from the return air grilles to prevent uncontrolled UVGI irradiation into the space. Yet UVGI intensity must be high enough to adequately disinfect the moving airborne *pathogens*. Also, the velocity of the particles must be addressed by the HVAC engineer and UVGI manufacturer to ensure the proper irradiation level. Another concern with UVGI systems installed in return air ducts is the difficulty in accessing the UVGI systems. Access is more limited in return air duct UVGI systems due to the systems being hidden above ceilings in crowded plenum spaces. Also, these UVGI systems only disinfect air being re-circulated within the systems and fail to disinfect any *pathogens* that may be introduced from outside air. The installation methods of UVGI systems installed in ductwork vary more among manufacturers than among the AHU installations. Some

manufacturers utilize UVGI lamps installed perpendicular to the airflow (across the ductwork) with the ballast and power source located outside the ductwork. An example of this UVGI in-duct system is shown in Figure 4.4 with both face plate and interior duct images. Other manufacturers employ UVGI lamps installed parallel to the ductwork at the center of the ductwork, supported by vertical mounts across the ductwork, as shown in Figure 4.5. The effectiveness of both methods has been successful, and HVAC engineers should consult with manufacturers when selecting in-duct UVGI applications.

Figure 4.4 UVGI Lamp System Perpendicular to Ductwork
(Lumalier, Inc.)

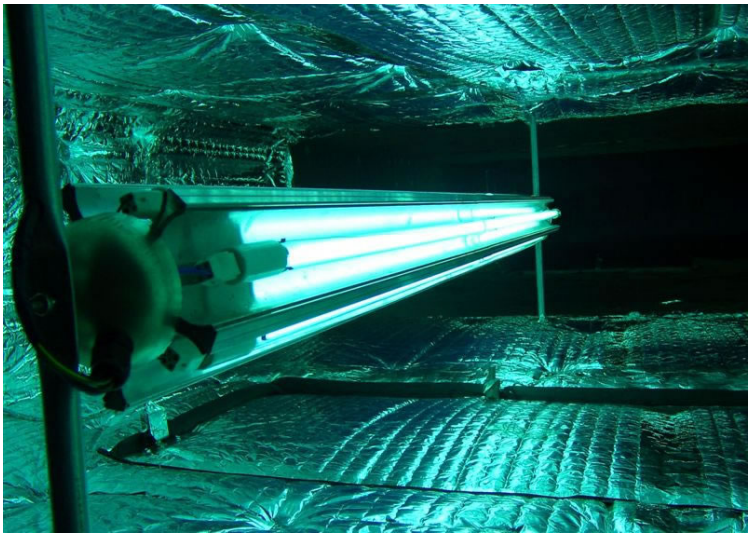


Figure 4.5 UVGI Lamp System Parallel to Ductwork
(Sanuvox Technologies)

The following study by Wladyslaw Kowalski shows the effectiveness of reducing airborne concentrations with an in-duct UVGI system in comparison to outside air purging and filtration control methods (W. J. Kowalski, 1997). The study is valuable for HVAC engineers to analyze the effectiveness of each method acting on spores, *bacteria*, and *viruses*. For the model, perfect air mixing is assumed as well as an initial 500 *CFU*/m^3 concentration of airborne *pathogens* in the space. Also, the outside air is assumed to contain spores at a concentration of 100 *CFU*/ m^3. Figure 4.6 shows the result of 25% OA (1 ACH) being used to dilute the airborne *pathogens*. *Bacteria* and *viruses* are removed at nearly the same rate and approach complete removal in five hours while spore concentrations remain higher based on the assumption of spores being contained in the outside air. The effectiveness of a MERV 13 filter on removing airborne *pathogens* while maintaining 1 ACH of outside air is displayed in Figure 4.7. All of the *pathogens* experience a significant reduction in a much shorter period of time than that seen with the outside air alone. With the spores being larger in diameter, their concentration was reduced more immediately than that of *bacteria* and *viruses*. The final graph for this section, Figure 4.8, shows the effectiveness of a 25 $\mu W/cm^2$ UVGI lamp in the recirculation air. Also, the outside air remains constant at 1 ACH with no filtration being applied. In the study, in-duct UVGI reduces the concentration of *viruses* better than the two previous methods while the reduction in *bacteria* result is between the other two methods. Moreover, the spores in the model are nearly unaffected by the UVGI and produce similar results as the outside air method alone. It is important to note the irradiance level of the UVGI is considerably low for this type of application. Therefore, applying a UVGI system with a higher intensity would affect the results positively. Overall, this study provides a strong basis for the effectiveness of in-duct UVGI for the different types of *pathogens* seen in health care facilities.

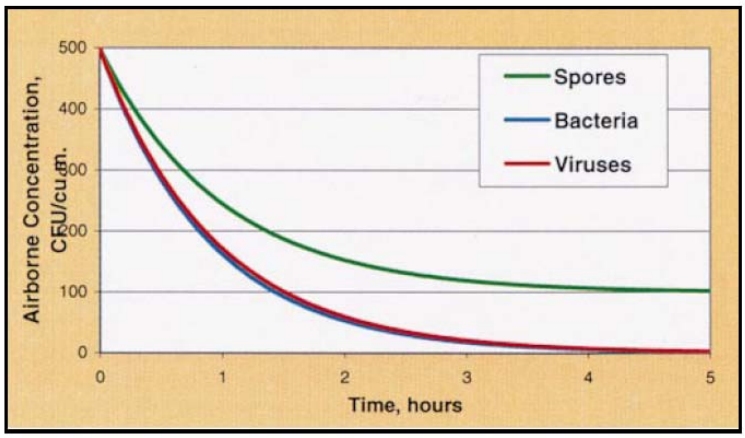


Figure 4.6 Outside Air Effectiveness

(W. J. Kowalski, 1997)

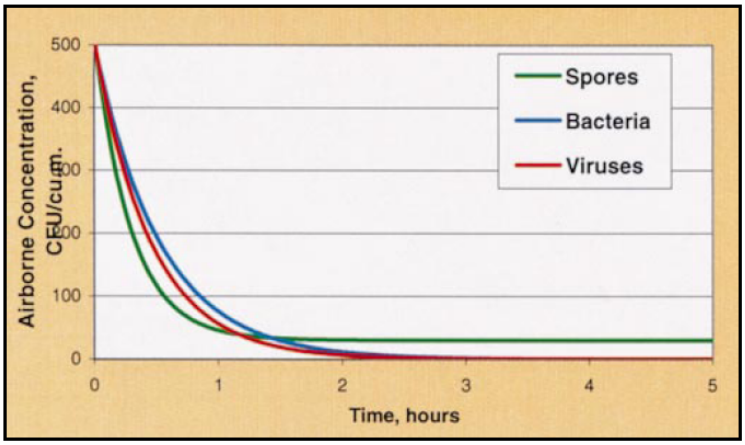


Figure 4.7 MERV 13 Filter Effectiveness

(W. J. Kowalski, 1997)

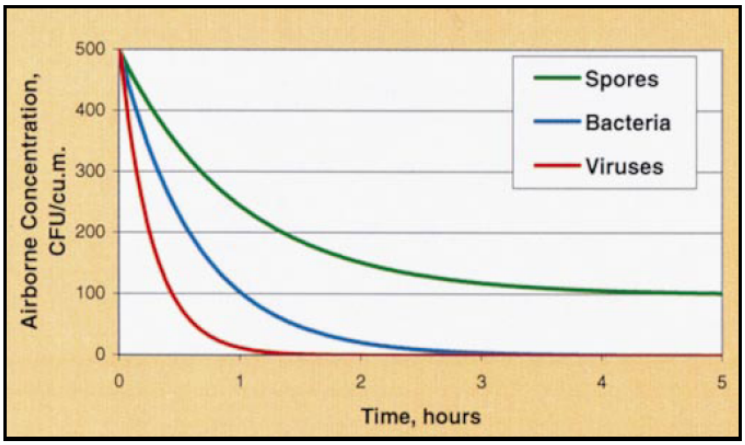


Figure 4.8 UVGI Effectiveness

(W. J. Kowalski, 1997)

These in-duct applications may greatly improve the IAQ by removing airborne *pathogens* better than standard engineering measures without restricting or compromising their capabilities. However, this configuration may not be providing occupants within the spaces the needed infection control with an infectious source in the same room (First, Nardell, Chaisson, & Riley, 1999a). This is because the system treats air entering and leaving the space, but does little to interrupt the transmission of *pathogens* between infectious cases and potential victims (Nardell, 1997). Other UVGI methods installed within the space are designed to combat this problem.

4.3.1.2 Upper-Room Applications

Upper-room UVGI applications consist of wall- or ceiling-mounted fixtures that irradiate a narrow horizontal band of airspace just below the ceiling. These passive devices rely on the mixing of the room air by both mechanical ventilation exchange rates and natural convection to induce contaminants into the UVGI irradiated zone. Airborne *microorganisms* are inactivated when exposed to the irradiation, therefore continually reducing the concentration of infectious particles in the space.

The upper-room UVGI fixtures consist of multi-bladed horizontal louvers six inches deep, spaced one-quarter of an inch apart to "hide" the UVGI lamps located at the inner portion of the fixture from direct exposure to occupants in the space. The components of the UVGI fixtures include a transformer, ballast, switch, and wiring. To increase the emission irradiance, many fixtures employ a parabolic reflector behind the UVGI lamp (First, Nardell, Chaisson, & Riley, 1999a). These fixtures are relatively small devices, measuring on average 4" high by 8" wide by 18" long or 36" long, depending upon the UVGI irradiation required for the space. Figure 4.9 shows an example of an upper-room UVGI fixture with the louvers, UVGI lamp, reflector and switch.

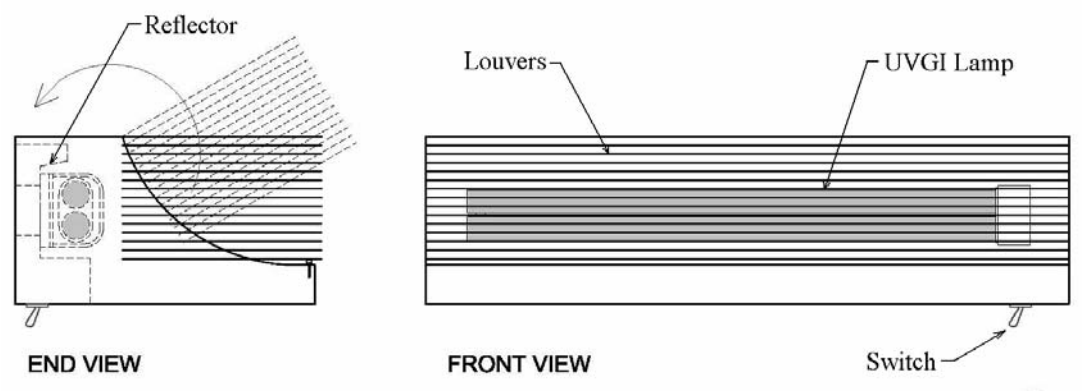


Figure 4.9 Upper-Room UVGI Fixture

(Lumalier, Inc.)

Upper-room devices have a number of advantages over other UVGI systems. The major advantage is that airborne *pathogens* are likely to be killed promptly by the UVGI since the *pathogens* are released into the room close to the irradiated zone. UVGI ceiling units and return air ducts with UVGI require the airborne *pathogens* to be introduced based on the real air mixing rate, while upper-room UVGI is only dependent on the theoretical *air change rate*. Therefore, *pathogens* will be removed this way more effectively than by ventilation rates, without sacrificing occupant comfort (Riley & Nardell, 1989). Another advantage to this type of system is its passive operation. Although located within the room, upper-room UVGI devices do not require a fan or motor, which could disturb occupants by producing noise or vibrations. An example of an installed upper-room UVGI fixture is shown in Figure 4.10.

Figure 4.10 Upper-Room UVGI Installation
(W. J. Kowalski, 2007)

The effectiveness of the upper-room UVGI is dependent on the correct selection of fixture quantity, UV output, and careful attention to location (First, Nardell, Chaisson, & Riley, 1999b). Without design standards and applied research, the engineering application of these devices has been "acquired by trial-and-error methods and translated into rules of thumb" (First, Nardell, Chaisson, & Riley, 1999b, 1). For example, fixtures should be located as close to the infectious source as possible while preventing a direct viewing angle to the lamps within the fixtures. Also, fixtures are manufactured for both wall and ceiling configurations to meet the needs of rooms with size and layout variations. Standard design procedures are outlined later in the paper.

The UV output of these fixtures may vary significantly between manufacturers and installation techniques. Thus, it is important to understand the fundamental approach of comparing devices on an equal basis of UV output. For instance, due to reflector losses and

louver blockage, the output from the fixture is less than the actual lamp output. The luminaire efficiency accounts for these losses and is defined as a ratio of the *luminous flux* emitted from the fixture compared to the amount emitted by the lamp (Dumyahn & First, 1999). "Luminaire efficiency and total UVGI output of a fixture are important when comparing different fixtures for antibacterial efficacy because efficient placement of fixtures and the determination of total UVGI dose require complete characterization of UVGI fields" (Dumyahn & First, 1999, 220). The characterization of the UVGI fields with computational fluid dynamics (CFD) models will more accurately predict the disinfection rates based on the variation of the UVGI dosage changing based on the distance away from the UVGI lamp.

Location of the upper-room UVGI within the space does present some risks if not addressed appropriately. For example, HVAC engineers need to verify the UVGI system is installed above the manufacturer's recommended minimum height to prevent direct exposure to occupants. Although there is potential for overexposure, owners consulting with experienced equipment providers are not required at this time to measure the actual UVGI irradiance levels in the space after the system has been installed. However, UVGI fixtures are tested to ensure safe operating conditions for occupants when the height requirement is met.

A study by Miller and Macher focused on the efficacy of upper-room UVGI for different airborne *pathogens* that spanned the range of UVGI sensitivity (Miller & Macher, 2000). The three *bacteria* chosen for the experiment were ***B. subtilis, M. luteus, and E. coli***. These *pathogens* were introduced into a 1271 ft^3 study room equipped with two 15 watt wall-mounted UVGI lamps at a height of 5.75 ft and a ventilation system supplying 6 ACH from ceiling diffusers. The study also investigated the introduction of airborne *pathogens* by a decay method and a steady-state method. The decay method represents a situation where an infectious patient occupies the space for a period of time and then leaves prior to another person entering the space. Therefore, the concentration of airborne *pathogens* would slightly decrease by dilution before the susceptible person enters. The steady-state method represents a patient occupying a space while a susceptible person enters. In this situation, the airborne *pathogen* concentration will remain steady. Both the effectiveness and equivalent air-exchange rates of UVGI are used to align the results with the steady-state and decay methods, respectively. The calculation method for equivalent air-exchange rates of UVGI are discussed in Section 4.4.2. "It is our opinion that effectiveness is best used with the steady-state method as it is independent of time and mixing

affects. Equivalent air-exchange rate should be used with the decay method provided mixing is ensured" (Miller & Macher, 2000, 289). Based on multiple trials, the average effectiveness of UVGI was 57% for *B. subtilis* and 36% for *M. luteus*. The average room effectiveness of UVGI on the *E. coli* could not be determined since it was isolated near the aerosol source. However, based on the isolated data, nearly a 100% reduction of *E. coli* was estimated. The results for the decay method suggested an equivalent air-exchange rate of 6.5 ACH for the *B. subtilis*. The results of this study show a reduction of airborne *pathogens*, yet the degree of protection may not be high enough to prevent the transmission of *pathogens*, especially in a high-risk setting (Miller & Macher, 2000).

To improve the effectiveness of this UVGI application in actual installations, more research is required to analyze the flow of air particulates in the space. Current research is focused on optimizing the air mixing within a space for effective air disinfection by upper-room UVGI. Additionally, CFD models are beginning to evaluate the characteristics of particulates when varying room layouts and ventilation procedures. As these techniques are further developed in collaboration with the National Institutes of Health, HVAC engineers will be more capable of providing optimal UVGI systems (Nardell, 1997).

4.3.1.3 HEPA-UV Ceiling Units

Another UVGI application that disinfects air in the space is HEPA-UV ceiling units. These devices consist of high-efficiency filtration devices paired with internal UVGI lamps and a supply fan to circulate room air through the system. The internal UVGI lamps inactivate *pathogens* two ways: as they move airborne *pathogens* through the systems (similar to UVGI in the AHU) and when they become immobilized on the filter surface (Kujundzic et al., 2005). Also, with the UV lamps confined inside the unit, the UVGI irradiance levels may be much more intense than in upper-room UVGI. The major advantage this system offers is the flexibility in locating the unit in spaces with a ceiling lower than standard. While upper-room UVGI applications require adequate ceiling height to prevent exposure to occupants, HEPA-UV ceiling units may be installed in ceilings lower than 8 ft without any potential exposure (First, Nardell, Chaisson, & Riley, 1999a).

The effectiveness of HEPA-UV ceiling units is limited by the airflow and mixing created in the space. Short circuiting of the airflow prevents contaminants in the lower portion of the

space from being circulated up to the unit to be disinfected. These devices are especially prone to airflow short-circuiting due to the supply and return locations being close in comparison to the room space. By attempting to resolve the problem with a larger supply fan, HVAC engineers may induce additional problems of noise, vibration, and drafts (Miller-Leiden, Lobascio, Nazaroff, & Macher, 1996). Engineers must be aware of the functions of the space and consider the harm to be caused by a ceiling unit producing distractive noise to occupants.

The redundancy of this combination system is debated by some sources. "The use of both HEPA filters and UVGI in the same room air disinfection unit is redundant. HEPA-filtered air is essentially sterile and need not be irradiated, and properly UV-disinfected air need not be HEPA-filtered. Irradiating the surfaces of HEPA filters in room air disinfection devices is not necessary and is unlikely to be helpful" (Spengler, Samet, & McCarthy, 2001, 11.8). The cost of HEPA-UV ceiling units is substantially higher than for upper-room UVGI devices, ranging from $4,000 to $5,000 for medical grade units intended for health care facilities. HVAC engineers need to further analyze the value of applying this system and evaluate the cost implications before implementing these devices in their projects.

4.3.1.4 Portable Fans with UVGI

The final air disinfection application available for health care facilities is portable fans with UVGI. Portable UVGI fans provide health care facilities with flexibility in locating the disinfection mechanism in locations with the most potential for contaminant concentrations. These units contain a UV lamp which treats the *pathogens* in the air as they are drawn through the system by a fan source. The effectiveness of the system is highly dependent on factors of the room as well as proper operating techniques. "The efficacy of portable air filter units can be reduced by handling them improperly, positioning them incorrectly within the room, or turning them off" (Menzies, Adhikari, Arietta, & Loo, 2003, 488). For reference, a portable fan with UVGI is displayed in Figure 4.11. Although this is an option for owners, this paper will focus on permanent applications for health care facilities.

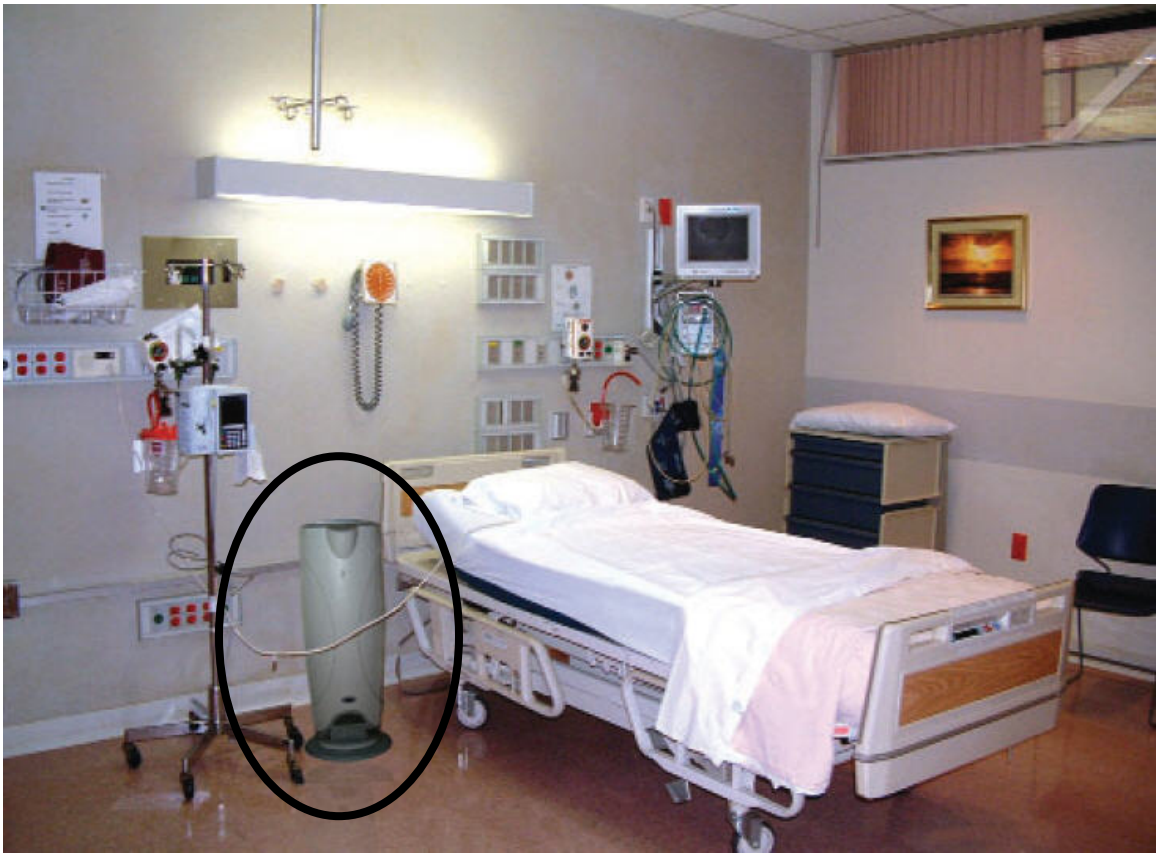


Figure 4.11 Portable UVGI Unit with Fan
(W. J. Kowalski, 2007)

4.3.2 Surface Disinfection

Surface disinfection removes *bacteria* deposited on surfaces of AHU cooling coils and on room contents. Use of surface disinfection is most common for AHU cooling coils because of effectiveness and virtually no risk to occupants. In particular, surface disinfection is highly effective and predictable because fewer variables exist to limit its ability as otherwise possible in air-stream disinfection. Therefore, HVAC engineers and owners are more likely to install these systems due to the visible cleaning effectiveness seen in the AHU coils and drip pans.

4.3.2.1 AHU Cooling Coils and Drip Pans

One of the best ways to prevent the spread of airborne *pathogens* throughout a building is to eliminate the possibility of distribution through the HVAC system, beginning with the AHU.

Central AHUs are notorious for microbial growth, termed *biofilm*, on cooling coils and drip pans. These systems have been linked to building-related symptoms (Mendell, 1993). "Therefore, microbial contamination of air-conditioning systems is a potentially remediable cause of building-related symptoms in susceptible workers" (Menzies, Popa, Hanley, Rand, & Milton, 2003, 1791). This benefit is even more substantial in health care settings where patients may be highly susceptible to a wide variety of diseases.

As a continuous form of source control, UVGI prevents microbial growth from occurring in new AHUs (F. Keikavousi, 2004). "For cooling coils the irradiance on the coil surface need be only a fraction of the average irradiance used in air disinfection applications since the exposure is typically continuous" (W. J. Kowalski, 2006, 255). However, existing AHUs may already be contaminated with microbial growth, which will require time for the UVGI to sterilize the coils. Figure 4.12 shows the UVGI irradiance levels and the time required for decontaminating existing coils with microbial growth. The figure shows that sterilization of the coils is assumed at a six log reduction. Therefore, even at a low UVGI irradiance of 10 $\mu W/cm^2$, the surface will be sterilized in about 50 hours.

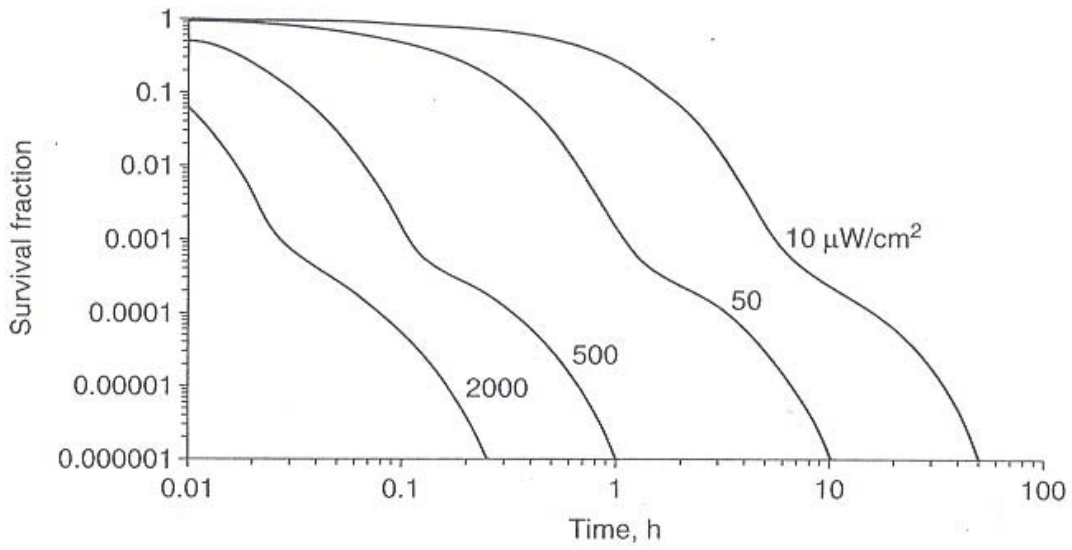


Figure 4.12 Effect of UVGI Irradiance on AHU Coils

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For optimal cleaning of the coil in the shortest amount of time, both sides of the coil should be irradiated by UVGI lamps unless limited by space. Irradiating only one side of the coil will require UVGI lamps more time to penetrate through the entire coil thickness. If the UVGI lamps are on one side of the coil only, it may be wise to oversize the system to ensure the entire coil will be sterilized. To increase the irradiation level on one side of the coil, reflective panels may be applied on the walls of the AHU to raise the irradiance levels (W. J. Kowalski, 2006). Figure 4.13 shows typical locations for UVGI lamps within an AHU. HVAC engineers should consult UVGI manufacturer's data and guidelines to ensure proper application of the UVGI system.

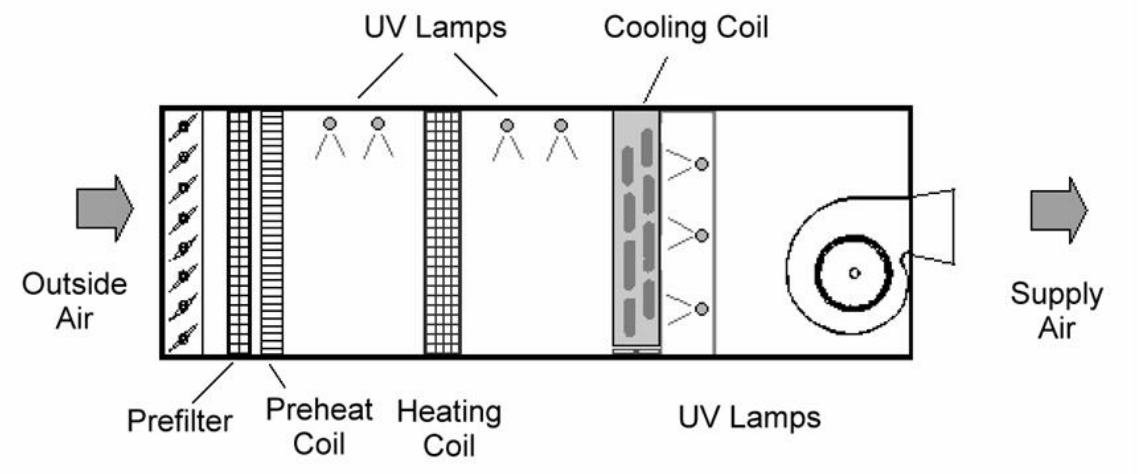

Figure 4.13 UVGI Locations within an AHU
(UV Air Treatment Steering Committee, 2005)

The following case study verifies the dramatic impact UVGI lamps can have in removing microbial build-up on the AHU coils and drip pans. UVGI was installed in numerous existing HVAC units by Florida Hospital, an acute-care health system, to test the technology's effectiveness (F. Keikavousi, 2004). First, UVGI lamps were installed in a 27-year-old, 6,000 CFM unit that had visible mold build-up such that the coil was approximately 50% clogged. Within weeks of the installation, the coil static pressure decreased from 1.8 in. w.g. to just 0.7 in. w.g., the air velocity increased from 230 fpm to 520 fpm, and the exiting wet bulb temperature decreased from 57°F to 53°C. The total energy savings of the unit for one year was $4,867 with an installation cost of less than $2,000. This amounts to a projected 15% energy savings for

operating the HVAC system. The process was repeated for another HVAC unit for which similar results occurred for static pressure and air velocity over the coil. To compare the effectiveness of UVGI to manual coil cleaning, a parallel HVAC unit's cooling coil was manually cleaned. Unfortunately, the pressure drop over the coil actually increased by 0.3 in. w.g. due to the build-up being compressed in the coil. Florida Hospital has had tremendous savings by applying UVGI in larger HVAC units in which the coils would have otherwise been replaced due to the extent of mold compressed inside the coil. The units consisted of 8 in. thick coils that would have cost between $16,000 and $18,000 per HVAC unit to replace. With UVGI installed for about $5,000, the mold build-up was destroyed through all six rows of the coil, and further growth has been prevented (F. Keikavousi, 2004). This case study shows the significant cost savings in energy and maintenance possible when applying UVGI technology to existing HVAC systems. Also, the age of these systems is a factor, which makes UVGI more appealing and impressive than if it were introduced to a new system. The cost information generally informs HVAC engineers of the potential savings, yet more detailed analysis must be performed on a building by building basis.

4.3.2.2 Room Applications

The other surface disinfection technique is irradiating bare UVGI lamps within spaces to "disinfect" the surfaces (First, Nardell, Chaisson, & Riley, 1999b). These systems decontaminate floors, carpets, and equipment by engaging timers to irradiate the surfaces after hours or when otherwise unoccupied. To prevent accidental exposure to occupants who may enter the space when the UVGI system is operating, motion detectors are installed to shut the system off (W. J. Kowalski, 2007).

These systems are aimed at disinfecting surfaces, not removing airborne *pathogens*. However, the half-life of mycobacteria and other human *pathogens* is less than six hours under ideal conditions. In addition, the *pathogens* are unlikely to be re-aerolized (First, Nardell, Chaisson, & Riley, 1999b). Therefore, the airborne *pathogens* and their potential to harm occupants will be diminished prior to the efforts of these UVGI room applications. This paper introduces "entire" room disinfection to inform HVAC engineers of the technology, but questions the validity and effectiveness of its application in health care facilities considering the other alternatives available.

4.4 Effectiveness of Technology

Owners and engineers want to know exactly how effective the UVGI technology is. Experimental studies, and even some real applications, prove the technology can be highly effective if designed and installed correctly. Unfortunately, a number of variables must be considered before estimating the overall effectiveness of UVGI. "Determinants of UVGI effectiveness include irradiance level, duration of irradiation, room configuration, lamp placement, lamp age, air movement patterns, and the amount of moisture in the air" (Centers for Disease Control and Prevention, 1994, 90). Some determinants can easily be controlled by the HVAC engineer and owner. Yet, the factors of air movement patterns and moisture in the air are more difficult to characterize in terms of their impact on UVGI effectiveness.

When analyzing the effectiveness of UVGI, HVAC engineers must distinguish between the disinfection and sterilization of infectious *pathogens*. "Sterilization is defined as the complete destruction of all microbial species. Disinfection on the other hand, is merely the reduction of microbial population" (W. J. Kowalski & Bahnfleth, 2000b, 104). For most UVGI applications involving *microorganisms* in air-streams and on surfaces, only levels of disinfection are possible. Thus, manufacturers aim to design UVGI systems based on the various parameters to achieve desired disinfection rates between 90% and 99.99%.

"Science has not uncovered a *microorganism* that's resistant to the damaging effects of mechanically generated 254 nm germicidal UV" (Fencl, 2007, 34). If conditions can be idealized for disinfection of *microorganisms*, then all can be treated due to the destructive properties of UVGI. However, depending on the variables, the effectiveness of UVGI on different microbes varies. Since, it is difficult to predict which *microorganisms* will be present in a health care facility, the most resistant microbes should be evaluated. One such *pathogen* that is more resistant to UVGI than most is Mycobacterium tuberculosis (TB). Therefore, TB is frequently used as a reference for determining the UVGI exposure requirements in practical applications to prevent airborne transmission indoors (Riley & Nardell, 1989). Many of the experimental case studies previously preformed have evaluated the UVGI systems on the basis of TB for this reason.

To classify effectiveness, *pathogen* survival rates are compared to the exposure dosage of UVGI. Equation No. 1 quantifies the relationship between *pathogen* survival and UVGI exposure factors of irradiance, time, and the microbe's susceptibility factor (First, Nardell,

Chaisson, & Riley, 1999a). This equation can be used for airborne *pathogens* exposed to UVGI in mechanically ventilated rooms. "Because the log scale representing survival fraction never goes to zero, total kill is theoretically impossible; although, as a practical matter, when survivors become few in number, it becomes difficult to distinguish that condition from total kill" (First, Nardell, Chaisson, & Riley, 1999a, 4). Equation No. 1 can be simplified to the form seen in Equation No. 2 (Department of Health and Human Services, 1993).

$$\frac{N_S}{N_O} = e^{-KIt} \qquad \text{(Equation No. 1)}$$

where

N_O = number of bacteria exposed

N_S = number of bacteria surviving after an exposure to UVGI

I = UVGI irradiance, $\mu W/cm^2$

t = time of UVGI exposure, s (the product, It, is the UVGI dose to the organism)

K = microbe susceptibility factor, $cm^2/\mu W \cdot s$

$$\%\ Survival = 100 \times e^{-KIt} \qquad \text{(Equation No. 2)}$$

A simple example shows how the above equation assists the HVAC engineer in estimating UVGI disinfection. For this example, UVGI is to be installed in an AHU with an air velocity of 480 fpm (8 ft/sec). Assuming the UVGI system will irradiate *pathogens* for a distance of 4 feet, an exposure time, t, of 0.5 seconds is expected. As mentioned previously, the UVGI system will be designed based on the ability to disinfect TB *pathogens* as a reference. TB has a microbe susceptibility factor, k, of 0.002132 $cm^2/\mu W \cdot s$ (W. J. Kowalski, 2006). To determine other microbe susceptibility factors, HVAC engineers should consult other resources such as the Aerobiological Engineering Handbook by Wladyslaw Kowalski. Yet, most microbe susceptibility factors remain unknown according to Kowalski (2006). A UVGI lamp with an average irradiance level, I, of 4,000 $\mu W/cm^2$ is assumed for the example. According to Sanuvox Technologies' product specifications, the average irradiance levels for many of their products extend beyond 10,000 $\mu W/cm^2$ (Sanuvox Technologies, 2007). Similar UVGI irradiance information can be determined from individual manufacturer lamp data. With this information

input in Equation No. 2, the survival percentage is calculated as shown in Equation No. 3. Thus, the percentage of TB *pathogens* surviving the UVGI system is only 1.4. Therefore, nearly 99% disinfection would occur for the given example.

$$\%\ Survival = 100 \times e^{-(0.002132 \times 4000 \times 0.5)} \approx 1.4\% \qquad \text{(Equation No. 3)}$$

4.4.1 UVGI Rating Value

To evaluate the effectiveness of UVGI systems, a UVGI rating value (URV) has been created (W. J. Kowalski & Dunn, 2006). The URV system is based on the MERV filter rating system, in that it complements its effectiveness. Combining a UVGI system of a specific URV with a filter of the same MERV rating will create approximately equal reductions of the airborne *pathogens* over the entire spectrum of sizes (W. J. Kowalski, 2003). These ratings are to be used with UVGI systems designed in AHUs or other in-duct applications where levels of irradiation are substantial. "Systems like those used for microbial growth control, or upper air systems, may use much lower values than 100 $\mu W/cm^2$, and URV ratings do not apply to these systems" (W. J. Kowalski, 2006, 243). Table 4.1 summarizes the UVGI rating values as well as the UVGI doses needed to obtain desired disinfection efficiencies. As defined in Equation No. 1, the UVGI dose is the product of the UVGI irradiance and the exposure time. As listed in the table, the higher the UVGI dose, the higher the inactivation rate of all the airborne *pathogens*.

Table 4.1 UVGI Rating Values and Inactivation Rates

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URV	Dose		Inactivation Rates			
	$\mu J/cm^2$	J/m^2	Anthrax%	Influenza%	Smallpox%	TB%
1	1	0.01	0	0	0	0
2	10	0.1	0	1	2	2
3	20	0.2	0	2	3	4
4	30	0.3	0	3	4	6
5	50	0.5	1	6	7	10
6	75	0.75	1	9	11	15
7	100	1	2	11	14	19
8	150	1.5	2	16	20	27
9	250	2.5	4	26	32	41
10	500	5	8	45	53	66
11	1000	10	15	69	78	88
12	1500	15	22	83	90	96
13	2000	20	28	91	95	99
14	3000	30	39	97	99	100
15	4000	40	49	99	100	100
16	5000	50	57	100	100	100
17	6000	60	63	100	100	100
18	8000	80	74	100	100	100
19	10000	100	81	100	100	100
20	20000	200	96	100	100	100
Rate constant k, cm2/μJ			0.000167	0.001187	0.001528	0.002132

4.4.2 Comparative Equivalent to ACH

To evaluate the effectiveness of UVGI disinfection, HVAC engineers calculate *equivalent air exchange rates* to give a direct relationship to the effectiveness of ventilation systems. "It is possible to express the reduction caused by radiation alone as an *equivalent air exchange rate*, thereby highlighting in terms familiar to HVAC specialists the savings obtainable when using UVGI to purge room air of viable *bacteria* rather than using an increased number of room air changes" (First, Nardell, Chaisson, & Riley, 1999a, 5). To do so, the fundamental equation for *pathogen* survival, Equation No. 1, will be utilized. This equation is transformed into a form capable of calculating the *equivalent air exchange rate*, as stated below.

$$-\ln \frac{N_S}{N_O} = K\, I\, t \qquad \text{(Equation No. 4)}$$

where

N_O = number of bacteria exposed

N_S = number of bacteria surviving after an exposure to UVGI

I = UVGI irradiance, $\mu W/cm^2$

t = time of UVGI exposure, s (the product, It, is the UVGI dose to the organism)

K = microbe susceptibility factor, $cm^2/\mu W \cdot s$

The mixing process of air into the UVGI zone has the same logarithmic decay function as seen in ventilation air changes alone where a fraction of the *pathogens* are inactivated or removed, respectively (First, Nardell, Chaisson, & Riley, 1999a). With this similarity, the equivalent air changes (EAC) equation is created as shown in Equation No. 5. "EAC is the number of air changes in a well-mixed room that would be required to reduce the number of viable airborne *bacteria* to the same degree as the UVGI irradiation alone" (First, Nardell, Chaisson, & Riley, 1999a, 5). Based on this equation, if a 63% reduction of airborne *pathogens* resulted from UVGI, then the N_S/N_O ratio would be 0.37. The negative logarithm of 0.37 is 1.0, therefore implying the UVGI system reduced the airborne *pathogens* by the same amount as one air change. An even greater reduction of airborne *pathogens* with UVGI, say 95%, would equate to the equivalent of three air changes. If the reduction occurs in just 15 minutes, an air exchange rate of 12 ACH (3 ACH x 4 per hour) would result (First, Nardell, Chaisson, & Riley, 1999a). With an upper room UVGI intensity of 10 $\mu W/cm^2$, 63% of airborne tuberculosis *pathogens*, the equivalent to one air change, would be killed in just 24 seconds (Riley et al., 1976). Furthermore, a 99% reduction, equivalent to five air changes, occurs in only two minutes (Riley et al., 1976). This tremendous reduction in a short period of time translates into a 150 ACH equivalent assuming perfect air mixing in the upper portion of the room where the UVGI irradiance is located. A much lower *equivalent air exchange rate* for the entire room results due to the large cross-sectional area of the room and the fluctuation of air mixing within the room. Therefore, it is estimated that an optimal upper room UVGI system has the potential of reducing airborne *pathogens* by a total equivalent of 20 ACH or more for the space (First, Nardell, Chaisson, & Riley, 1999a).

$$EAC = -\ln \frac{N_S}{N_O} = K\,I\,t \qquad \text{(Equation No. 5)}$$

Quantifying the percentage reduction of airborne *microorganisms* in standard applications is the most difficult process of calculating an accurate *equivalent air exchange rate* due to the absence of perfect mixing. To achieve perfect air mixing, experimental studies included additional space fans to circulate air extensively throughout the space. However, in a real application, it is unlikely the health care spaces will have multiple, if any, fans moving additional air in each space. Therefore, the calculated *equivalent air exchange rate* alone may be overestimated. However, minimum ventilation rates are still required since UVGI can only be applied as a supplemental control method for health care facilities. Consequently, the air exchange rates supplied by the mechanical ventilation system will be added to the *equivalent air exchange rates* of UVGI to establish the total air exchange rate (First, Nardell, Chaisson, & Riley, 1999a).

The *equivalent air exchange rate* may be more significant than many HVAC engineers would anticipate. "In one set of experiments, a single 17 watt UVGI fixture suspended 0.6 m from the ceiling resulted in disappearance rates for mycobacteria equivalent to adding 10 ACH to the existing 2 ACH" (Nardell, 1997, 29). Creating the equivalent of 10 ACH from just one 17 watt UVGI fixture translates into tremendous savings when applied to a majority of spaces. The larger AHUs, larger ductwork, and increased number of diffusers needed to supply the additional 10 ACH by ventilation, rather than the equivalent with UVGI, would result in much higher installation costs in addition to increased operating costs.

Determining an accurate *equivalent air exchange rate* of UVGI will strengthen the HVAC engineer's and owner's ability to determine the economic impact of the comparative UVGI system. "The ability to express the bacteria-destroying effect of upper-room UVGI as equivalent air changes makes it possible to compare the purchase, installation, and operating costs of upper-room UVGI with an equivalent amount of heating, ventilating, and air-conditioning (HVAC) capacity to provide the same level of air sanitation" (First, Nardell, Chaisson, & Riley, 1999a, 5). The economic analysis in Section 4.8 is based on the equivalent air exchange method introduced here.

4.4.3 Combined Performance of UVGI and Filtration

UVGI technology and filtration methods complement the effectiveness of each other. On the one hand, filtration removes larger *pathogens* in the air-stream, such as spores, which tend to be more difficult to inactivate with UVGI. On the other hand, UVGI disinfects small airborne *bacteria* and *viruses* quite effectively that may pass through MERV 12 or lower filters (W. J. Kowalski & Bahnfleth, 2000a). Thus, HVAC engineers may design the filtration and UVGI system with the combination effect to achieve any desired level of disinfection. Figure 4.14 shows the results of a combination MERV 14 filter and URV 14 UVGI system for 45 microbes of increasing diameters, from microbe number 1 to 45. The larger particles were dramatically reduced by the MERV 14 filter, yet over 40 percent of isolated small microbes survived. With the addition of the URV 14 UVGI system, the survival rates of the smaller microbes were greatly decreased, as expected. Notably, select microbes (Microbe numbers 4, 9, 12, and 15) were more resistant to the UVGI and did not result in a much higher disinfection even with the addition of the URV 14 UVGI. Overall, the combination provided a much more effective system for removing and disinfecting the wide range of microbes.

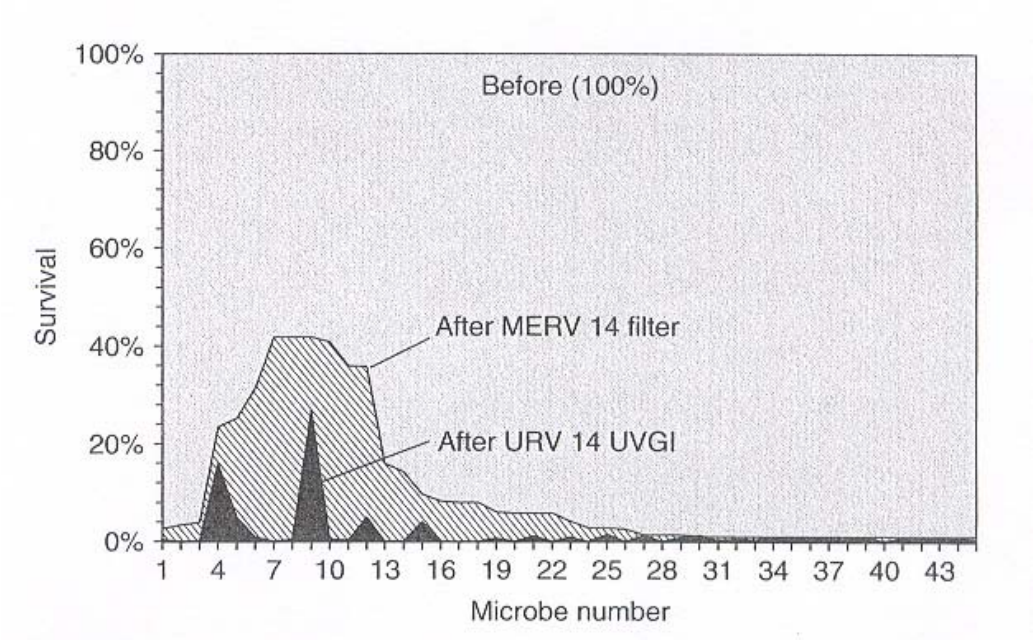

Figure 4.14 MERV 14 Filtration and URV 14 UVGI System

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As the effectiveness of UVGI is increased and ensured, UVGI systems in combination with filtration may have great impact in health care facilities that are currently using HEPA filtration. "The combination of UVGI and high-efficiency filters in the MERV-13-to-15 range may be able to provide performance virtually equivalent to HEPA filtration, thus offering health care facilities the possibility of reducing energy costs without increasing health risks" (W. J. Kowalski, 2007, 42). This potential energy savings is based on the fact that the fan energy required to overcome HEPA static pressure loss which is greater than the energy consumed by the UVGI lamps. However, further research and development is required for the combination system to be adopted by codes and guidelines.

4.5 Advantages of UVGI

Implementing UVGI into health care facilities would translate into major advantages not only to the patients, but to staff and owners as well. The advantages experienced with UVGI to be addressed in the following sections include disinfecting airborne *pathogens*, improving the efficiency of mechanical systems, and lowering maintenance costs and system downtime.

4.5.1 Disinfection of Pathogens

UVGI systems employing UV-C radiation minimize the ability of infectious *pathogens* to reproduce and infect building occupants. Even though the effectiveness is not as well-defined as the other engineering control methods, it is still a viable technology that produces more benefits than concerns. The ASHRAE HVAC Design Manual for Hospitals and Clinics emphasizes this point stating, "Perhaps we should not reject measures of infection protection because they have not yet proven to be effective but, rather, reject them only when they have proven to be ineffective" (Geshwiler et al., 2003, 219). Therefore, this study suggests HVAC engineers should pursue UVGI systems as a supplemental engineering control method with the assistance of manufacturers to ensure maximum occupant safety.

Without regulating guidelines for the industry, manufacturers must recommend installations that meet their standards based on practical application and experience. If UVGI applications mimic the principles used in testing UVGI fixtures in laboratory settings, a

reasonably certain effectiveness can be expected. With so many factors affecting each and every installation, manufacturers must design systems that are specific to individual applications.

Applying UVGI correctly in individual rooms, corridors, or mechanical equipment can only increase the overall disinfection effectiveness within the health care facility, although the actual UVGI effectiveness may vary substantially due to any number of factors or situations. Certainly, adding UVGI will not minimize the disinfection of *microorganisms* either in air-streams or on surfaces; indeed, the reduction of these infectious *pathogens* can be instrumental in benefiting the occupants as well as the operation of the mechanical system.

4.5.2 Higher Efficiency and Lower Maintenance Costs

The benefits of UVGI in HVAC systems extend beyond the effectiveness in eliminating *pathogens*. For instance, UVGI lamps directed at cooling coils within an AHU prevent microbial growth and maintain a certain level of cleanliness. Removing and preventing microbial growth is critical in improving and maintaining the heat transfer efficiency of the coils. In addition, clean coils improve the airflow through the system allowing AHUs to operate at near peak performance (F. Keikavousi, 2004). If microbial growth occurs on the coils, fan energy use will be increased to account for a higher pressure drop over the coils. In addition, the chiller and chiller pump may be required to operate at higher conditions with the decrease in heat transfer of the cooling coils, further increasing the total energy use of the system.

"Health care facilities continuously face the challenge, and pressure, of being cost-effective. The annual operating costs of HVAC systems, including both energy consumption and maintenance materials and manpower, constitute a significant portion of overall building costs" (Geshwiler et al., 2003, 32). The added benefit of UVGI systems in the AHU in preventing microbial growth is reduced maintenance. Instead of cleaning the coils with hazardous chemicals, maintenance personnel will only be required to wash the coils with a mixture of soap and water to remove stubborn dust particles. The costs for cleaning AHU coils can range from $500 to $6,000 or more for coils requiring extensive cleaning (F. Keikavousi, 2004). Cleaning of the coils is typically performed annually to maintain an efficient system. Therefore, evaluating the life-cycle cost of the UVGI application reveals significant savings.

Traditionally, the maintenance of coils induces a period of downtime for chemical cleaning. The chemical agents are allowed time to dry, therefore preventing them from being introduced into the system and space, which could harm building occupants. During this downtime, the indoor conditions are compromised, and patient comfort and IAQ may be affected (F. Keikavousi, 2004). Maintenance personnel required to perform the cleaning process are also exposed the hazardous chemicals, which could impact their health. HVAC engineers should evaluate these advantages of UVGI with owners, while understanding the disadvantages discussed in the next section.

4.6 Disadvantages of UVGI

Although UVGI technology has many advantages, also some disadvantages need to be identified. Specifically, HVAC engineers need to understand the disadvantages currently seen in the industry that may be causing the resistance to overall acceptance. Frankly, UVGI is associated with risk and unpredictable results. Unfortunately, engineers have not been introduced to detailed design criteria for proven UVGI effectiveness. Also, liability is assumed by the owners and engineers for a technology that can cause harm to occupants of the building if not properly installed and maintained. These disadvantages as well as a discussion on initial and annual expenses follow.

4.6.1 Absence of UVGI Design Standards

One of the largest factors limiting the implementation of UVGI technologies is the lack of consistent design standards and guidelines. "Guidelines for the design and installation of upper-room UVGI systems have been published from time to time by a number of lamp and fixture manufacturers over the past half century of their use, but basic engineering studies and technical publications devoted to the technology are scanty and not susceptible to broad generalization" (First, Nardell, Chaisson, & Riley, 1999b, 9). Installation techniques widely vary among manufacturers and are not being regulated by a governing body to ensure proper efficacy of UVGI after the installation. Nonetheless, proper disinfection effectiveness is vital to health care facilities where a higher level of expectation exists for control of *pathogens* compared to that for commercial buildings.

Although many laboratory studies have been conducted to analyze the efficacy of UVGI for numerous *microorganisms* in a range of temperature and humidity conditions, little has been done to evaluate the practical application of UVGI in health care buildings (First, Nardell, Chaisson, & Riley, 1999b). "Therefore the knowledge base that exists on UVGI and its application is relatively small, and health care authorities have few guidelines on which to make decisions" (Beggs, Kerr et al., 2000, 142).

Currently, the design criteria are determined by the product manufacturers, yet, the manufacturers are not willing to ensure the efficacy of their technologies. Even UVGI lamp manufacturers, such as Philips plc., acknowledge that important information is not available (Beggs et al., 2000). "For example, with regard to the sizing of UV lamps for installation in ductwork systems, a Philips technical document on UV disinfection states: 'In the calculation…it should be emphasized that it results only in a rough estimation; we did not incorporate the possible effects of humidity and temperature on the killing rate. Philips is not a specialist in that field; we always advise to contact qualified authorities to evaluate the bacteriological aspects" (Beggs et al., 2000, 24). However, the introduction of CFD models and improved distribution studies on UVGI lamps and fixtures is moving the industry in the right direction. The CFD models characterize the room and air distribution in coordination with any UVGI systems applied within the space to evaluate the effectiveness quantitatively (First, Nardell, Chaisson, & Riley, 1999b). With this data, manufacturers and HVAC engineers will be more capable of accurately predicting the results in on-site application rather than in a laboratory setting.

An instrumental move by ASHRAE will further solidify the acceptability of the technology to engineers and owners. ASHRAE will be publishing the first design standards for UVGI in the 2008 ASHRAE Handbook – HVAC Systems and Equipment. With the establishment of these guidelines, all manufacturers will be required to have their UVGI products perform to a minimum standard ensuring the advancement of the technology in a safe and successful manner.

4.6.2 Risk to Occupants and Objects

In health care facilities, the safety and health of patients and staff is of the highest importance. Any system that hinders the safety of occupants will be evaluated with expected

resistance. The disadvantage to in-room UVGI applications is the potential for overexposure to UVGI irradiation by patients or staff.

Overexposure of UVGI irradiation can be harmful to occupants. Accidental UVGI overexposure usually occurs to maintenance workers who enter the irradiated zone of the UVGI fixtures that are still operating (Nardell, 1997). Occupants in the room may also be exposed to higher doses of UVGI irradiation if the fixtures are not located or installed properly within the space. Health care workers are at a higher risk since they occupy the space for longer periods of time than most patients. UVGI overexposure has the potential of causing unpleasant eye and skin irritations, yet they are temporary and present no known long-term consequences (Kujundzic et al., 2007). To prevent overexposure, UVGI exposure limits have been set by the American Conference of Government Industrial Hygienists (ACGIH) and the National Institute of Occupational Safety and Health (NIOSH). Both organizations set the exposure limits at 0.2 $\mu W/cm^2$ for 8 hours of continuous exposure and 0.4 $\mu W/cm^2$ for 4 hours of exposure (UV Air Treatment Steering Committee, 2005). UVGI manufacturers account for these exposure limits and ensure their systems will operate below these limits when installed properly. With the selection methods and safety criteria met by the UVGI manufacturers, irradiance readings are typically not measured after the UVGI systems are installed.

Beyond the risk to occupants, UVGI overexposure may cause damage to objects within the space. "Overexposure to UV also produces fading of colors in many paints and fabrics, accelerated deterioration of plastics, and wilting of some plants. When UV-sensitive plants, plastics, and colored fabrics cannot be removed from irradiated areas, they can be covered or shaded with ordinary glass as it is opaque to UV radiation and provides protection" (First, Nardell, Chaisson, & Riley, 1999b, 8). The extent of fading and damage to room objects is subjective. Other sources maintain the stance that due to the inability of UV-C to deeply penetrate objects, fading will be slight if any.

It is also important to consider the initial goal of applying the UVGI technology. The primary purpose is to eliminate airborne contaminants with the highest UVGI efficacy possible. "Modifications to increase safety for long-term human occupancy of a space may reduce irradiation of airborne infectious agents to levels that are not lethal" (Miller & Macher, 2000, 291). HVAC engineers and manufacturers must consider balancing both elements to create the

optimal UVGI system that is effective in deactivating *pathogens* without infringing on the safety of the occupants.

Awareness must also be addressed for UVGI applications in AHUs and ductwork. Maintenance personnel may be at a much higher risk even if their exposure time to the UVGI irradiation is short because they will be in close proximity to the UVGI source. Precautions in ensuring that the system is turned off and that service personnel wear protective clothing and eyewear should be stressed to prevent any possibility of harm to workers.

4.6.3 Initial and Annual Expenses

HVAC engineers and owners are concerned with both the initial and annual expenses of implementing UVGI. The initial expense for UVGI includes the installation and fixture costs. However, compared to the overall budget of many new health care projects, which can extend upwards of $250 million, the initial cost of various UVGI systems, which may range from $10,000 to $50,000 is comparatively minimal. Initial expenses for upper-room UVGI and UVGI in AHUs are presented in the economic analysis in Section 4.8. HVAC engineers should consult with UVGI manufacturers for estimated expenses for their particular application.

To maintain the proper UVGI effectiveness, replacement UVGI lamps are required due to the decline in UVGI irradiation with time. The efficacy of UVGI fixtures is highly dependent on the lamp output. It is important to know when UVGI lamps are operating below the design minimum. The typical decline in UV output is 10% to 20% per year for the lamps (First, Nardell, Chaisson, & Riley, 1999b). With the consistent decline in output, many owners choose to install new lamps annually to maintain the most effective system. Annual expenses for UVGI include energy consumption, maintenance, and replacement lamps. According to Lumalier, Inc., 36 watt twin tube UVGI replacement lamps cost around $25 each, with costs increasing for larger lamps. The labor cost for replacing lamps fluctuates with the type of UVGI system. UVGI systems installed in an AHU will require maintenance personnel to service one location to replace all the UVGI lamps, taking approximately one hour to perform. On the other hand, upper-room UVGI systems or UVGI systems in return air ductwork will require the maintenance personnel to service devices in individual rooms or ceiling locations, greatly increasing the replacement time to approximately one-third of an hour for each UVGI lamp replacement. The

annual and initial costs related to example UVGI systems are summarized in the economic evaluation in Section 4.8.6.

4.7 Design Methods/Selection

Effective design of the UVGI system will create the optimal disinfection system, which reduces the susceptibility of patients and staff to *contagious pathogens*. In regards to UVGI design parameters, "the most important factors are the airflow of HVAC equipment that will be disinfected, the lamp wattage and distance, and the ventilation system design itself" (W. J. Kowalski & Bahnfleth, 2000b, 104). Based on the preceding information, the engineer and owner can be confident in selecting the system(s) most suited for their projects. The following design information and examples are provided to inform the HVAC engineer of the necessay considerations. However, the final selection and design of the UVGI system should be performed by UVGI manufacturers due to the resources available to them. This is because selection methods of experienced UVGI equipment providers have been accepted by the industry based on their selection data sheets. These companies use proprietary software to accurately select the most effective design for each individual project and assume the liability of providing safe systems to the owners.

4.7.1 Upper-Room UVGI

Upper-room UVGI selection is based on many factors that affect the UVGI effectiveness: room characteristics, UVGI fixture location, total UVGI irradiation, number of fixtures, and air distribution in the space (First, Nardell, Chaisson, & Riley, 1999b). Due to vast industry experience, manufacturers are an excellent resource for the HVAC engineer and can often provide insight into these influential factors.

It is important for the HVAC engineer to understand the UVGI fixture selections. To confirm the validity of the selections suggested by a manufacturer, guidelines seen in the industry are presented for the HVAC engineer to evaluate and compare. According to the Guidelines for the Application of Upper-Room Ultraviolet Germicidal Irradiation for Preventing Transmission of Airborne Contagion—Part II: Design and Operation Guide by Melvin First et al., even with the infinite number of variables, a simplified application of upper-room UVGI

accounts for installing 30 watts of UVGI lamp output for 200 ft^2 of floor area (First, Nardell, Chaisson, & Riley, 1999b). For instance, a 14 ft x 14 ft room should have approximately one 30 watt UVGI lamp located in the center of the room at least 7 ft above the floor. In higher occupancy spaces, the authors recommend that 30 watts of UVGI output be installed for every seven people (Riley et al., 1976). Increasing the UVGI output in more populated spaces is effective with the increased potential for more *pathogens* to be released in closer proximity to all occupants. "Another installation guideline that has been proposed is based on minimum germicidal dose per pass through the irradiated zone of 50 $\mu W \cdot s/cm^2$" (First, Nardell, Chaisson, & Riley, 1999b, 4). This installation guideline is much more difficult for HVAC engineers to validate until air circulation patterns and UVGI emission fields are produced with CFD studies. This design guideline may become more frequently used by HVAC engineers and manufacturers as CFD studies continue.

As mentioned above, the UVGI output wattage is the basis of the selection. HVAC engineers need to be certain to differentiate between lamp input and lamp output ratings. The lamp output ratings are often the sole parameter to select the UVGI fixtures (W. J. Kowalski & Bahnfleth, 2000b). "Typically, the lamp UV output ratings range from 25% to 33% of the input power, depending on the particular lamp and transformer combination" (First, Nardell, Chaisson, & Riley, 1999b, 2). For example, Figure 4.15 shows an upper-room UVGI fixture data sheet with a lamp input (nominal) wattage of 36 watts and UVGI wattage of only 12 watts, accounting for 33% of the input power. Manufacturers should provide this information with product selections to the HVAC engineers.

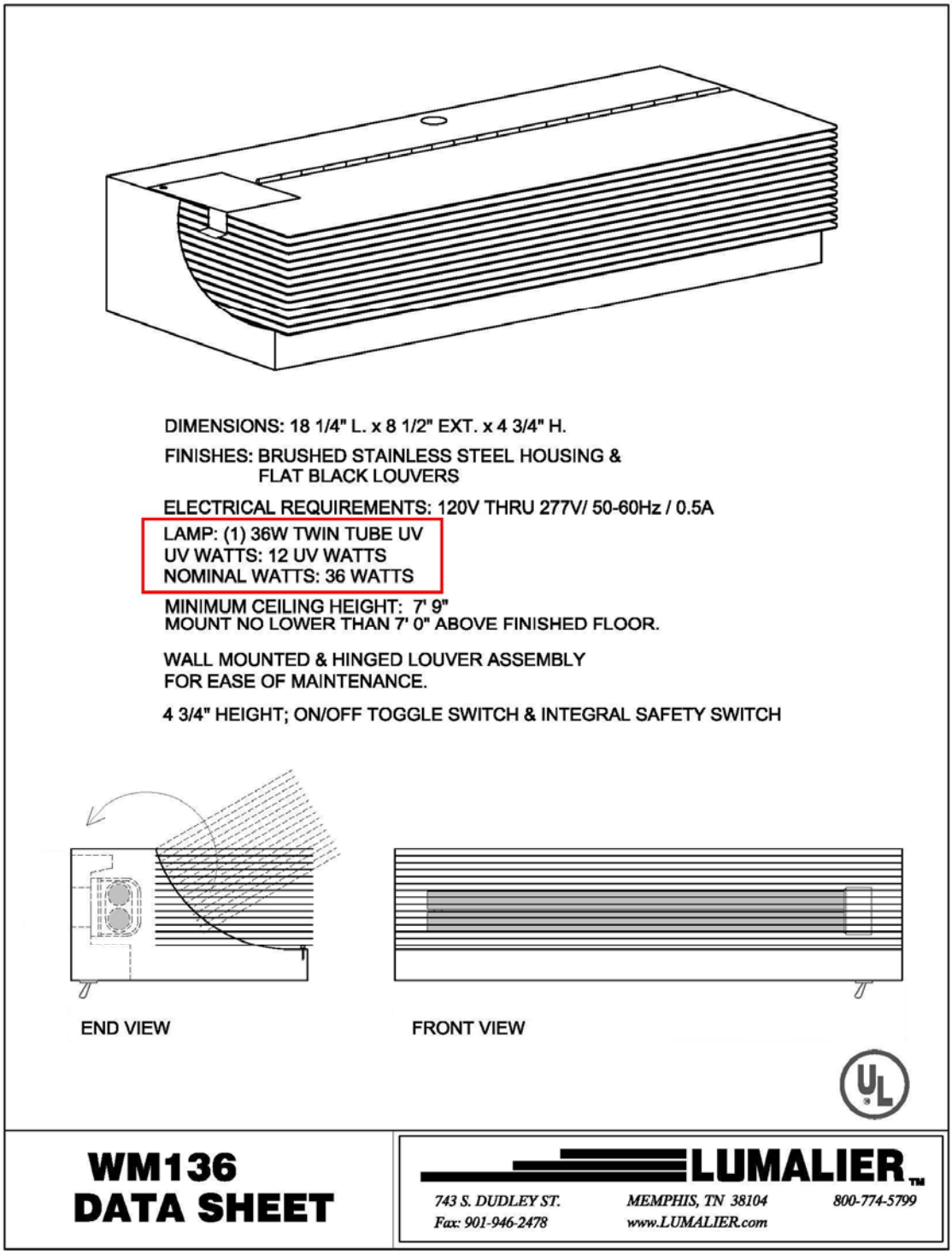

Figure 4.15 UVGI Lamp Output Ratings

(Lumalier, Inc.)

For upper-room UVGI systems, louvered fixtures are used because they prevent direct exposure to occupants in the lower portion of the room. Manufacturers recommend they be installed at a minimum ceiling height of 8 ft (bottom of fixture 7 ft from the finish floor), where the UV beam sightline may extend 24 ft before reaching eye level. With incremental ceiling height increases, the fixture height can be increased half the distance of the ceiling height increase above 8 ft. For instance, with a 9 ft ceiling height, the UVGI fixture can be mounted at a height of 7.5 ft above the finish floor. Every increase in mounting height will decrease the risk of direct exposure to occupants in the space because the sightline is further extended. However, increasing the distance between the occupants and the UVGI irradiance zone may slightly decrease the effectiveness of the UVGI system, depending upon the air mixing in the space.

The example following of upper-room UVGI design from the economic study shows the variance of the guidelines and reinforces the idea that expertise provided by manufacturers can reduce overall cost while maintaining effectiveness. The medical examination room chosen is approximately 250 ft^2, measuring 18'-0" x 13'-10" with an 8 ft ceiling height. With the rectangular shape of the room, two wall-mounted UVGI fixtures with the UVGI output directed to the center of the room were recommended by Lumalier, Inc. Each fixture houses one twin tube UVGI lamp with a nominal wattage of 36 and UVGI wattage of 12. Therefore, the 250 ft^2 space is irradiated with 24 UVGI watts. According to the simplified guideline of 30 UVGI watts for each 200 ft^2, the selected UVGI wattage is lower than expected. However, based on the selection software of the manufacturer, the system provides effective disinfection without installing the higher UVGI wattage listed by the guideline. This not only saves money in the initial cost but also in the energy cost and lamp replacement cost.

4.7.2 In-Duct UVGI

As with upper-room UVGI selections, HVAC engineers are encouraged to consult with UVGI manufacturers to provide owners with an effective and efficient system. Since exposure time is critical to deactivating airborne *pathogens*, air velocity is a major factor in designing UVGI systems within AHUs and ductwork. Inadequate UVGI irradiance will allow *pathogens* to pass the irradiated zone without being deactivated. Other important factors for in-duct UVGI selection is airflow quantity, duct or AHU dimensions, and air temperature and relative humidity.

Manufacturers would use the data provided by HVAC engineers to recommend the proper selections.

HVAC engineers must ensure UVGI manufacturers base the selection of these systems on airborne disinfection, not surface sterilization. Although UVGI lamps installed in AHUs inherently clean the coils, the intention is for the system primarily to provide effective air disinfection. *Pathogens* must be exposed to a much higher UVGI dose for airborne disinfection than surface disinfection to be lethal, as outlined in Section 4.4. General guidelines are difficult to establish for in-duct UVGI with so many installation factors as well as differences among the systems produced by manufacturers. For example, some manufacturers install the UVGI lamps in parallel to the duct, while others install perpendicularly. HVAC engineers should consult manufacturer literature for further evaluation.

An example of a UVGI system within an AHU shows practical application of the technology. A McQuay Skyline constant volume unit, AHU-1, was selected for the economic study based on space requirements and load calculations for the given space layout. AHU-1 has a cooling coil face area of 7.5 ft^2, air velocity of 520 FPM, and supply air quantity of 3,900 CFM. The air conditions passing over the UVGI lamps, located prior to the cooling coil, are representative of the mixed air temperature. The highest mixed air temperature and relative humidity encountered by the UVGI lamps is 78.5°F and 48%, respectively, so these system and air conditions were used to select the required UVGI lamps. The selections were made for 99% removal effectiveness for airborne *pathogens*, in addition to the near sterilization provided on the coil surface. Lumalier, Inc. recommended a UVGI system consisting of four twin tube UVGI lamps with a combined nominal wattage of 240 and UVGI wattage of 72. A manufacturer specified support system was included to space the UVGI lamps equally across the air space to provide an even UVGI irradiance field. As expected, the UVGI wattage installed in the AHU is much higher than that applied in the upper-room UVGI fixtures due to the increased air velocity, among other factors. The validity of design information will only increase as further research is performed and communicated to the UVGI manufacturers and HVAC engineers.

4.8 Economic Evaluation

An economic evaluation analyzes the life-cycle costs for systems with varying alternatives. This economic evaluation quantifies the estimated costs health care facilities will incur in applying UVGI technologies. With the results, HVAC engineers will be able to evaluate their specific application in relation to the more general study outlined here. A baseline system designed to meet code requirements is compared to three alternate systems designed above the code minimums: incorporation of upper-room UVGI fixtures to the baseline system, a system with an increased ventilation rate, and a system with UVGI installed within the HVAC unit. The combined UVGI systems were chosen because they are the more commonly installed devices in health care facilities. The system with the increased ventilation rate is evaluated for direct economic comparison to the upper-room UVGI system on the basis of equivalent air changes. This case study not only compares the effectiveness of airborne *pathogen* removal but also includes a comparative life-cycle cost analysis. It must be stressed that this annualized cost is not an all-encompassing cost the owner should assume for operating the building system. Instead, only those costs that vary among the systems are evaluated.

4.8.1 Space and Location Criteria

To evaluate the economic impacts of applying UVGI technology, the UVGI fixtures are applied to simulate actual installation. UVGI fixtures are commonly used in health care facilities where undiagnosed or *contagious* patients may be located, such as diagnostic and treatment areas. These are areas where high levels of airborne contaminants may be introduced; including *bronchoscopy*, *sputum collection*, and *pentamidine* administration areas. Therefore, this case study consists of a diagnostic and treatment area located within a health care facility, served by one dedicated HVAC system. More specifically, eight examination rooms, four treatment rooms, one *sputum collection* room, one *bronchoscopy* room, one medication room, one soiled workroom, one clean workroom, and patient corridors comprise the study layout. The floor plan of the study is included in Appendix C.1.

The design criteria for each of the rooms are established using guidelines and standards. The ASHRAE Design Manual for Hospitals and Clinics (2003) offers a tabular comparison between the design criteria (pressure relationships, minimum air changes per hour, relative

humidity, and temperature) listed in the AIA Guidelines (2001), ASHRAE Handbook (1999), and the Design Manual, documented in Appendix B. For the diagnostic and treatment spaces designated in the study, the 2007 ASHRAE Handbook design ventilation requirements are verified with the 1999 requirements, listed in the table. All criteria for the spaces in this study are identical between the 1999 and 2007 Handbooks; therefore, it meets the most current requirements of ASHRAE. According to the table, the sputum collection room, bronchoscopy room, and soiled workroom are required to maintain a negative pressure relationship compared to the adjacent space, the patient corridor. For conservative design, a temperature of 70°F, the lowest temperature documented from the guidelines and standards, was used with a relative humidity of 50%. Table 1 of the 2007 ASHRAE Handbook, namely Table 3.3 in this paper, addresses the required level of filtration for diagnostic and treatment areas. For the areas identified in this study, two filter beds of MERV 8 and MERV 14 ratings are to be installed. This level of filtration was applied to all HVAC systems in the case study, even when UVGI systems were included. AIA, ASHRAE, and the CDCP permit UVGI as a supplement system, but not to replace filtration as the control method (Leung & Chan, 2006). The aforementioned room design criteria are summarized in Table 4.2.

Table 4.2 Room Design Criteria

ROOM NO.	ROOM NAME	AREA (SF)	CEILING HEIGHT (FT)	MIN OA ACH[1]	MIN TOTAL ACH[1]	DESIGN TEMP °F[2]	RELATIVE HUMIDITY %[2]
101	Sputum Collection	250	8	2	12	70 - 75	30 - 60
102	Bronchoscopy	250	8	2	12	70 - 75	30 - 60
103	Examination Room 1	250	8	2	6	70 - 75	30 - 60
104	Examination Room 2	250	8	2	6	70 - 75	30 - 60
105	Examination Room 3	250	8	2	6	70 - 75	30 - 60
106	Examination Room 4	250	8	2	6	70 - 75	30 - 60
107	Examination Room 5	250	8	2	6	70 - 75	30 - 60
108	Examination Room 6	250	8	2	6	70 - 75	30 - 60
109	Examination Room 7	250	8	2	6	70 - 75	30 - 60
110	Examination Room 8	250	8	2	6	70 - 75	30 - 60
111	Treatment Room 1	250	8	2	6	70 - 75	30 - 60
112	Treatment Room 2	250	8	2	6	70 - 75	30 - 60
113	Treatment Room 3	250	8	2	6	70 - 75	30 - 60
114	Treatment Room 4	250	8	2	6	70 - 75	30 - 60
115	Medication Room	150	8	2	4	70 - 75	30 - 60
116	Soiled Room	150	8	2	10	70 - 75	30 - 60
117	Clean Workroom	150	8	2	4	70 - 75	30 - 60
118	Patient Corridors	550	8	2	4	70 - 75	30 - 60

Notes:
1.) Most stringent of HVAC Design Manual for Hospitals and Clinics, AIA Guidelines, and ASHRAE Handbook (Appendix B)
2.) From 2007 ASHRAE Handbook-HVAC Applications

With the room criteria well outlined, next the location design factors are determined. The location of the study will be Kansas City, Missouri since it offers a mixed-humid climate, not an extreme hot or cold climate (*ANSI/ASHRAE/IESNA standard 90.1-2004 energy standard for buildings except low-rise residential buildings*2004). The 0.4% design conditions for dry-bulb (DB) and mean coincident wet-bulb (MWB) temperatures provide conservative values in the economic evaluation (*2005 ASHRAE Handbook - fundamentals*). In addition, many criteria call for the 0.4% temperatures for inpatient and some outpatient (normally surgical) facilities when indoor conditions are critical to patients' well being, such as the areas selected for this study (Geshwiler et al., 2003). The DB temperature and MWB temperature for Kansas City, MO are 96°F and 75°F, respectively. In summary, the location and room design criteria discussed here establish the fundamental basis of the economic evaluation.

4.8.2 Baseline HVAC System

A baseline HVAC system, AHU-1, designed to meet the code requirements for the diagnostic and treatment areas is established for comparison to the UVGI systems and increased ventilation options. Given the nature of the diagnostic and treatment area, the study assumes occupancy could occur at any hour of the day; thus, the design conditions should be maintained continuously (24 hours a day, 365 days a year). For the HVAC system selection process, the space loads are calculated based on the design criteria from Table 4.2. The outside air, exhaust air, and supply air CFM rates for the baseline system are tabulated in Appendix D.3. In addition, the internal loads from people and equipment are added to the space loads. The sensible, latent, and total space loads from the table are determined and are used in calculating the system coil loads. Appendix D.5 outlines the calculations performed to obtain the system coil loads. Next, an AHU schedule is constructed with all of the information needed for a manufacturer to make a product selection. The coil loads, as well as the MERV 8 and MERV 14 filters are specified in this table, located in Appendix E.1.

Knowing the CFM to be delivered to the spaces, an air distribution system is then designed. The supply and exhaust CFM values as well as the ductwork sizing are shown on the HVAC plan in Figure 4.16; ductwork is sized using the assumptions listed in Appendix I. Using the HVAC plan, an external static pressure drop of 1.0 in. w.g. for AHU-1 results and is added to the AHU schedule. Consequently, a single constant volume McQuay Skyline AHU by Thermal Components, Inc. meets the requirements listed in the AHU schedule, and manufacturer selections are given in Appendix E.2. To maintain the negative pressure in the collection room, bronchoscopy room, and soiled workroom, a roof mounted upblast centrifugal exhaust ventilator, EF-1, is selected using the Loren Cook Company software.

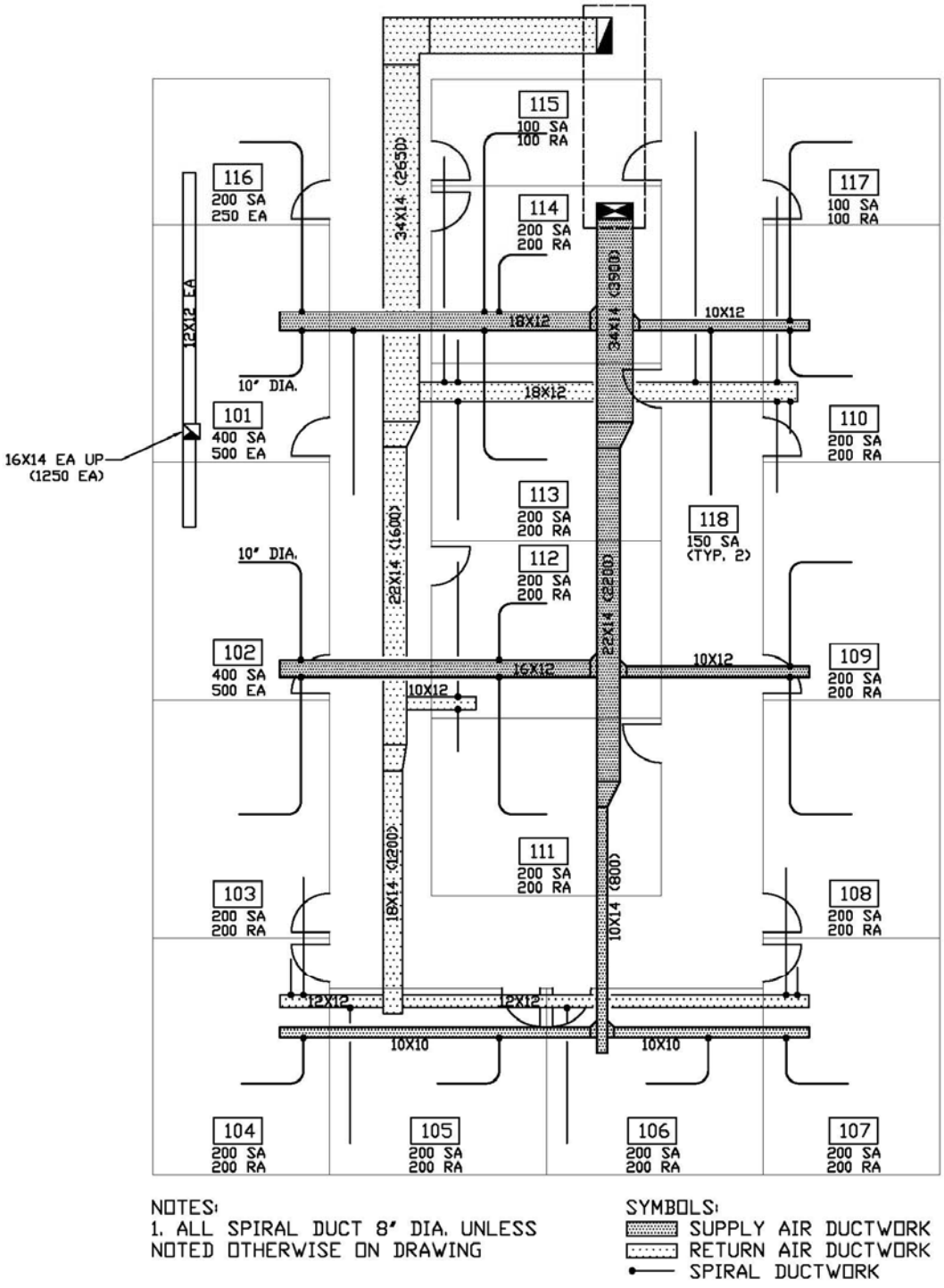

Figure 4.16 AHU-1 HVAC Plan

The effectiveness of the baseline system is intended to establish a reference upon which the effectiveness of the other alternatives is compared relative to time. First, a predicted airborne

disinfection of 99% within the examination and treatment rooms is assumed for this study. Also, all disinfection rates assume perfect mixing in the room. Although perfect mixing is unlikely, it is a valid assumption since it is applied to all of the system options being evaluated in the study. Next, the time it takes to achieve the desired effectiveness will be the basis of comparing one system against another. Based on Table 3.1, the baseline system provides 99% disinfection with 6 ACH in 46 minutes. Additionally, the importance of the estimated time to achieve the desired disinfection is evaluated when looking at the space use, so if infectious *pathogens* are released from a patient in the treatment room, it will take 46 minutes to effectively reduce the contaminants by 99%. Although not all the infectious *pathogens* are removed, a 99% reduction will greatly diminish the opportunity for the next susceptible patient or health care worker to be infected.

One primary goal of the study is to accurately determine the economic variance among system options so HVAC engineers may educate owners about the cost implications. The first costs may play a major role in deciding whether or not to pursue system options beyond that required by code. The first costs for the baseline system are divided among the AHU, ductwork, and exhaust fan, and these costs are primarily taken from the 2006 RSMeans cost data publications. Both material and labor expenses are estimated and location factors for Kansas City, MO are then applied, and the overall cost of AHU-1 is calculated to be $11,548. The cost details for the system are shown in Appendix F.3. The ductwork costs are based on detailed take-offs of the system layout, and costs are estimated on the basis of metal ductwork (rectangular and spiral), flexible ductwork, and blanket insulation. Air distribution devices are ignored on the assumption their cost difference would be negligible based on only the inlet diameter size changing among different systems. The overall cost of the ductwork for the baseline system is $23,509, as calculated in Appendix F.4. Next, the exhaust fan, EF-1, installed to maintain negative pressure in the three critical spaces is estimated at an overall cost of $734, as shown in Appendix F.6. The first cost of the AHU, ductwork, and exhaust fan are annualized in the study to be included in the total comparative annual cost. This annualized life cycle cost of $3,645 is based on the assumption of an eight percent interest rate over a twenty year period, the life of the system.

The energy costs of HVAC equipment can represent a large portion of the annualized cost of the system. The energy rate established for the economic evaluation is $0.078/KWH,

based on current rates for Kansas City, MO. For the baseline system, the only energy consumption considered is that from fans. When evaluating the energy costs, the operation hours greatly impact the annual expense; so with the system operating continuously all year, the annual energy cost is $2,921. A detailed calculation for the total fan energy consumed by the AHU is in Appendix H.1. The determination of the static pressure used in the fan energy calculation is based on assumptions for the UVGI in the AHU, described in Section 4.8.5.

Maintenance costs are the final element considered in the economic evaluation. For the baseline system, chemical cleaning of the coils is required to remove the microbial growth and coil fouling. The annual procedure requires personnel time and chemicals. Contractors in the study location estimate $40 for the chemical costs and 4 labor hours for the coil cleaning process (Burton, 10/15/2007). The labor rate of $23.95 is determined from the 2004 RSMeans Facilities Maintenance and Repair Cost Data manual. In-house maintenance rates are used on the assumption of the health care facility having sufficient trained maintenance personnel. Consequently, the overall annual maintenance cost is calculated to be $136 for the baseline system.

The baseline system design information, first costs, energy costs, and maintenance costs are summarized in Table 4.3. The total comparative annual cost of $6,702 is the reference by which the other system options will be economically compared. As stated earlier, this is not the total annual operating cost an owner will see, but rather the cost for comparison among the system options.

Table 4.3 Economic Evaluation: Baseline System

* Table modified from "UVGI Design Basics for Air and Surface Disinfection" by Kowalski, W.J. and Bahnfleth, William P.

SYSTEM DESIGN	Baseline System
System	AHU - 1
Design Airflow (CFM)	3,900
Velocity (FPM)	520
ACH (Exam & Treatment Rooms)	6
Predicted disinfection in room	99%
Predicted time required for room disinfection	46
Predicted coil disinfection	0%
FIRST COSTS (Installed costs)	
AHU	$11,548
Ductwork	$23,509
Exhaust Fan	$734
Life cycle	20 years
Interest rate	8%
Annualized first cost [1]	*$3,645*
ENERGY COSTS	
AHU hours of operation	8,760
Total fan energy (KWH)	37,446
Electrical energy - UVGI lamps (KWH)	0
Total energy (KWH)	37,446
Energy rate ($/KWH)	0.078
Annual energy cost	*$2,921*
MAINTENANCE COSTS	
Chemical costs	$40
Chemical cleanings per year	1
Labor hours for chemical cleaning	4
Labor rate ($/Hr)	$23.95
Total maintenance cost for chemical cleaning	$136
Annual maintenance cost	*$136*
COMPARATIVE ANNUAL COST	**$6,702**

Notes:

1.) Annualized first cost equation: A/P = P x 0.10185 (20 years at 8%)

4.8.3 Upper-Room UVGI System

Implementation of upper-room UVGI fixtures goes beyond the code requirements aimed at increasing the disinfection effectiveness of the spaces, and so this system option is in addition to the design criteria applied to the baseline system. The performance of the baseline mechanical system will be retained for this system option. The upper-room UVGI fixtures are applied in 14 spaces; *sputum collection* room, *bronchoscopy* room, eight examination rooms, and four treatment rooms. These spaces are chosen for UVGI because infectious patients can occupy these spaces for periods of time, which may be harmful to occupants who enter the space after the infected patient has left. All chosen spaces vary slightly in the room dimensions but have a floor area of 250 ft^2. Given the space criteria and expected disinfection rate of 99%, Lumalier, Inc. recommends two Lumalier upper-room UVGI #WM-136 wall-mounted fixtures in each space. The upper-room UVGI fixture data sheet is available in Appendix G.1. Each fixture houses one Philips-L36WTUV lamp consuming a nominal 36 watts and producing 12 UV watts for disinfection purposes. As with the AHU operating continuously, the UVGI fixtures are to be on at all times other than for maintenance. The fixtures are to be installed on opposing walls at a minimum mounting height of 7'-0" above the floor. A sample room layout with the UV beam patterns is shown in Appendix G.2.

The effectiveness of the upper-room UVGI will decrease the time required to achieve a 99% reduction in airborne *pathogens* compared to the baseline system. As discussed in Section 4.4.2, a comparative ACH rate can be determined to evaluate the effectiveness in removing the *pathogens*. Using Equation No. 5 with the assumption of 99% reduction, 4.6 air changes will occur. Based on the assumption of improved mixing within the space due to mechanical ventilation and occupants within the space, the comparison assumes the 4.6 air changes will occur in 30 minutes, resulting in an *equivalent air exchange rate* of 9.2 ACH. The 9.2 ACH is in addition to the 6.0 ACH already being produced by the baseline HVAC system, therefore equating to a total *equivalent air exchange rate* of 15.2 ACH. This equivalent calculation and all assumptions are addressed in Appendix D.2. With the 15.2 ACH representing the air exchange rate that would be produced by dilution of supply air, the predicted time required for the disinfection can be found using Table 3.1. From the table, the 99% reduction with an equivalent 15.2 ACH will occur in an estimated 18 minutes. The projected disinfection by upper-room

UVGI in addition to the baseline system will reduce the time required by nearly a third of the time required for the baseline system.

The additional first cost for upper-room UVGI must be applied to the first costs of the baseline system identified in the earlier section. An estimated cost for each fixture of $824 is provided by Lumalier, Inc. The first cost for installation of the upper-room UVGI fixtures in the rooms is $25,018. The installation and UVGI fixture costs are detailed in Appendix F.1. The additional cost of the UVGI fixtures significantly increases the annualized cost from $3,645 for the baseline system to $6,193.

The electrical energy consumption of the UVGI lamps is another factor that needs to be considered compared to the baseline system. With the added energy consumption, the annual energy cost increases from $2,921 to $3,610. Notably, some of the energy consumed by the UVGI lamps is translated into heat generation. However, the heat generated by the UVGI lamps within the space is not included in this study's internal load calculations due to its minimal impact on the systems.

An additional maintenance cost accrues with the installation of upper-room UVGI fixtures. The UVGI lamps are to be replaced annually, costing $25 per replacement lamp, to maintain the desired effectiveness, thus requiring many labor hours. Ultimately, the total maintenance cost for upper-room UVGI is $908, further increasing the combined annual maintenance cost with the coil cleaning to $1,044.

All of the upper-room UVGI data and cost calculations are summarized in Table 4.4. The total comparative annual cost of applying upper-room UVGI in addition to the baseline HVAC system is $10,847. This is a significant increase compared to the annual cost of the baseline system. Further analysis of the comparison between these system options will be discussed once all options are introduced.

Table 4.4 Economic Evaluation: Upper-Room UVGI

* Table modified from "UVGI Design Basics for Air and Surface Disinfection" by Kowalski, W.J. and Bahnfleth, William P.

SYSTEM DESIGN	Baseline System	Upper-Room UVGI
System	AHU - 1	AHU - 1
Design Airflow (CFM)	3,900	3,900
Velocity (FPM)	520	520
ACH (Exam & Treatment Rooms)	6	15.2 (Equivalent)
Predicted disinfection in room	99%	99%
Predicted time required for room disinfection	46	18
Predicted coil disinfection	0%	0%
UVGI Fixture Model	-	#WM-136
Number of UVGI Fixtures per space	-	2
Number of Lamps per fixture	-	1
Nominal Power per Lamp (W)	-	36
Number of spaces with UVGI fixtures	-	14
UVGI hours of operation	-	8,760
FIRST COSTS (Installed costs)		
AHU	$11,548	$11,548
Ductwork	$23,509	$23,509
Exhaust Fan	$734	$734
UVGI system	$0	$25,018
Life cycle	20 years	20 years
Interest rate	8%	8%
Annualized first cost [1]	*$3,645*	*$6,193*
ENERGY COSTS		
AHU hours of operation	8,760	8,760
Total fan energy (KWH)	37,446	37,446
Electrical energy - UVGI lamps (KWH)	0	8,830
Total energy (KWH)	37,446	46,276
Energy rate ($/KWH)	0.078	0.078
Annual energy cost	*$2,921*	*$3,610*
MAINTENANCE COSTS		
UVGI replacement lamp cost	-	$25
Total UVGI replacement lamp costs	-	$700
Lamp replacements per year	-	1
Labor hours per UVGI lamp replacement	-	0.31
Total labor hours for UVGI lamp replacement	-	8.68
Labor rate ($/Hr)	-	$23.95
Total maintenance cost for UVGI	-	$908
Chemical costs	$40	$40
Chemical cleanings per year	1	1
Labor hours for chemical cleaning	4	4
Labor rate ($/Hr)	$23.95	$23.95
Total maintenance cost for chemical cleaning	$136	$136
Annual maintenance cost	*$136*	*$1,044*
COMPARATIVE ANNUAL COST	**$6,702**	**$10,847**

Notes:

1.) Annualized first cost equation: A/P = P x 0.10185 (20 years at 8%)

4.8.4 HVAC System with an Increased ACH

The next system option increases the ACH of the HVAC system to be the same as the equivalent ACH of the upper-room UVGI. The time required to reach the effectiveness is identical to the time required for the upper-room UVGI alternative, therefore offering improved occupant protection beyond the baseline system's ability. Given identical disinfection effectiveness, the HVAC engineer will be able to determine if this system option possesses any financial benefits over those of the upper-room UVGI application.

In the load calculations table of Appendix D.8, the additional 9.2 ACH are combined with the minimum total ACH. The increased ACH rates are applied in the same 14 spaces as the UVGI; *sputum collection* room, *bronchoscopy* room, eight examination rooms, and four treatment rooms. Increasing the ACH rates in these spaces increased the supply air, outside air, and exhaust airflow values. The coil loads are also adjusted to accommodate the increased CFM values in Appendix D.9. The updated coil loads are also transferred to the AHU schedule in Appendix E.1.

The air distribution system from the baseline system is upsized accordingly to account for the increased CFM levels through the ductwork without altering the overall layout, therefore maintaining an accurate comparison. The HVAC plan for AHU-2 is shown in Appendix C.3. A larger constant volume air handling unit, AHU-1, is selected to meet the increased requirements of the system. Appendix E.3 presents the manufacturer selection for the HVAC unit. In addition, the exhaust ventilator, EF-2, is increased accordingly to maintain the negative pressure in the required spaces.

The first costs for the AHU, ductwork, and exhaust fan are calculated in a similar manner as the baseline system first costs. The overall cost of AHU-2 is calculated to be $24,867, and the cost details for the system are shown in Appendix F.3. The overall cost of the ductwork for this system is $35,727, and the detailed ductwork costs are calculated in Appendix F.5. The overall cost of EF-2 is calculated to be $764, with the detailed exhaust fan costs shown in Appendix F.6. The annualized first cost of the AHU, ductwork, and exhaust fan is $6,249. This annualized cost is significantly higher than that of the baseline system, yet nearly the same as the upper-room UVGI system option. Although a smaller HVAC system is utilized with the upper-room UVGI system, the initial expense of the individual fixtures and smaller HVAC system equates to nearly the same cost expense as that for a larger HVAC unit without UVGI.

The energy consumption and maintenance costs are calculated in the same way as for the baseline system. With the system operating continuously all year, the annual energy cost is $4,515, with a detailed calculation for the total fan energy consumed by the AHU in Appendix H.1. The energy consumption of a larger fan operating continuously has a greater impact than the UVGI lamps. Therefore, the annual energy cost of $4,515 is significantly higher than for both of the previous system options at $2,921 and $3,610. The maintenance costs for this system are identical to those for the baseline system at an annual cost of $136.

All of the design and cost information presented for this system is summarized in Table 4.5, and the total comparative annual cost is $10,900. This annualized cost is nearly identical to that for the upper-room UVGI system. Further analysis between this system option and the others is later discussed.

Table 4.5 Economic Evaluation: HVAC System with Increased 9.2 ACH

* Table modified from "UVGI Design Basics for Air and Surface Disinfection" by Kowalski, W.J. and Bahnfleth, William P.

SYSTEM DESIGN	Baseline System	Upper-Room UVGI	HVAC System with Increased 9.2 ACH
System	AHU - 1	AHU - 1	AHU - 2
Design Airflow (CFM)	3,900	3,900	8,240
Velocity (FPM)	520	520	495
ACH (Exam & Treatment Rooms)	6	15.2 (Equivalent)	15.2
Predicted disinfection in room	99%	99%	99%
Predicted time required for room disinfection	46	18	18
Predicted coil disinfection	0%	0%	0%
UVGI Fixture Model	-	#WM-136	-
Number of UVGI Fixtures per space	-	2	-
Number of Lamps per fixture	-	1	-
Nominal Power per Lamp (W)	-	36	-
Number of spaces with UVGI fixtures	-	14	-
UVGI hours of operation	-	8,760	-
FIRST COSTS (Installed costs)			
AHU	$11,548	$11,548	$24,867
Ductwork	$23,509	$23,509	$35,727
Exhaust Fan	$734	$734	$764
UVGI system	$0	$25,018	$0
Life cycle	20 years	20 years	20 years
Interest rate	8%	8%	8%
Annualized first cost [1]	*$3,645*	*$6,193*	*$6,249*
ENERGY COSTS			
AHU hours of operation	8,760	8,760	8,760
Total fan energy (KWH)	37,446	37,446	57,888
Electrical energy - UVGI lamps (KWH)	0	8,830	0
Total energy (KWH)	37,446	46,276	57,888
Energy rate ($/KWH)	0.078	0.078	0.078
Annual energy cost	*$2,921*	*$3,610*	*$4,515*
MAINTENANCE COSTS			
UVGI replacement lamp cost	-	$25	-
Total UVGI replacement lamp costs	-	$700	-
Lamp replacements per year	-	1	-
Labor hours per UVGI lamp replacement	-	0.31	-
Total labor hours for UVGI lamp replacement	-	8.68	-
Labor rate ($/Hr)	-	$23.95	-
Total maintenance cost for UVGI	-	$908	-
Chemical costs	$40	$40	$40
Chemical cleanings per year	1	1	1
Labor hours for chemical cleaning	4	4	4
Labor rate ($/Hr)	$23.95	$23.95	$23.95
Total maintenance cost for chemical cleaning	$136	$136	$136
Annual maintenance cost	*$136*	*$1,044*	*$136*
COMPARATIVE ANNUAL COST	**$6,702**	**$10,847**	**$10,900**

Notes:

1.) Annualized first cost equation: A/P = P x 0.10185 (20 years at 8%)

4.8.5 UVGI System in AHU

The final system option involves applying UVGI lamps within the baseline AHU. The UVGI lamps will irradiate the cooling coils, therefore preventing microbial growth and the introduction of airborne spores within the unit. In addition to eliminating surface growth, the lamps will also disinfect airborne contaminants that are not caught by the pre-filter through exposure.

For this system, the UVGI lamps are located within the AHU. To support the UVGI lamps within the AHU, a manufactured support made of structural aluminum and stainless steel is required. The UVGI lamps are mounted vertically on the support and spaced evenly across the width of the unit to create an even field of UVGI irradiation. The Lumalier #EXTV-60-1R4 system is applied in this case study consisting of four Philips PL-L60WTUV lamps. Each lamp consumes a nominal 60 watts while producing 18 UV watts. The data sheet for the Lumalier UVGI system is shown in Appendix G.3.

The airborne disinfection effectiveness seen within the spaces will be identical to that seen in the baseline system. Although the system will deactivate infectious *pathogens* within the AHU, its location away from the space limits its ability to provide improved removal efficiency at the space level. The UVGI system will, however, provide surface disinfection of approximately 99.99% on the cooling coils. With continuous operation, nearly all microbial growth will be prevented.

The AHU, ductwork, and exhaust fan first costs are identical to those for the baseline system. The additional first cost of the UVGI system is calculated to be $1,567. A detailed calculation of the UVGI first cost is shown in Appendix F.2. With the addition of the UVGI system, the annualized first cost is $3,808, slightly higher than that of the baseline system at $3,645.

As with the upper-room UVGI system, the energy costs can be divided into fan energy and electrical energy consumption. With the UVGI lamps near the cooling coils, a percentage of coil fouling due to microbial growth will be eliminated, enabling air to pass through the cooling coil more efficiently, minimizing pressure drop. With the UVGI assembly being placed in the AHU, it may cause a slight pressure drop. However, this pressure drop will generally be negligible and therefore is ignored for this study (W. J. Kowalski, 2003). In contrast to the room application of UVGI previously analyzed, the pressure drop seen at the supply fan between the

base system and UVGI system will be different. The estimation of coil fouling is difficult to predict and studies have not quantified the effect of microbial growth on pressure drop. According to one study, the reduction in airflow can typically be 5% or less (Siegel, Walker, & Sherman). Information from industry experience estimates the reduction due to coil fouling to be upwards of 7 to 10% in some cases (Skelton, 10/16/2007). For this study, a 5% reduction in airflow is assumed for cooling coils not utilizing the UVGI within the AHU. The reduction in airflow accounts for an increased pressure drop based on the manufacturer's fan curve. The adjustment due to the airflow reduction is shown on the fan curves of AHU-1 and AHU-2 in Appendix H.2 and Appendix H.3, respectively. With the UVGI being applied to the cooling coils, the unaltered mean static pressure determined by the manufacturer for design conditions is used. The fan energy consumption for this system option is calculated in Appendix H.1. The total fan energy of the system with UVGI is 33,102 KWH while it is 37,446 KWH for the baseline system. As a result, this decrease in the energy consumption decreases the annual energy cost. The electrical energy consumption of the UVGI lamps is calculated in Table 4.6. Even with the added energy consumption of the UVGI lamps, the total annual energy cost decreases from $2,921 to $2,746.

With the UVGI system, the only maintenance performed annually is replacing the UVGI lamps in the unit. The time required for this procedure is much less than time for the chemical cleaning, therefore requiring less AHU downtime. Although some particulates will pass through the pre-filter, the buildup on the UV lamp is minimal. "Some practitioners suggest that if lamps are installed downstream of an effective filter, the lamps will not need to be cleaned at all before they need to be replaced" (Blatt, 2006, 6). Therefore, with an annual replacement of four UVGI lamps, the total maintenance cost is $124, as shown in Table 4.6. This maintenance cost is slightly lower than the cost required for performing chemical cleaning of the coils at $136. The cost of chemicals and hours required to perform the cleaning process is eliminated with UVGI. However, coils may need to be washed down with soap and water periodically to remove any dust particulates that collect on the coils.

The design and cost information given for all of the systems is summarized in Table 4.6. The total comparative annual cost is determined to be $6,678. This annualized cost is slightly lower than the baseline system annualized cost. The following section summarizes the comparison of all four system options presented.

Table 4.6 Economic Evaluation: UVGI in AHU

* Table modified from "UVGI Design Basics for Air and Surface Disinfection" by Kowalski, W.J. and Bahnfleth, William P.

SYSTEM DESIGN	Baseline System	Upper-Room UVGI	HVAC System with Increased 9.2 ACH	UVGI in AHU
System	AHU - 1	AHU - 1	AHU - 2	AHU - 1
Design Airflow (CFM)	3,900	3,900	8,240	3,900
Velocity (FPM)	520	520	495	520
ACH (Exam & Treatment Rooms)	6	15.2 (Equivalent)	15.2	6
Predicted disinfection in room	99%	99%	99%	99%
Predicted time required for room disinfection	46	18	18	46
Predicted coil disinfection	0%	0%	0%	99.99%
UVGI Fixture Model	-	#WM-136	-	#EXTV-60-1R4
Number of UVGI Fixtures per space	-	2	-	-
Number of Lamps per fixture	-	1	-	4
Nominal Power per Lamp (W)	-	36	-	60
Number of spaces with UVGI fixtures	-	14	-	-
UVGI hours of operation	-	8,760	-	8,760
FIRST COSTS (Installed costs)				
AHU	$11,548	$11,548	$24,867	$11,548
Ductwork	$23,509	$23,509	$35,727	$23,509
Exhaust Fan	$734	$734	$764	$734
UVGI system	$0	$25,018	$0	$1,567
Life cycle	20 years	20 years	20 years	20 years
Interest rate	8%	8%	8%	8%
Annualized first cost[1]	*$3,645*	*$6,193*	*$6,249*	*$3,805*
ENERGY COSTS				
AHU hours of operation	8,760	8,760	8,760	8,760
Total fan energy (KWH)	37,446	37,446	57,888	33,102
Electrical energy - UVGI lamps (KWH)	0	8,830	0	2,102
Total energy (KWH)	37,446	46,276	57,888	35,204
Energy rate ($/KWH)	0.078	0.078	0.078	0.078
Annual energy cost	*$2,921*	*$3,610*	*$4,515*	*$2,746*
MAINTENANCE COSTS				
UVGI replacement lamp cost	-	$25	-	$25
Total UVGI replacement lamp costs	-	$700	-	$100
Lamp replacements per year	-	1	-	1
Labor hours per UVGI lamp replacement	-	0.31	-	0.25
Total labor hours for UVGI lamp replacement	-	8.68	-	1
Labor rate ($/Hr)	-	$23.95	-	$23.95
Total maintenance cost for UVGI	-	$908	-	$124
Chemical costs	$40	$40	$40	-
Chemical cleanings per year	1	1	1	-
Labor hours for chemical cleaning	4	4	4	-
Labor rate ($/Hr)	$23.95	$23.95	$23.95	-
Total maintenance cost for chemical cleaning	$136	$136	$136	-
Annual maintenance cost	*$136*	*$1,044*	*$136*	*$124*
COMPARATIVE ANNUAL COST	**$6,702**	**$10,847**	**$10,900**	**$6,675**

Notes:

1.) Annualized first cost equation: A/P = P x 0.10185 (20 years at 8%)

4.8.6 Summary of Economic Evaluation

The results of the economic evaluation provide insight on the expected disinfection and economic costs of concern to HVAC engineers and owners. Ultimately, the results of the study show improving the disinfection effectiveness at the space level comes with an added cost to the owner. For the two alternatives with a substantial expected disinfection improvement, upper-room UVGI and the HVAC system with increased ACH, the comparative annual cost increased significantly. Therefore, the HVAC engineer and owner must further evaluate their expectations regarding the additional expense. Secondary benefits that were unable to be evaluated in this study include medical savings (i.e. medication use), third party savings, and savings with the reduction of *nosocomial* lawsuits (Burke, 2003). By quantifying these savings, an owner may be more inclined to apply the UVGI alternatives.

Applying upper-room UVGI technology has an increased annual cost compared to that of the baseline system. Table 4.6 shows the comparative annual costs of $6,702 and $10,847 for the baseline system and upper-room UVGI system, respectively. Although an economic savings is not seen with upper-room UVGI, the predicted time for 99% disinfection is greatly reduced from 46 minutes to 18 minutes. Therefore, the chances of a susceptible patient being exposed to airborne *pathogens* in a space with upper-room UVGI are significantly reduced. By not being exposed to the airborne *pathogens*, the occupants will be even less likely to obtain a *nosocomial infection*. As stated previously, the savings experienced from factors beyond this economic evaluation may outweigh the nearly 62% increase in comparative annual cost. Outside the economic realm, health care facilities operate to improve the health and wellbeing of humans, and this intention should reinforce the application of a technology that will only help protect the occupants when applied correctly.

The HVAC system with an increased ACH shows comparable results to the upper-room UVGI system. The predicted effectiveness is identical based on the two alternatives having the same ACH rate. Yet, even with the large differences between first costs, energy costs, and maintenance costs, the comparative annual costs are almost identical. As listed in Table 4.6, the comparative annual cost for upper-room UVGI is $10,847 while for the HVAC system with increased ACH, it is $10,900. The result shows that if the actual effectiveness of the UVGI system is verified to be the same, then the expense would be validated. However, without evaluating the air mixing within the space, the UVGI removal effectiveness may be slightly

inflated since it is very dependent on the air mixing. Additional factors not evaluated in this study strengthen the use of upper-room UVGI over a larger HVAC system. The larger system will require larger ductwork and clearances for air distribution, therefore increasing the plenum space required. As a result, the structural elements, floor-to-floor heights, and coordination efforts may be increased with an additional cost not applicable for upper-room UVGI.

The final alternative exposes the benefits and limitations of the application of UVGI. With the UVGI lamps being installed in the AHU, the disinfection of airborne *pathogens* occurs prior to the MERV 14 filters and the occupied spaces. Therefore, the predicted room disinfection is not assumed to be higher than that of the baseline system. The evaluation of this UVGI technology is more focused on the fan energy consumption and its impact on the comparative annual cost. As Table 4.6 shows, the initial investment of $1,567 for the UVGI system has a comparative annual cost of $6,675, slightly lower than that of the baseline system. This savings is based on the assumption that coil fouling is minimized. Manufacturers are suggesting even higher energy savings and shorter payback periods for this UVGI technology. Even the small savings evident in this evaluation should propel HVAC engineers to apply UVGI in AHUs. Ultimately, applying this technology in health care facilities will eliminate a potential source of harm to occupants. It is also likely that the UVGI system in the AHU would have more of an impact on the removal of airborne *pathogens* than can be accurately evaluated in this study. For instance, further improving the removal effectiveness at the AHU would lead to improved room disinfection by supplying higher quality air to the space. The first costs, energy costs, and maintenance costs are also minimal relative to the health care facilities' expenses. Factors beyond the scope of this evaluation that may further increase the energy savings produced by UVGI include chiller and chiller pump use. Finally, removing any coil fouling would increase the heat transfer, thereby improving the operation of the chiller and its components.

Health care facilities should be applying UVGI technologies for both their economic and performance benefits. As documented in this study, UVGI installed in the AHU results in a slight economic saving. In addition, it provides another level of protection for the occupants by removing a potential source of harm. The initial expense of these systems is comparatively low compared to the total construction costs of new health care facilities. However, the effectiveness of the system may be affected by the installation location. Humid climates are more likely to

produce microbial growth on coils, which leads to an increased level of coil fouling compared to that in a dry climate. Locations with higher concentrations of contaminants and airborne *pathogens* have the added benefit of further removal of the contaminants beyond the capability of filtration. Nevertheless, upper-room UVGI systems should be applied more selectively than systems in AHUs based on the higher cost implication. Moreover, health care facilities need to determine the most critical spaces where room disinfection provides the greatest benefit. Spaces such as the *sputum collection* room and *bronchoscopy* room are more critical than examination or treatment rooms because infected patients will be concentrated in these spaces for medical testing. Another area within health care facilities where upper-room UVGI may be most beneficial is emergency room waiting areas. Patients with unknown infections may occupy the space along with highly-susceptible patients. Upper-room UVGI would help reduce the concentration of *pathogens* at the space location, further reducing *nosocomial* infections among occupants. More isolated installations of upper-room UVGI would lower the initial, operating, and maintenance costs in comparison to those for the wide-spread use of upper-room UVGI in this study. In the end, upper-room UVGI systems may not be as economically attractive to owners, yet they provide the most effective UVGI system in reducing *pathogen* levels at the space location and should be considered for the safety and protection of all occupants.

This economic evaluation quantifies many of the elements considered by HVAC engineers regarding the implementation of the alternatives. With this information, HVAC engineers will be more informed about selecting and ensuring their effectiveness to owners. As more research on the practical application of UVGI develops, this comparative analysis can be further refined.

CHAPTER 5 - Future Research of UVGI

To advance UVGI technology as an engineering control method, HVAC engineers and manufacturers must create more certainty through research and testing. Through research, manufacturers will be capable of providing the most effective and efficient systems to owners, thus furthering the engineer's ability to create an even safer indoor environment for all building occupants. Research emphasis should be placed on CFD modeling, analysis of practical applications, and use of upper-room UVGI in spaces other than those selected for this paper's economic study.

CFD models provide engineers and manufacturers crucial data that aid the design of fixtures and estimation of effectiveness. "In order to determine the effectiveness of any UVGI air disinfection system it is necessary to determine the length of time and cumulative dose of irradiation experienced by a microbial particle. It is possible to determine the length of time spent by a particle within a UV field by using a CFD package" (Beggs et al., 2000, 25). Such CFD modeling would provide much greater accuracy than estimation based on removal effectiveness calculations. Since the exposure of particles to UVGI directly corresponds to the mechanical ventilation and air distribution within a space, most studies performed assume complete mixing of the air occurs. However, this is rarely the case in practical applications due to short circuiting of air and obstructions in the room altering fluent airflow throughout the space (Beggs et al., 2000). Therefore, analyzing the interaction between air mixing and UVGI would provide engineers with the information needed to design an optimal system. "Until research results are published that make CFD analytical methods readily available to engineers for designing optimum-efficiency UVGI installations, reliance must be placed on experience and the application of empirical methods derived from it" (First, Nardell, Chaisson, & Riley, 1999b, 9).

New UVGI systems are being developed and advertised to consumers without verified data on the effectiveness in practical applications. More testing of current systems and their installations needs to be conducted to assist the HVAC engineer in validating the effectiveness of the system being recommended. This is partly because the effectiveness of UVGI systems can fluctuate depending on the installation method. Therefore, a field verification method needs to be developed to ensure the system is operating as expected. In addition to removal effectiveness,

research needs to be conducted on microbial growth on cooling coils in real applications. In particular, HVAC engineers need information on the magnitude of coil fouling for different climates. By quantifying the coil fouling, HVAC engineers could determine more accurately the subsequent static pressure drop. Therefore, HVAC engineers would be able to properly estimate the economic savings when applying UVGI, which has already been proven to sterilize microbial growth on coils.

The economic study in this paper focuses on diagnostic and treatment areas within health care facilities where health care workers are exposed face to face to patients. Consequently, 14 of the 18 total spaces have upper-room UVGI applied, resulting in high initial, operation, and maintenance costs compared to those for the baseline system. An economic study with upper-room UVGI applied in more selective locations may provide more influential economic benefits for UVGI use. Furthermore, emergency room waiting areas are locations where infectious patients and highly-susceptible patients are located in close distance, allowing for *nosocomial infections* to occur. Therefore, a study should be performed for locations such as this to gain a better understanding of UVGI applications in other locations of health care facilities. "Nevertheless, enough is known, through extensive research and long experience, to make the technology useful today while we learn more" (First, Nardell, Chaisson, & Riley, 1999a, 7).

CHAPTER 6 - Conclusion

HVAC engineers play a crucial role in protecting the occupants of health care facilities from acquiring *nosocomial infections*. To continue to protect occupants, engineers must first understand the differences in airborne *pathogens* that may be present in the building. *Pathogen* size, susceptibility, and transportation methods influence the design of the optimal engineering control methods. Traditional infection control methods include mechanical ventilation and air distribution, filtration, and differential pressure control. These engineering methods have been tested, and their results are predictable and successful when designed or selected correctly. However, as a supplement to these traditional methods, UVGI applications have proven to increase the overall disinfection of airborne contaminants beyond the effectiveness of traditional methods alone. Having the responsibility to provide the optimal indoor environment, free of harmful airborne contaminants, HVAC engineers are evaluating the applications and effectiveness of the technology as it develops. UVGI applications are divided into air-stream and surface disinfection. Air-stream disinfection methods include in-duct devices, upper-room devices, HEPA-ceiling units, and portable fan units. These devices offer the HVAC engineer flexibility based on installation locations and desired effectiveness levels. Surface disinfection methods are primarily for AHU cooling coils and drip pans as well as some room applications. In this capacity, *pathogens* are eliminated at the surface location, therefore preventing their growth as well as reintroduction into the air-stream. Many studies have documented high effectiveness of the UVGI systems when designed and installed properly, and the benefits in increased disinfection of the space or building outweigh the concerns with applying the technology. The major concern for owners, due to liability, is overexposure of UVGI to occupants, which may cause skin or eye irritations. This concern has been addressed by agencies and industry experience in providing safe UVGI systems. Another concern, primarily of owners, is the economic impact of the technology based on the predicted effectiveness.

UVGI technologies are useful systems for health care facilities given their effectiveness and economic impact as shown in the economic study in this report. Both upper-room UVGI and in-duct UVGI systems offer many advantages that benefit the patients, health care professionals, and owners. A dramatic improvement in the disinfection effectiveness of upper-

room UVGI resulted in the likelihood of a much higher comparative annual cost. If the upper-room UVGI fixtures are applied in more selective locations that have a higher priority for *nosocomial infection* prevention, the comparative annual cost would be closer to that of the baseline system. This study shows the economic factor cannot be the only variable to decide the fate of UVGI applications. Since UVGI technology will increase the health care facility's ability to reduce *nosocomial infections*, this fact should be of vital importance. Also, the UVGI system in the AHU shows the potential for reducing the comparative annual cost from the baseline system. Beyond the savings, the system eliminates a source of airborne *pathogens* from the health care facility. With both of these elements being advantageous, UVGI systems within AHUs should always be considered for health care facilities. Based on the findings of the economic analysis and previous studies, HVAC engineers are strongly encouraged to evaluate applying UVGI technologies in their health care facilities. In addition, HVAC engineers are responsible for informing owners of the benefits of the technology and the major impact it can have on all the health care professionals, patients, and visitors who occupy the building each and every day.

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Appendix A - Glossary

Air change rate: Ratio of the airflow in volume units per hour to the volume of the space under consideration in identical volume units, usually expressed in air changes per hour (ACH). (Jensen et al., 2005)

Antimicrobial coatings: Coatings that prevent surface adhesion of microorganisms on ductwork, filters, and appliances. These coatings are also called hygienic coatings. (W. J. Kowalski, 2006)

Bacteria: Any of a class of microscopic plants having round, rod-like, spiral, or filamentous single-celled or noncellular bodies. (Hines, Ghosh, Loyalka, & Warder, 1993)

Bioaerosol: Microorganisms or particles, gases, vapors, or fragments of biological origin (i.e., alive or released from a living organism) that are present in the air. (Public Employees Occupational Safety and Health Program, 1997)

Biofilm: The growth of environmental bacteria that provide fungal spores a nutrient base in excessive moisture locations. (W. J. Kowalski, 2006)

Bronchoscopy: A procedure that allows the medical doctor to look at a patient's airway through a thin viewing instrument called a bronchoscope. (WebMD, 2008)

Colony-forming units (CFU): A measure of viable bacterial numbers. Unlike in direct microscopic counts where all cells, dead and living, are counted, CFU measures viable cells. (Babylon.com LTD, 2007)

Contagious: Describes a characteristic of a disease that can be transmitted from one living being to another through direct contact or indirect contact; communicable. The agent

responsible for the contagious character of a disease is also described as being infectious; the usual culprits are microorganisms. (Jensen et al., 2005)

Cryogenics: The method of freezing pathogens, thereby inactivating them. This method has certain success in the food industry but is currently impractical in the sterilization of air-streams. (W. J. Kowalski, 2006)

Desiccation: The destruction of bacteria due to the removal of water, which is essential for normal bacterial cellular functions. (W. J. Kowalski, 2006)

Dilution ventilation: An engineering control technique to dilute and remove airborne contaminants by the flow of air into and out of an area. Air that contains droplet nuclei is removed and replaced by contaminant-free air. If the flow is sufficient, droplet nuclei become dispersed, and their concentration in the air is diminished. (Centers for Disease Control and Prevention, 1994)

Droplet nuclei: Microscopic particles produced when a person coughs, sneezes, shouts, or sighs. These particles can remain suspended in the air for prolonged periods and can be carried on normal air currents in a room and beyond to adjacent spaces or areas receiving exhaust air. (Jensen et al., 2005)

Electrostatic filtration: Filters that generally rely on air movement across the filter fibers to generate a small electric charge on the passing airborne particles that enhances filtration efficiency. (W. J. Kowalski, 2006)

Equivalent air exchange rate: Ratio of the volumetric air loss rate associated with an environmental control (or combination of controls) (e.g., an air cleaner or UVGI system) divided by the volume of the room where the control has been applied. The equivalent air exchange rate is useful for describing the rate at which bioaerosols are removed by means other than ventilation. (Jensen et al., 2005)

Fungi: Any of a major group of saprophytic and parasitic lower plants that lack chlorophyll. (Hines et al., 1993)

Gas phase filtration: The removal of gases or vapors from an air-stream with equation such as carbon adsorption. (W. J. Kowalski, 2006)

Green technologies: Technologies that incorporate active, passive, or natural technologies, or sustainable materials and renewable energy resources. For airborne pathogens, three technologies are under development including solar exposure disinfection, vegetation air cleaning, and biofiltration of air. (W. J. Kowalski, 2006)

Immunocompromised: Describes conditions in which at least part of the immune system is functioning at less than normal capacity. (Jensen et al., 2005)

Ionization: The process of stripping electrons from atoms to produce ions. (W. J. Kowalski, 2006)

Luminous flux: The quantity of light emitted from a point source in a given time. (Dumyahn & First, 1999)

Microorganism: An organism of microscopic size, such as a bacterium, virus, fungus, viroid, or mycoplasma. (The Regents of the University of California, 2003)

Microwaves: Nonionizing electromagnetic radiation that is a method of disinfection of cells. (W. J. Kowalski, 2006)

Nosocomial infection: A hospital-acquired infection.

Ozone: A corrosive form of oxygen consisting of three bond oxygen molecules. No systems are currently available for air disinfection that remove the ozone to safe levels. (W. J. Kowalski, 2006)

Pathogen: A disease-causing organism. (The Regents of the University of California, 2003)

Pentamidine: An anti-infective agent that helps to treat or prevent pneumonia caused by the organism Pneumocystis carinii. (U.S. National Library of Medicine, 2003)

Photocatalytic oxidation (PCO): A technology in which material coated with titanium dioxide is irradiated to produce an oxidative effect. (W. J. Kowalski, 2006)

Pulsed light: Disintegrating bacterial cells by excess power levels of pulsed light. (W. J. Kowalski, 2006)

Sputum collection: A method of coughing deeply and expelling the material (sputum) that comes from the lungs into a sterile cup. (MedHelp, 2006)

Sputum induction: A method used to obtain sputum from a patient who is unable to cough up a specimen spontaneously. The patient inhales a saline mist, which stimulates a cough from deep within the lungs. (Babylon.com LTD, 2007)

Thermal disinfection: The disinfection of microbes by exposure to heat. (W. J. Kowalski, 2006)

Virus: Any of a large group of submicroscopic infective agents that are regarded either as extremely simple microorganisms or as extremely complex molecules. (Hines et al., 1993)

Appendix B - Comparison of Engineering Best Practice

ASHRAE 2003. ©American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., www.ashrae.org.

	Pressure relationship to adjacent areas (a) (2)			Minimum air changes of outdoor air per hour (b) (3)			Minimum total air changes per hour (c) (4) (5)			All air exhausted directly to outdoors (6)		
Function Space	**Manual**	**Handbook**	**AIA (1)**	**Manual**	**Handbook**	**AIA (1)**	**Manual**	**Handbook**	**AIA (1)**	**Manual**	**Handbook**	**AIA (1)**
Surgery And Critical Care												
Operating Room (all outdoor air system)		P	-		15	-		15	-		YES	-
Operating Room (recirculating air system)	P	P	-	5	5	-	25	25	-	-	OPTIONAL	-
Operating /surgical cystoscopic rooms (10), (11)	P	-	OUT	5	-	3	25	-	15	-		-
Delivery Room (all outdoor air system)		P	-		15	-		15	-		OPTIONAL	-
Delivery Room (recirculating air system)		P	-		5	-		25	-		OPTIONAL	-
Delivery Room (10)	P	-	OUT	5	-	3	25	-	15	-	-	-
Recovery Room	-	E	-	2	2	2	6	6	6	-	OPTIONAL	-
Critical and Intensive Care	-	-	-	2	-	2	6	-	6	-	-	-
Newborn Intensive Care	-	-	-	2	-	2	6	-	6	-	-	-
Treatment Room (13)	-	-	-	-	-	-	6	-	6	-	-	-
Nursery Suite	P	P	-	5	5	-	12	12	-	-	OPTIONAL	-
Trauma Room (f) (13)		P	OUT		5	3	12	12	15		OPTIONAL	-
Trauma Room (crisis or shock) (f) (13a)	P			3			15			YES		
Trauma Room (conventional ED or treatment) (f) (13a)	P			2			6			-		
Anesthesia Storage (see code requirements)		+/-	-		OPTIONAL	-		8	-		YES	-
Anesthesia Gas Storage	N	-	IN	-	-	-	8	-	8	YES	-	YES
Endoscopy (11)	N	-	IN	2	-	2	6	-	6	-	-	-
Bronchoscopy	N	-	IN	2	-	2	12	-	12	YES	-	YES
ER Waiting Rooms	N	-	IN	2	-	2	12	-	12	YES	-	YES (14), (15)
Triage	N	-	IN	2	-	2	12	-	12	YES	-	YES (14)
Radiology Waiting Rooms	N	-	IN	2	-	2	12	-	12	YES	-	YES (14), (15)
Class A Operating (procedure) Room	N	-	OUT	3	-	3	15	-	15	-	-	-
Nursing												
Patient Room	-	+/-	-	2	2	2	6	4	6 (16)	-	OPTIONAL	-
Toilet Room (g)	N	N	IN	OPTIONAL	OPTIONAL	-	10	10	10	YES	YES	YES
Intensive Care		P	-		2	-		6	-		OPTIONAL	-
Newborn Nursery Suite	-	-	-	2	-	2	6	-	6	-	-	-
Protective Isolation (i)		P	-		2	-		15	-		YES	-
Infectious Isolationg (b)		+/-	-		2	-		6	-		YES	-
Protective Environment Room (11), (17)	P	-	OUT	2	-	2	12	-	12	-	-	-
Airborne Infection Isolation Room (11), (18)	N	-	IN	2	-	2	12	-	12	YES	-	YES (15)
Isolation Alcove or Anteroom (11), (17)	P/N	+/-	IN/OUT	2	2	-	10	10	10	YES	YES	YES
Labor/Delivery/Recovery		-	-		-	2		-	6 (16)		-	-
Labor/Delivery/Recovery/Postpartum		-	-		-	2		-	6 (16)		-	-
Labor/Delivery/Recovery/Postpartum (LDRP) (16)	-	E	-	2	2	-	6	4	-	-	OPTIONAL	-
Patient Corridor	-	E	-	2	2	-	4	4	2	-	OPTIONAL	-
Public Corridor	N		-	2			2			-		
Ancilliary												
Radiology (19) x-ray (surgery and critical care)		P	-		3	-		15	-		OPTIONAL	-
Radiology (19) x-ray (diagnostic and treatment)	-	+/-	-	2	2	-	6	6	6	-	OPTIONAL	-
Radiology (19) x-ray (surgery/critical care)	P	-	OUT	3	-	3	15	-	15	-		-
Radiology (19) Darkroom	N	N	IN	2	2	-	10	10	10	YES	YES (j)	YES
Laboratory, general (19)	N	N	-	2	2	-	6	6	6	YES	YES	-
Laboratory, bacteriology	N	N	-	2	2	-	6	6	-	YES	YES	-
Laboratory, biochemistry	P	P	OUT	2	2	-	6	6	6	OPTIONAL	OPTIONAL	-
Laboratory, cytology	N	N	IN	2	2	-	6	6	6	YES	YES	YES
Laboratory, glasswashing	N	N	IN	OPTIONAL	OPTIONAL	-	10	10	10	YES	YES	YES
Laboratory, histology	N	N	IN	2	2	-	6	6	6	YES	YES	YES
Microbiology (19)	N	-	IN	-	-	-	6	-	65	YES	-	YES
Laboratory, nuclear medicine	N	N	IN	2	2	-	6	6	6	YES	YES	YES
Laboratory, pathololgy	N	N	IN	2	2	-	6	6	6	YES	YES	YES
Laboratory, serology	P	P	OUT	2	2	-	6	6	6	YES	OPTIONAL	-
Laboratory, sterilizing	N	N	IN	OPTIONAL	OPTIONAL	-	10	10	10	YES	YES	YES
Laboratory, media transfer	P	P	-	2	2	-	4	4	-	OPTIONAL	OPTIONAL	-
Autopsy		N	-		2	-		12	-		YES	-
Autopsy Room (11)	N	-	IN	2	-	-	12	-	12	YES	-	YES
Nonrefrigerated Body-Holding Room (k)	N	N	IN	OPTIONAL	OPTIONAL	-	10	10	10	YES	YES	YES
Pharmacy	P	P	OUT	2	2	-	4	4	4	-	OPTIONAL	-
Administration												
Admitting and Waiting Rooms	N	-	-	2	2	-	6	6	-	YES	YES	-
Diagnosting And Treatment												
Bronchoscopy, sputum collection, and pentamidene administration	N	-	-	2	2	-	12	10	-	YES	YES	-
Exmination Room	-	-	-	2	2	-	6	6	6	-	OPTIONAL	-
Medication Room	P	OUT	OUT	2	2	-	4	4	4	-	OPTIONAL	-
Treatment Room	-	-	-	2	2	-	6	6	6	-	OPTIONAL	-
Physical Therapy and Hydrotherapy	N	IN	IN	2	2	-	6	6	6	-	OPTIONAL	-
Soiled Workroom or Soiled Holding	N	IN	IN	2	2	-	10	10	10	YES	YES	YES
Clean Workroom or Clean Holding	P	OUT	OUT	2	2	-	4	4	4	-	OPTIONAL	-
Sterilizing And Supply												
ETO-Sterilizer Room	N	IN	IN	-	-	-	10	-	10	YES	-	YES
Sterilizer Equipment Room	N	IN	IN	-	OPTIONAL	-	10	10	10	YES	YES	YES
Central Medical and Surgical Supply						-						
Soiled or Decontamination Room	N	IN	IN	2	2	-	6	6	6	YES	YES	YES
Clean Workroom	P	OUT	OUT	2	-	-	4	-	4	-	-	-
Sterile Storage	P	OUT	OUT	2	-	-	4	-	4	-	-	-
Clean Workroom and Sterile Storage		-	-		2	-		4	-		OPTIONAL	-
Equipment Storage		-	-		2 (OPTIONAL)	-		2	-		OPTIONAL	
Service												
Food Preparation Center (1) (20)	-	-	-	2	2	-	10	10	10	YES	YES	-
Warewashing	N	IN	IN	OPTIONAL	OPTIONAL	-	10	10	10	YES	YES	YES
Dietary Dry Storage	-	IN	IN	OPTIONAL	OPTIONAL	-	2	2	2	-	OPTIONAL	-
Laundry, general	N	-	-	2	2	-	10	10	10	YES	YES	YES
Soiled Linen Sorting and Storage	N	IN	IN	OPTIONAL	OPTIONAL	-	10	10	10	YES	YES	YES
Clean Linen Storage	P	OUT	OUT	2 (OPTIONAL)	2 (OPTIONAL)	-	2	2	2	-	OPTIONAL	-
Linen and Trash Chute Room	N	-	-	OPTIONAL	OPTIONAL	-	10	10	-	YES	YES	-
Soiled Linen and Trash Chute Room		IN	IN		-	-		-	10		-	YES
Bedpan Room	N	IN	IN	OPTIONAL	OPTIONAL	-	10	10	10	YES	YES	YES
Bathroom	N	IN	IN	OPTIONAL	OPTIONAL	-	10	10	10	YES	OPTIONAL*	-
Janitor's Closet	N	IN	IN	OPTIONAL	OPTIONAL	-	10	10	10	YES	OPTIONAL	YES

Function Space	Air recirculated within room units (d) (7)			Relative humidity (8) (5)			Design temperature (9) (°F/°C)			Proposed comments
	Manual	Handbook	AIA (1)	Manual	Handbook	AIA (1)	Manual	Handbook	AIA (1)	
Surgery And Critical Care										
Operating Room (all outdoor air system)	NO	NO	-		45-55	-		62-80	-	
Operating Room (recirculating air system)	NO	NO	-	30-60		-	68-75		-	A1
Operating /surgical cystoscopic rooms (10), (11)			NO	30-60		30-60	68-75		68-73 (20-23) (12)	A1
Delivery Room (all outdoor air system)		NO	-		45-55	-		62-80	-	
Delivery Room (recirculating air system)	NO	NO	-			-			-	
Delivery Room (10)	NO	-	NO	30-60		30-60	68-75		68-73 (20-23)	B1
Recovery Room	NO	NO	NO	30-60	45-55	30-60	70-75	75	70-75 (21-24)	C1
Critical and Intensive Care	NO	-	NO	30-60		30-60	70-75		70-75 (21-24)	C2
Newborn Intensive Care	-	-	NO	30-60		30-60	72-78		72-78 (22-26)	C2
Treatment Room (13)	NO	-	-	30-60		-	70-75		75 (24)	C2
Nursery Suite		NO	-	30-60	30-60	-	75-80	75-80	-	D1
Trauma Room (f) (13)	YES	NO	NO		45-55	30-60		62-80	70-75 (21-24)	
Trauma Room (crisis or shock) (f) (13a)	NO			30-60			70-75			B2
Trauma Room (conventional ED or treatment) (f) (13a)				30-60			70-75			B2
Anesthesia Storage (see code requirements)	-	NO	-			-			-	
Anesthesia Gas Storage	NO	-	-	-		-	-		-	C3
Endoscopy (11)	NO	-	NO	30-60		30-60	68-73		68-73 (20-23)	C2
Bronchoscopy	-	-	NO	30-60		30-60	68-73		68-73 (20-23)	C2
ER Waiting Rooms	-	-	-	30-60		-	70-75		70-75 (21-24)	C2
Triage	-	-	-	-		-	70-75		70-75 (21-24)	C2
Radiology Waiting Rooms	NO	-	-	-		-	70-75		70-75 (21-24)	C2
Class A Operating (procedure) Room	NO	-	NO	30-60		30-60	70-75		70-75 (21-24)	A4
Nursing										
Patient Room	-	OPTIONAL	-	30-60	30 (winter), 50 (summer)	-	70-75	75	70-75 (21-24)	B3
Toilet Room (g)	NO	NO	-	-		-	-		-	C3
Intensive Care		NO	-		30-60	-		75-80	-	
Newborn Nursery Suite	NO	-	NO	30-60		30-60	72-78		72-78 (22-26)	C2
Protective Isolation (i)		OPTIONAL	-			-			-	
Infectious Isolationg (b)		NO	-		30 (winter), 50 (summer)	-		75	-	
Protective Environment Room (11), (17)	NO	-	NO	-		-	70-75		75 (24)	C2
Airborne Infection Isolation Room (11), (18)	NO	-	NO	-		-	70-75		75 (24)	C2
Isolation Alcove or Anteroom (11), (17)	NO	NO	NO	-		-	-		-	D1
Labor/Delivery/Recovery		-	-			-			70-75 (21-24)	
Labor/Delivery/Recovery/Postpartum		-	-			-			70-75 (21-24)	
Labor/Delivery/Recovery/Postpartum (LDRP) (16)	-	OPTIONAL	-	30-60	30 (winter), 50 (summer)	-	70-75	75	-	A2
Patient Corridor	-	OPTIONAL	-	-		-	-		-	D2
Public Corridor	-			-			-			
Ancilliary										
Radiology (19) x-ray (surgery and critical care)		NO	-			-			-	
Radiology (19) x-ray (diagnostic and treatment)	-	OPTIONAL	-	30-60	40-50	-	72-78	78-80	75 (24)	D2
Radiology (19) x-ray (surgery/critical care)	NO	-	NO	30-60		30-60	70-75		70-75 (21-24)	C2
Radiology (19) Darkroom	NO	NO	NO	-		-	-		-	D2
Laboratory, general (19)	NO	NO	-	30-60	Comfort Range	-	70-75	Comfort Range	75 (24)	D2
Laboratory, bacteriology	NO	NO	-	30-60	Comfort Range	-	70-75	Comfort Range	-	D2
Laboratory, biochemistry	NO	NO	NO	30-60	Comfort Range	-	70-75	Comfort Range	75 (24)	D2
Laboratory, cytology	NO	NO	NO	30-60	Comfort Range	-	70-75	Comfort Range	75 (24)	D3
Laboratory, glasswashing	-	OPTIONAL	-	-	Comfort Range	-	-	Comfort Range	-	D3
Laboratory, histology	NO	NO	NO	30-60	Comfort Range	-	70-75	Comfort Range	75 (24)	C3
Microbiology (19)	NO	-	NO	30-60		-	70-75		75 (24)	C4
Laboratory, nuclear medicine	NO	NO	NO	30-60	Comfort Range	-	70-75		75 (24)	C5
Laboratory, pathololgy	NO	NO	NO	30-60	Comfort Range	-	70-75		75 (24)	C4
Laboratory, serology	NO	NO	NO	30-60	Comfort Range	-	70-75		75 (24)	C4
Laboratory, sterilizing	NO	NO	-	30-60	Comfort Range	-	70-75		-	C4
Laboratory, media transfer	NO	NO	-	30-60	Comfort Range	-	70-75		-	D2
Autopsy		NO	-			-			-	
Autopsy Room (11)	NO	-	NO	-		-	-		-	C4
Nonrefrigerated Body-Holding Room (k)	NO	NO	-	-		-	70		70 (21)	C3
Pharmacy	-	OPTIONAL	-	30-60		-	70-75		-	C4
Administration										
Admitting and Waiting Rooms	-	OPTIONAL	-	30-60		-	70-75		-	D4
Diagnosting And Treatment										
Bronchoscopy, sputum collection, and pentamidene administration	-	OPTIONAL	-	30-60		-	70-75		-	D4
Exmination Room	-	OPTIONAL	-	30-60		-	70-75		75 (24)	C4
Medication Room	-	OPTIONAL	-	30-60		-	70-75		-	C4
Treatment Room	-	OPTIONAL	-	30-60	30 (winter), 50 (summer)	-	70-75	75	75(24)	C6
Physical Therapy and Hydrotherapy	-	OPTIONAL	-	30-60	Comfort Range	-	72-80	Comfort Range up to 80	75 (24)	C4
Soiled Workroom or Soiled Holding	NO	NO	NO	30-60	Comfort Range	-	72-78	Comfort Range	-	D3
Clean Workroom or Clean Holding	-	OPTIONAL	-	-		-	-		-	C3
Sterilizing And Supply										
ETO-Sterilizer Room	NO	-	NO	-		30-60	-		72 (24)	C5
Sterilizer Equipment Room	NO	NO	-	-		-	-		-	C4
Central Medical and Surgical Supply									-	
Soiled or Decontamination Room	NO	NO	NO	30-60	Comfort Range	-	72-78	Comfort Range	68-73 (20-23)	D5
Clean Workroom	NO	-	NO	30-60		30-60	72-78		75 (24)	D8
Sterile Storage	-	-	-	30-60		(Max) 70	72-78		-	D7
Clean Workroom and Sterile Storage		OPTIONAL	-		Under 50	-		Comfort Range	-	
Equipment Storage		OPTIONAL	-			-			-	
Service										
Food Preparation Center (1) (20)	NO	NO	NO	-		-	-		-	C3
Warewashing	NO	NO	NO	-		-	-		-	C3
Dietary Dry Storage	NO	NO	-	-		-	-		-	C7
Laundry, general	NO	NO	-	-		-	-		-	D3
Soiled Linen Sorting and Storage	NO	NO	NO	-		-	-		-	C3
Clean Linen Storage	-	OPTIONAL	-	-		-	-		-	C3
Linen and Trash Chute Room	NO	NO	-	-		-	-		-	C2
Soiled Linen and Trash Chute Room		-	NO			-			-	D2
Bedpan Room	NO	NO	-	-		-	-		-	C3
Bathroom	NO	NO	-	-		-	72-78		75 (24)	C8
Janitor's Closet	NO	NO	NO	-		-	-		-	D3

* AIA Guidelines - Guidelines for Design and Construction of Hospital and Health Care Facilities, Chapter 7, Table 7.2, American Institute of Architects Academy, 2001.

** ASHRAE Handbook - 1999 ASHRAE Handbook - HVAC Applications, Chapter 7, Table 3.

Notes to Table F-1, I

I. 1999 ASHRAE Handbook table references with some clarifications

P = Positive
N = Negative
± = Continuous directional control not required

(a) Where continuous directional control is not required, variations should be minimized, and in no case should a lack of directional control allow the spread of infection from one area to another. Boundaries between functional areas (wards or departments) should have directional control. Lewis (1998) describes methods for maintaining directional control by applying air-tracking controls.

(b) Ventilation in accordance with ASHRAE Standard 62, *Ventilation for Acceptable Indoor Air Quality*, should be used for areas for which specific ventilation rates are not given. Where a higher outdoor air requirement is called for in Standard 62 than in Table 3 (*1999 ASHRAE Handbook—HVAC*), the higher value should be used.

(c) Total air changes indicated should be either supplied or, where required, exhausted.

(d) Recirculating HEPA filter units used for infection control (without heating or cooling coils) are acceptable.

(e) For operating rooms, 100% outside air should be used only when codes require it and only if heat recovery devices are used.

(f) The term "trauma/shock room" as used here is the entry area to the emergency room used for general initial treatment and stabilization of accident victims. The operating room within the Emergency Department that is routinely used for emergency surgery should be treated as an operating room.

(g) See section on Patient Rooms for discussion on design of central toilet exhaust systems.

(h) The Airborne Infection (infectious) isolation rooms described in this table are those that might be used for infectious patients in the average community hospital. The rooms are negatively pressurized. Some isolation rooms may have a separate anteroom. Refer to the discussion in the chapter for more detailed information. Where highly infectious respirable diseases such as tuberculosis are to be isolated, increased air change rates should be considered.

(i) Protective Environment isolation rooms are those used for immunosuppressed patients. The room is positively pressurized to protect the patient. Anterooms are generally required and should be negatively pressurized with respect to the patient room.

(j) All air need not be exhausted if darkroom equipment has scavenging exhaust duct attached and meets ventilation standards on NIOSH, OSHA, and local employee exposure limits.

(k) The nonrefrigerated body-holding room is only for facilities that do not perform autopsies on-site and use the space for short periods while waiting for the body to be transferred.

(l) Food preparation centers should have an excess of air supply for positive pressure when hoods are not in operation. The number of air changes may be reduced or varied for odor control when the space is not in use. Minimum total air changes per hour should be that required to provide proper makeup air to kitchen exhaust systems. See Chapter 30 *(1999 ASHRAE Handbook)*, "Kitchen Ventilation."

Notes to Table F-1, II

II. 2001 AIA Guidelines table references with some clarifications

(1) The ventilation rates in this table cover ventilation for comfort, as well as for asepsis and odor control in areas of acute care hospitals that directly affect patient care and are determined based on health care facilities being predominantly "No Smoking" facilities. Where smoking may be allowed, ventilation rates will need adjustments. Areas where specific ventilation rates are not given in the table shall be ventilated in accordance with ASHRAE Standard 62, *Ventilation for Acceptable Indoor Air Quality*, and *ASHRAE Handbook—HVAC Applications*. Specialized patient care areas, including organ transplant units, burn units, specialty procedure rooms, etc., shall have additional ventilation provisions for air quality control as may be appropriate. OSHA standards and/or NIOSH criteria require special ventilation requirements for employee health and safety within health care facilities.

(2) Design of the ventilation system shall provide air movement that is generally from clean to less clean areas. If any form of variable air volume or load shedding system is used for energy conservation, it must not compromise the corridor-to-room pressure balancing relationships or the minimum air changes required by the table.

(3) To satisfy exhaust needs, replacement air from the outside is necessary. Table 7.2 (2001 AIA Guidelines) does not attempt to describe specific amounts of outside air to be supplied to individual spaces except for certain areas such as those listed. Distribution of the outside air, added to the system to balance required exhaust, shall be as required by good engineering practice. Minimum outside air quantities shall remain constant while the system is in operation.

(4) Number of air changes may be reduced when the room is unoccupied if provisions are made to ensure that the number of air changes indicated is reestablished any time the space is being utilized. Adjustments shall include provisions so that the direction of air movement shall remain the same when the number of air changes is reduced. Areas not indicated as having continuous directional control may have ventilation systems shut down when space is unoccupied and ventilation is not otherwise needed, if the maximum infiltration or exfiltration permitted in Note 2 is not exceeded and if adjacent pressure balancing relationships are not compromised. Air quantity calculations must account for filter loading such that the indicated air change rates are provided up until the time of filter change-out.

(5) Air change requirements indicated are minimum values. Higher values should be used when required to maintain indicated room conditions (temperature and humidity), based on the cooling load of the space (lights, equipment, people, exterior walls and windows, etc.). Certain operating rooms may require lower or higher temperature or humidity conditions.

(6) Air from areas with contamination and/or odor problems shall be exhausted to the outside and not recirculated to other areas. Note that individual circumstances may require special consideration for air exhaust to the outside, e.g., in intensive care units, in which patients with pulmonary infection are treated, and rooms for burn patients.

(7) "Air Recirculated within Room Units" refers to those local units that are used primarily for heating and cooling of air and not disinfection of air. Because of cleaning difficulty and potential for buildup of contamination, recirculating room units shall not be used in areas marked "No." However, for airborne infection control, air may be recirculated within individual isolation rooms if HEPA filters are used. Isolation and intensive care unit rooms may be ventilated by reheat induction units in which only the primary air supplied from a central system passes through the reheat unit. Gravity-type heating or cooling units, such as radiators or convectors, shall not be used in operating rooms and other special care areas. See Appendix A (2001 AIA Guidelines) for a description of recirculation units to be used in isolation rooms. Recirculating devices with HEPA filters may have potential uses in existing facilities as interim, supplemental environmental controls to meet requirements for the control of airborne infectious agents. Limitations in design must be recognized. The design of either portable or fixed systems should prevent stagnation and short-circuiting of airflow. The supply and exhaust locations should direct clean air to areas where health care workers are likely to work, across the infectious source, and then to the exhaust, so that the health care worker is not in position between the infectious source and the exhaust location. The design of such systems should also allow for easy access for scheduled preventive maintenance and cleaning.

(8) The ranges listed are the minimum and maximum limits where control is specifically needed. The maximum and minimum limits are not intended to be independent of a space's associated temperature. The humidity is expected to be at the higher end of the range when the temperature is also at the higher end, and vice versa.

(9) Where temperature ranges are indicated, the systems shall be capable of maintaining the rooms at any point within the range during normal operation. A single figure indicates a heating or cooling capacity of at least the indicated temperature. This is usually applicable when patients may be undressed and require a warmer environment. Nothing in these guidelines shall be construed as precluding the use of temperatures lower than those noted when the patients' comfort and medical conditions make lower temperatures desirable. Unoccupied areas such as storage rooms shall have temperatures appropriate for the function intended.

(10) National Institute for Occupational Safety and Health (NIOSH) Criteria Documents regarding Occupational Exposure to Waste Anesthetic Gases and Vapors, and Control of Occupational Exposure to Nitrous Oxide indicate a need for both local exhaust (scavenging) systems and general ventilation of the areas in which the respective gases are utilized.

(11) Differential pressure shall be a minimum of 0.01 in. w.g. (2.5 Pa). If alarms are installed, allowances shall be made to prevent nuisance alarms of monitoring devices.

Notes to Table F-1, II (Continued)

The verification of airflow direction can include a simple visual method such as smoke trail, ball-in-tube, or flutter-strip. These devices will require a minimum differential air pressure to indicate airflow direction.

(12) Some surgeons may require room temperatures that are outside of the indicated range. All operating room design conditions shall be developed in consultation with surgeons, anesthesiologists, and nursing staff.

(13) The note in AIA Guidelines is clarified. **(13a)** The term trauma room as used here is the operating room space in the emergency department or other trauma reception area that is used for emergency surgery. **(13b)** The first aid room and/or "emergency room" used for initial treatment of accident victims may be ventilated as noted for the "treatment room." Treatment rooms used for bronchoscopy shall be treated as bronchoscopy rooms. Treatment rooms used for cryosurgery procedures with nitrous oxide shall contain provisions for exhausting waste gases.

(14) In a ventilation system that recirculates air, HEPA filters can be used in lieu of exhausting the air from these spaces to the outside. In this application, the return air shall be passed through the HEPA filters before it is introduced into any other spaces.

(15) If it is not practical to exhaust the air from the airborne infection isolation room to the outside, the air may be returned through HEPA filters to the air-handling system exclusively serving the isolation room.

(16) Total air changes per room for patient rooms, labor/delivery/recovery rooms, and labor/delivery/recovery/postpartum rooms may be reduced to 4 when supplemental heating and/or cooling systems (radiant heating and cooling, baseboard heating, etc.) are used.

(17) The protective environment airflow design specifications protect the patient from common environmental airborne infectious microbes (i.e., *Aspergillus* spores). These special ventilation areas shall be designed to provide directed airflow from the cleanest patient area to less clean areas. These rooms shall be protected with HEPA filters at 99.97 percent efficiency for 0.3 μm sized particle in the supply airstream. These interrupting filters protect patient rooms from maintenance-derived release of environmental microbes from the ventilation system components. Recirculation HEPA filters can be used to increase the equivalent room air exchanges. Constant volume airflow is required for consistent ventilation for the protected environment. If the facility determines that airborne infection isolation is necessary for protective environment patients, an anteroom should be provided. Rooms with reversible airflow provisions for the purpose of switching between protective environment and airborne infection isolation functions are not acceptable.

(18) The infectious disease isolation room described in these guidelines is to be used for isolating the airborne spread of infectious diseases, such as measles, varicella, or tuberculosis. The design of airborne infection isolation (AII) rooms should include the provision for normal patient care during periods not requiring isolation precautions. Supplemental recirculating devices may be used in the patient room, to increase the equivalent room air exchanges; however, such recirculating devices do not provide the outside air requirements. Air may be recirculated within individual isolation rooms if HEPA filters are used. Rooms with reversible airflow provisions for the purpose of switching between protective environment and AII functions are not acceptable.

(19) When required, appropriate hoods and exhaust devices for the removal of noxious gases or chemical vapors shall be provided (see Section 7.31.D14 and 7.31.D15, 2001 AIA Guidelines, and NFPA 99).

(20) Food preparation centers shall have ventilation systems whose air supply mechanisms are interfaced appropriately with exhaust hood controls or relief vents so that exfiltration or infiltration to or from exit corridors does not compromise the exit corridor restrictions of NFPA 90A, the pressure requirements of NFPA 96, or the maximum defined in the table. The number of air changes may be reduced or varied to any extent required for odor control when the space is not in use. See Section 7.31.D1.p., 2001 AIA Guidelines.

Notes to Table F-1, III

III. Notes

A1 The operating room ventilation rates are different between the 2001 *AIA Guidelines for Design and Construction of Hospital and Health Care Facilities* (2001 AIA Guidelines) and *1999 ASHRAE Handbook—HVAC Applications* (1999 ASHRAE Handbook). Consider if the surgery performed is minor or major. No reduction of ventilation rate is suggested even when 100% outside air is used. Ventilation rate recommendation based upon 1999 ASHRAE Handbook. Special temperature and humidity conditions in certain situations may be required. The temperature setpoint should be able to be adjusted by surgical staff over a range of 62 to 80°F (17 to 27°C). It should also be noted that 64 to 72°F (18 to 22°C) is the usual temperature range for ORs unless special circumstances exist, and 45-45% humidity is a preferable target but 30-60% is an acceptable range.

The required air change rates are also a function of space temperature setpoint, supply air temperature, sensible and latent heat load in the space. Appendix I describes the recent research on this subject and describes different ventilation system performances at different ACH. Continued use of 25 ACH (as recommended in ASHRAE Handbook—Applications) provides a safety margin to accommodate cooling load in modern operating rooms generated due to increasing use of electronic equipment during surgery, which generates large sensible heat load.

The designer should review the type of clinical activity and severity of the surgery performed before selecting the appropriate ventilation rates, temperature, and humidity conditions.

A2 The labor/delivery/recovery/postpartum ventilation rates are different between the 2001 AIA Guidelines and 1999 ASHRAE Handbook. The designer should review the type of clinical activity and severity of the surgery performed before selecting the appropriate ventilation rates.

Ventilation rate recommendation based upon 2001 AIA Guidelines. Temperature and humidity is from 1999 ASHRAE Handbook. The design temperature is shown to have range.

A3 The Protective or Infectious Isolation room ventilation rates are different between the 2001 AIA Guidelines and 1999 ASHRAE Handbook. The designer should review the type of clinical activity and severity of the surgery performed before selecting the appropriate ventilation rates: recommendation based upon 2001 AIA Guidelines, recommendation based upon 1999 ASHRAE Handbook.

A4 New category added to account for operating rooms in day surgery application.

B1 The delivery room ventilation rates are different between the new 2001 AIA Guidelines and 1999 ASHRAE Handbook. The designer should review the type of clinical activity and severity of the surgery performed before selecting the appropriate ventilation rates. Ventilation rate recommendation are based upon 1999 ASHRAE Handbook. 2001 AIA Guidelines for temperature and humidity conditions are adopted.

B2 The trauma room ventilation rates are different between the 1999 ASHRAE Handbook and the 2001 AIA Guidelines. The designer should review the type of clinical activity and severity of the surgery performed before selecting the appropriate ventilation rates. Consider if the surgery performed is minor or major

Ventilation rate recommendation is based upon 1999 ASHRAE Handbook. Temperature and humidity requirements are also based upon 1999 ASHRAE Handbook.

B3 2001 AIA Guidelines and 1999 ASHRAE Handbook standards are different. However, recent 1999 ASHRAE Handbook published research was used to determine ventilation rates in the new 2001 AIA Guidelines. Humidity and temperature recommendations are based upon 1999 ASHRAE Handbook. Space temperature design range is defined.

C1 Similar standards between 2001 AIA Guidelines and 1999 ASHRAE Handbook. No pressure difference between recommendation is made. The relative humidity requirement is more restrictive in 1999 ASHRAE Handbook and as a design guide it is recommended. The design guide is more restricted for space temperature as well.

C2 Only defined in 2001 AIA Guidelines. Same condition adapted for best practices.

C3 Similar standards between 2001 AIA Guidelines and 1999 ASHRAE Handbook.

C4 Similarly between 2001 AIA Guidelines and 1999 ASHRAE Handbook. Wider temperature is recommended and humidity ranges are also specified.

C5 Mostly defined in 2001 AIA Guidelines. New humidity and temperature ranges are also specified.

C6 In Treatment Room similar standard between 1999 ASHRAE Handbook and 2001 AIA Guidelines. However, 1999 ASHRAE Handbook temperature and humidity range is adopted. A range is provided for temperature setting.

C7 Similarity between 1999 ASHRAE Handbook and 2001 AIA Guidelines. However, 2001 AIA Guidelines recommendation that space be negative is not adopted.

C8 Similar between 2001 AIA Guidelines and 1999 ASHRAE Handbook. Toilet is exhausted directly outdoors.

Notes to Table F-1, III (Continued)

D1	Only defined in 1999 ASHRAE Handbook. The pressure with respect to adjacent space may be positive or negative depending upon the type of anteroom.
D2	Only defined in 1999 ASHRAE Handbook.
D3	Similar standards between 2001 AIA Guidelines and 1999 ASHRAE Handbook. One has more details. Recommendation based upon 1999 ASHRAE Handbook.
D4	Defined in 1999 ASHRAE Handbook. Humidity and design temperature added.
D5	Some similarities between 1999 ASHRAE Handbook and 2001 AIA Guidelines. However, 2001 AIA Guidelines has no humidity recommendation and has a lower temperature range. 2001 AIA Guidelines suggests 68-73°F (20-23°C), which appears too restrictive.
D6	Defined by 2001 AIA Guidelines. Minimum outside air is added.
D7	Similar between 2001 AIA Guidelines and 1999 ASHRAE Handbook. Humidity levels are adopted from 1999 ASHRAE Handbook. Specific temperature range is provided.

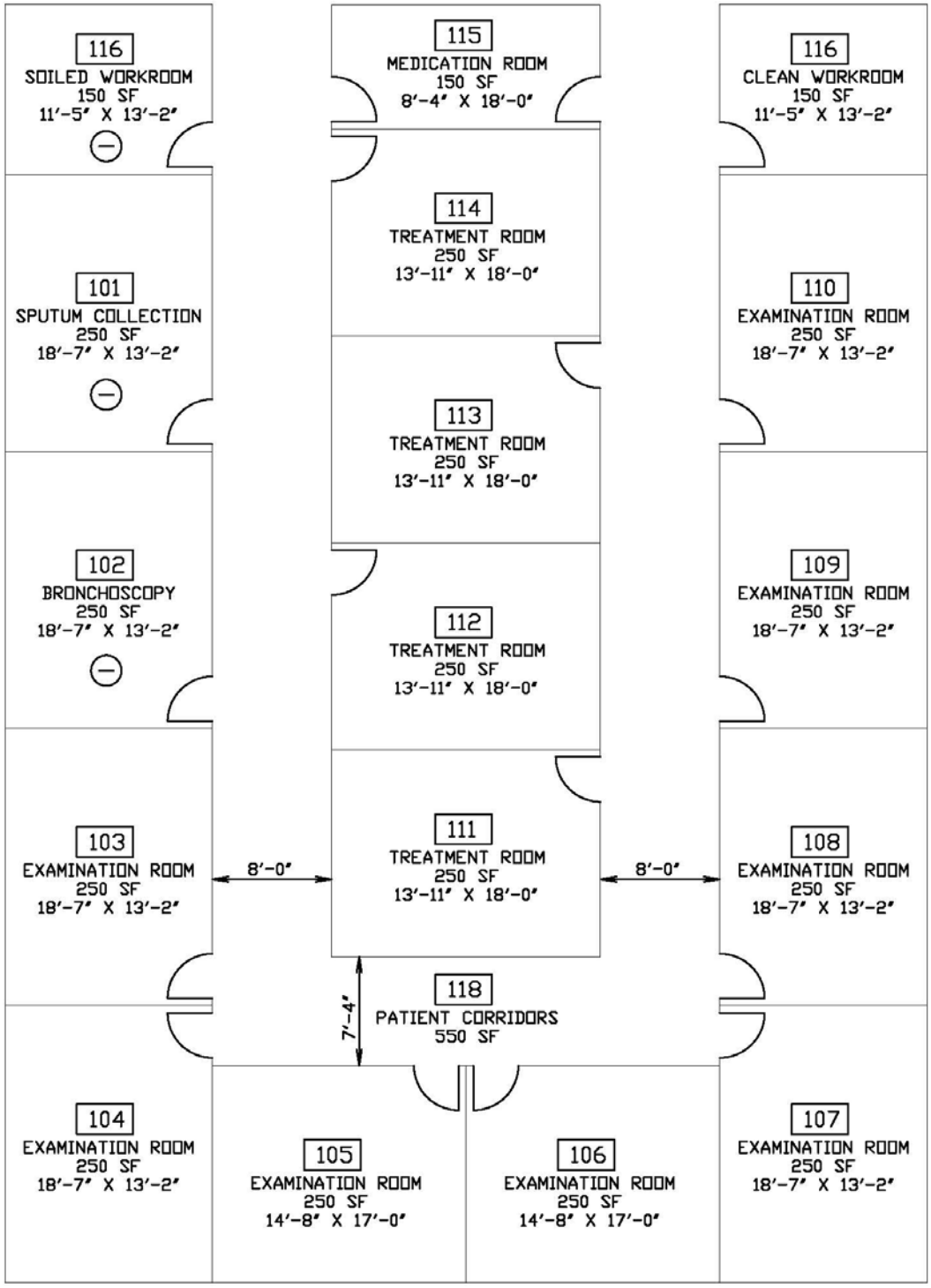
Appendix C - Study Floor Plan & System Layouts

C.1 Study Floor Plan

C.2 System Layout: AHU-1

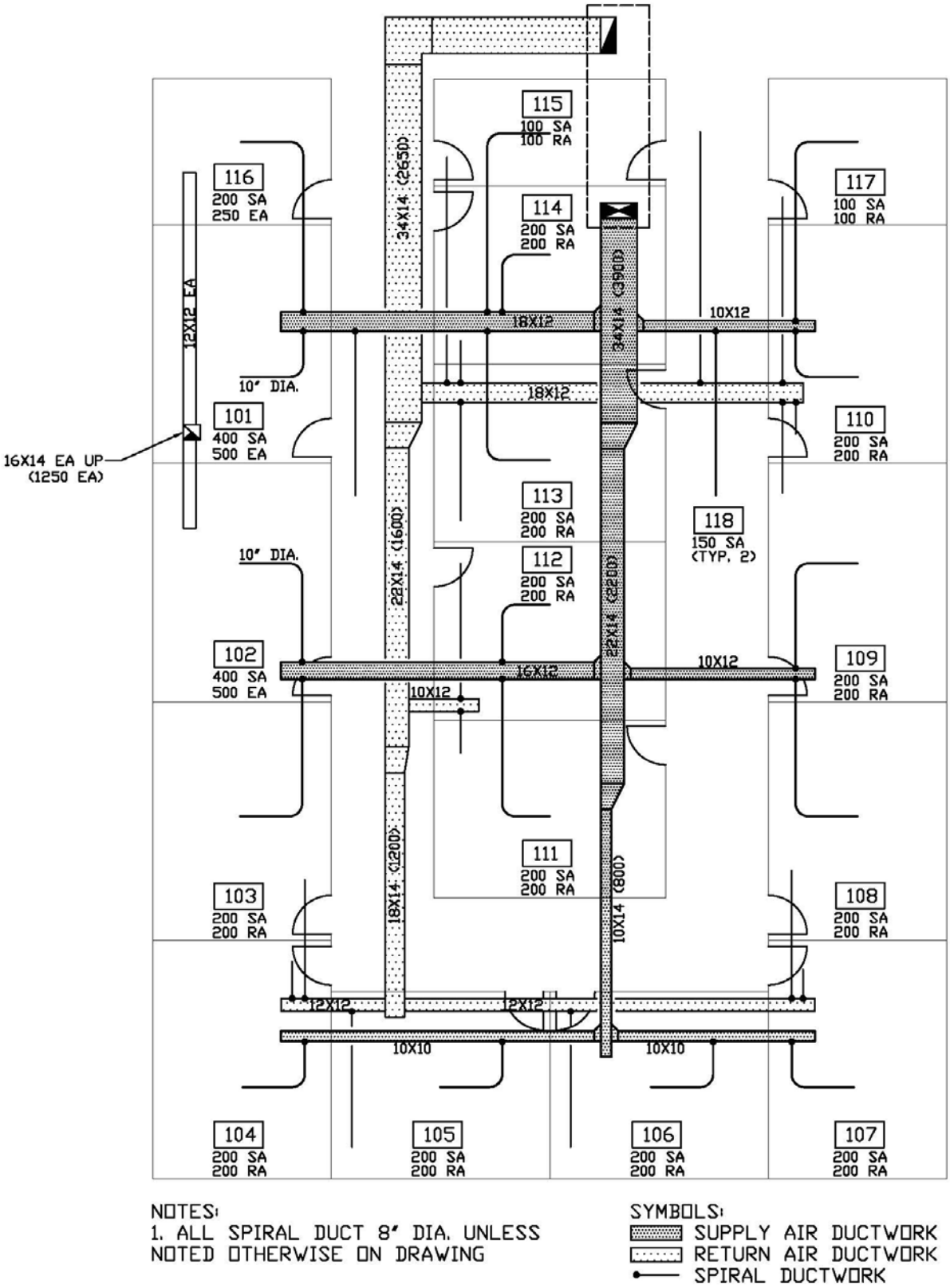
C.3 System Layout: AHU-2

C.1 Study Floor Plan

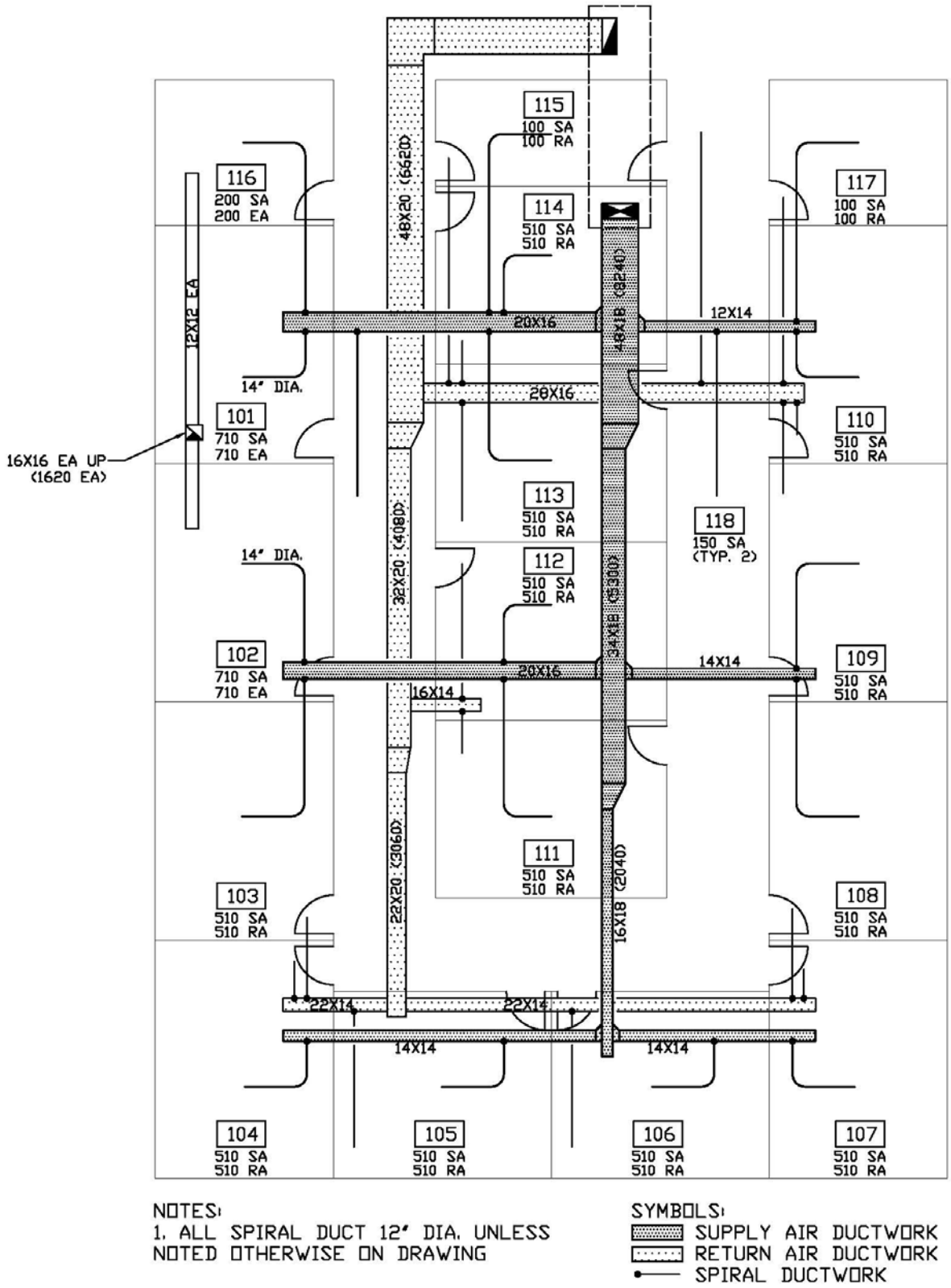


NOTES:
⊖ NEGATIVE PRESSURE RELATIONSHIP TO ADJACENT SPACE.

C.2 System Layout: AHU-1



C.3 System Layout: AHU-2



NOTES:
1. ALL SPIRAL DUCT 12" DIA. UNLESS NOTED OTHERWISE ON DRAWING

SYMBOLS:
- SUPPLY AIR DUCTWORK
- RETURN AIR DUCTWORK
- SPIRAL DUCTWORK

Appendix D - Design Calculations

D.1 Reference Information

*Based on information from "A Systematic Breakdown and Comparison of the ASHRAE Standards" by Julia Holman (89).

Abbreviations and Symbols:

Q_T: Unit Total Load

Q_S: Unit Sensible Load

Q_L: Unit Latent Load

q_T: Space Total Load

q_S: Space Sensible Load

q_L: Space Latent Load

MA: Mixed Air

OA: Outside Air

RA: Return Air

SA: Supply Air

T_{MA}: Mixed Air Temperature

T_{RA}: Return Air Temperature

T_{SA}: Supply Air Temperature

G_{MA}: Mixed Air Grains

G_{RA}: Return Air Grains

G_{SA}: Supply Air Grains

CFM: Cubic Feet per Minute

RSHR: Room Sensible Heat Ratio

RH: Relative Humidity

DB: Dry Bulb

MWB: Mean Coincident Wet Bulb

Equations:

Unit Sensible Load: $Q_S = 1.08 \times CFM \times (T_{MA} - T_{SA})$

Unit Latent Load: $Q_L = 0.69 \times CFM \times (G_{MA} - G_{SA})$

Unit Total Load: $Q_T = Q_S + Q_L$

Space Sensible Load: $q_S = 1.08 \times CFM \times (T_{RA} - T_{SA})$

Space Latent Load: $q_L = 0.69 \times CFM \times (G_{RA} - G_{SA})$

Space Total Load: $q_T = q_S + q_L$

Mixed Air Temperature: $T_{MA} = \frac{T_{OA} \times CFM_{OA} + T_{RA} \times CFM_{RA}}{CFM_{SA}}$

D.2 Equivalent ACH Calculation

Design Goal:

- Achieve 99% airborne pathogen disinfection in the space

Assumptions:

- Assume 99% reduction occurs in 30 minutes (conservative estimation)
- Natural convection of a human moves air at 95 turns per hour (almost every 40 seconds new air is introduced to the upper-room UVGI system) (David Skelton)
- Perfect mixing in the space (Although this is unlikely, it is applied for all other system options when determining the removal effectiveness and can therefore be assumed.)

Calculations:

$$EAC = -\ln\frac{N_S}{N_O} \qquad \text{(Equation No. 5)}$$

EAC: Equivalent Air Changes

N_S: Number of Bacteria Surviving

N_O: Number of Bacteria Exposed to UVGI

- To achieve a 99% reduction, $N_S = 1$ and $N_O = 100$

- $EAC = -\ln\frac{N_S}{N_O} = -\ln\frac{1}{100} = 4.6\ AC$ for each 99% reduction

- Based on the assumption of 99% reduction in just 30 minutes, the equivalent air exchange rate would be 9.2 ACH (2 x 4.6 ACH).

D.3 ACH and CFM Design Calculation Table: AHU-1

AHU - 1												
ROOM NO.	ROOM NAME	AREA (SF)	CEILING HEIGHT (FT)	MIN CFM (AREA x .65cfm/sf)	MIN OA ACH[1]	MIN TOTAL ACH[2]	OA CFM BASED ON ACH	**OA CFM**	SA CFM BASED ON ACH	REQUIRED EA CFM	**EA CFM**	SA CFM FROM qs^3	**DESIGN CFM**
101	Sputum Collection	250	8	163	2	12	67	70	400	400	500	163	400
102	Bronchoscopy	250	8	163	2	12	67	70	400	400	500	163	400
103	Examination Room 1	250	8	163	2	6	67	70	200	-	-	163	200
104	Examination Room 2	250	8	163	2	6	67	70	200	-	-	163	200
105	Examination Room 3	250	8	163	2	6	67	70	200	-	-	163	200
106	Examination Room 4	250	8	163	2	6	67	70	200	-	-	163	200
107	Examination Room 5	250	8	163	2	6	67	70	200	-	-	163	200
108	Examination Room 6	250	8	163	2	6	67	70	200	-	-	163	200
109	Examination Room 7	250	8	163	2	6	67	70	200	-	-	163	200
110	Examination Room 8	250	8	163	2	6	67	70	200	-	-	163	200
111	Treatment Room 1	250	8	163	2	6	67	70	200	-	-	163	200
112	Treatment Room 2	250	8	163	2	6	67	70	200	-	-	163	200
113	Treatment Room 3	250	8	163	2	6	67	70	200	-	-	163	200
114	Treatment Room 4	250	8	163	2	6	67	70	200	-	-	163	200
115	Medication Room	150	8	98	2	4	40	40	80	-	-	95	100
116	Soiled Room	150	8	98	2	10	40	40	200	200	250	95	200
117	Clean Workroom	150	8	98	2	4	40	40	80	-	-	95	100
118	Patient Corridors	550	8	358	2	4	147	150	293	-	-	63	300
	TOTAL	4,500					1,200	**1,250**	3,853	1,000	**1,250**	2,625	**3,900**

Notes:

1.) Minimum OA ACH from most stringent of HVAC Design Manual for Hospitals and Clinics, AIA Guidelines, and ASHRAE Handbook (Appendix B)

2.) Minimum total ACH from most stringent of HVAC Design Manual for Hospitals and Clinics, AIA Guidelines, and ASHRAE Handbook (Appendix B)

3.) Reference Space Loads Design Calculation Table: AHU-1

D.4 Space Loads Design Calculation Table: AHU-1

AHU - 1										
ROOM NO.	ROOM NAME	NO. PEOPLE	LIGHTING SENSIBLE[1]	EQUIP. SENSIBLE[2]	PEOPLE SENSIBLE	SPACE COOLING LOADS				
						ΔT	**qs (BTUh)**	**ql (BTUh)**	**qt (BTUh)**
101	Sputum Collection	2	1,280	855	500	15.0	2,635	400	3,035
102	Bronchoscopy	2	1,280	855	500	15.0	2,635	400	3,035
103	Examination Room 1	2	1,280	855	500	15.0	2,635	400	3,035
104	Examination Room 2	2	1,280	855	500	15.0	2,635	400	3,035
105	Examination Room 3	2	1,280	855	500	15.0	2,635	400	3,035
106	Examination Room 4	2	1,280	855	500	15.0	2,635	400	3,035
107	Examination Room 5	2	1,280	855	500	15.0	2,635	400	3,035
108	Examination Room 6	2	1,280	855	500	15.0	2,635	400	3,035
109	Examination Room 7	2	1,280	855	500	15.0	2,635	400	3,035
110	Examination Room 8	2	1,280	855	500	15.0	2,635	400	3,035
111	Treatment Room 1	2	1,280	855	500	15.0	2,635	400	3,035
112	Treatment Room 2	2	1,280	855	500	15.0	2,635	400	3,035
113	Treatment Room 3	2	1,280	855	500	15.0	2,635	400	3,035
114	Treatment Room 4	2	1,280	855	500	15.0	2,635	400	3,035
115	Medication Room	1	770	515	250	15.0	1,535	200	1,735
116	Soiled Room	1	770	515	250	15.0	1,535	200	1,735
117	Clean Workroom	1	770	515	250	15.0	1,535	200	1,735
118	Patient Corridors	0	1,025	0	0	15.0	1,025	0	1,025
	TOTAL						**42,520**	**6,200**	**48,720**

Notes:

1.) Lighting Sensible Load: 1.5 W/SF x SF x 3.413 BTUh/W = BTUh (1.0 W/SF for Patient Corridors)

2.) Equipment Sensible Load: 1.0 W/SF x SF x 3.413 BTUh/W = BTUh

Variables:

Outside Design Conditions =	96	
Thermostatic Setpoint =	70	
ΔT =	15	
Latent Heat Gain =	200	Moderately active office work
Sensible Heat Gain =	250	Moderately active office work

D.5 Design Calculations: AHU-1

Design Conditions:

70°F DB / 50% RH Space Design Condition (Section 4.8.1)

96°F DB / 75°F MWB Outside Air Condition (Section 4.8.1)

51.5°F DB / 90% RH Coil Discharge Condition (From Psychrometric Chart)

Space Loads:

$q_S = 42{,}520\ Btuh$ (Appendix D.3)

$q_L = 6{,}200\ Btuh$ (Appendix D.3)

$q_T = 48{,}720\ Btuh$ (Appendix D.3)

$$RSHR = \frac{q_S}{q_T} = \frac{42{,}520}{48{,}720} = 0.87$$

Air Conditions:

OA:	96°F DB	98 GRAINS	1,250 CFM
SA:	55°F DB	51 GRAINS	3,900 CFM
RA:	70°F DB	55 GRAINS	2,650 CFM
EA:			1,250 CFM

$$T_{MA} = \frac{96°F \times 1{,}250CFM + 70°F \times 2{,}650CFM}{3{,}900CFM}$$

$T_{MA} = 78.5°F$ DB, 69 GRAINS (From Psychrometric Chart)

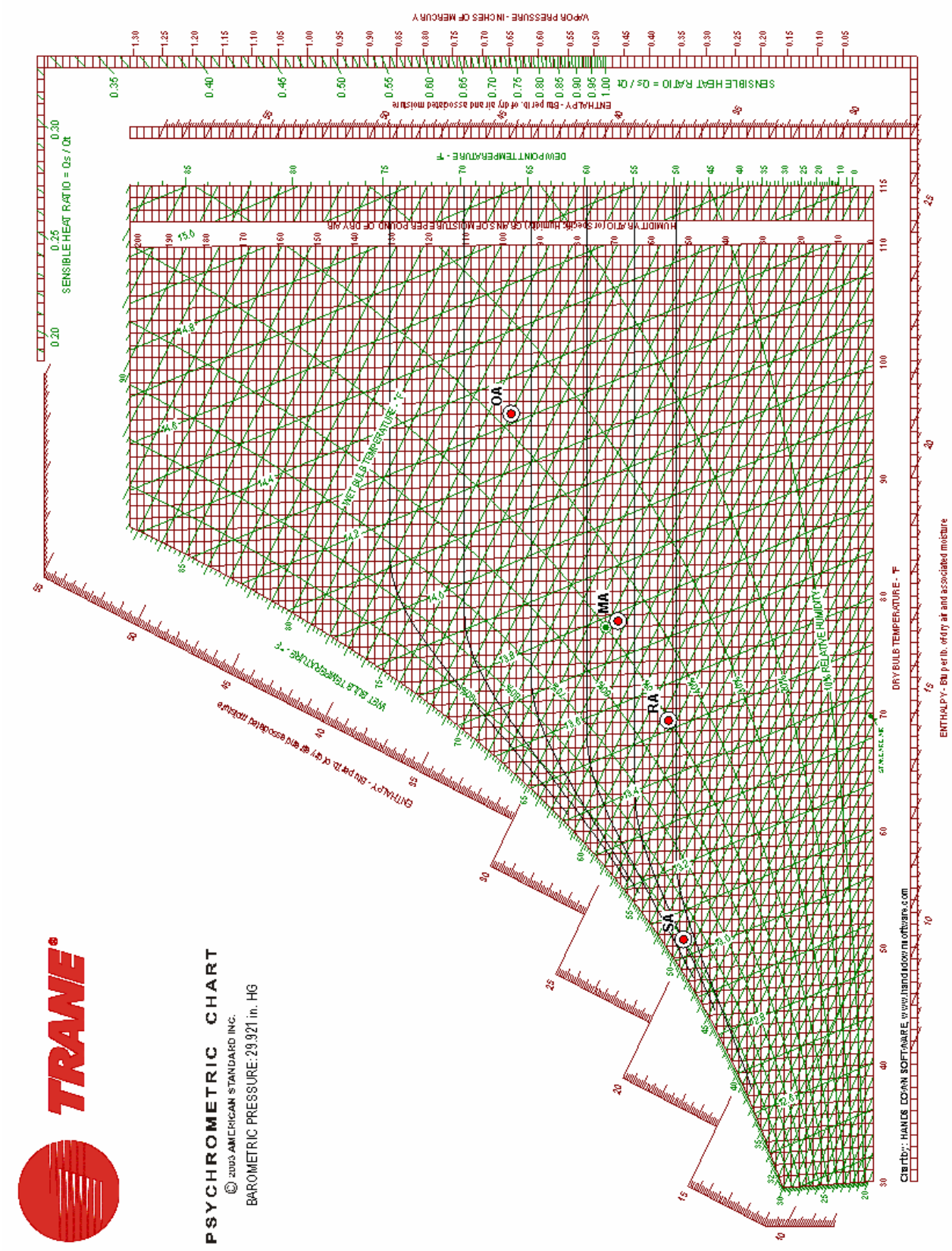
Unit Load Calculations:

Q_S = 1.08 x 3,900*CFM* x *(78.5°F – 51.5°F)* = 113,724 *Btuh*

Q_L = 0.69 x 3,900*CFM* x *(69G – 51G)* = 48,438 *Btuh*

Q_T = 113,724 *Btuh* + 48,438 *Btuh* = 162,162 *Btuh*

D.6 Psychrometric Chart: AHU-1



D.7 ACH and CFM Design Calculation Table: AHU-2

AHU - 2												
ROOM NO.	ROOM NAME	AREA (SF)	CEILING HEIGHT (FT)	MIN CFM (AREA x .65cfm/sf)	MIN OA ACH[1]	TOTAL EQUIV. ACH[2]	OA CFM BASED ON ACH	**OA CFM**	SA CFM BASED ON ACH	REQUIRED EA CFM	**EA CFM**	SA CFM FROM qs[3]	**DESIGN CFM**
101	Sputum Collection	250	8	163	2	21.2	67	255	707	707	710	163	710
102	Bronchoscopy	250	8	163	2	21.2	67	255	707	707	710	163	710
103	Examination Room 1	250	8	163	2	15.2	67	70	507	-	-	163	510
104	Examination Room 2	250	8	163	2	15.2	67	70	507	-	-	163	510
105	Examination Room 3	250	8	163	2	15.2	67	70	507	-	-	163	510
106	Examination Room 4	250	8	163	2	15.2	67	70	507	-	-	163	510
107	Examination Room 5	250	8	163	2	15.2	67	70	507	-	-	163	510
108	Examination Room 6	250	8	163	2	15.2	67	70	507	-	-	163	510
109	Examination Room 7	250	8	163	2	15.2	67	70	507	-	-	163	510
110	Examination Room 8	250	8	163	2	15.2	67	70	507	-	-	163	510
111	Treatment Room 1	250	8	163	2	15.2	67	70	507	-	-	163	510
112	Treatment Room 2	250	8	163	2	15.2	67	70	507	-	-	163	510
113	Treatment Room 3	250	8	163	2	15.2	67	70	507	-	-	163	510
114	Treatment Room 4	250	8	163	2	15.2	67	70	507	-	-	163	510
115	Medication Room	150	8	98	2	4.0	40	40	80	-	-	95	100
116	Soiled Room	150	8	98	2	10.0	40	40	200	200	200	95	200
117	Clean Workroom	150	8	98	2	4.0	40	40	80	-	-	95	100
118	Patient Corridors	550	8	358	2	4.0	147	150	293	-	-	63	300
	TOTAL	4,500					1,200	**1,620**	8,147	1,000	**1,620**	2,625	**8,240**

Notes:

1.) Minimum OA ACH from most stringent of HVAC Design Manual for Hospitals and Clinics, AIA Guidelines, and ASHRAE Handbook (Appendix B)

2.) Minimum total ACH from most stringent of HVAC Design Manual for Hospitals and Clinics, AIA Guidelines, and ASHRAE Handbook (Appendix B)

3.) Reference Space Loads Design Calculation Table: AHU-1

D.8 Space Loads Design Calculation Table: AHU-2

AHU - 2										
ROOM NO.	ROOM NAME	NO. PEOPLE	LIGHTING SENSIBLE[3]	EQUIP. SENSIBLE[4]	PEOPLE SENSIBLE	SPACE COOLING LOADS				
						ΔT	qs (BTUh)	ql (BTUh)	qt (BTUh)
101	Sputum Collection	2	1,280	855	500	15.0	2,635	400	3,035
102	Bronchoscopy	2	1,280	855	500	15.0	2,635	400	3,035
103	Examination Room 1	2	1,280	855	500	15.0	2,635	400	3,035
104	Examination Room 2	2	1,280	855	500	15.0	2,635	400	3,035
105	Examination Room 3	2	1,280	855	500	15.0	2,635	400	3,035
106	Examination Room 4	2	1,280	855	500	15.0	2,635	400	3,035
107	Examination Room 5	2	1,280	855	500	15.0	2,635	400	3,035
108	Examination Room 6	2	1,280	855	500	15.0	2,635	400	3,035
109	Examination Room 7	2	1,280	855	500	15.0	2,635	400	3,035
110	Examination Room 8	2	1,280	855	500	15.0	2,635	400	3,035
111	Treatment Room 1	2	1,280	855	500	15.0	2,635	400	3,035
112	Treatment Room 2	2	1,280	855	500	15.0	2,635	400	3,035
113	Treatment Room 3	2	1,280	855	500	15.0	2,635	400	3,035
114	Treatment Room 4	2	1,280	855	500	15.0	2,635	400	3,035
115	Medication Room	1	770	515	250	15.0	1,535	200	1,735
116	Soiled Room	1	770	515	250	15.0	1,535	200	1,735
117	Clean Workroom	1	770	515	250	15.0	1,535	200	1,735
118	Patient Corridors	0	1,025	0	0	15.0	1,025	0	1,025
	TOTAL						**42,520**	**6,200**	**48,720**

Notes:

1.) Lighting Sensible Load: 1.5 W/SF x SF x 3.413 BTUh/W = BTUh (1.0 W/SF for Patient Corridors)

2.) Equipment Sensible Load: 1.0 W/SF x SF x 3.413 BTUh/W = BTUh

Variables:

Outside Design Conditions =	96	
Thermostatic Setpoint =	70	
ΔT =	15	
Latent Heat Gain =	200	Moderately active office work
Sensible Heat Gain =	250	Moderately active office work

D.9 Design Calculations: AHU-2

Design Conditions:

70°F DB / 50% RH Space Design Condition (Section 4.8.1)

96°F DB / 75°F MWB Outside Air Condition (Section 4.8.1)

51.5°F DB / 90% RH Coil Discharge Condition (From Psychrometric Chart)

Space Loads:

$q_S = 42{,}520\ Btuh$ (Appendix D.3)

$q_L = 6{,}200\ Btuh$ (Appendix D.3)

$q_T = 48{,}720\ Btuh$ (Appendix D.3)

$$RSHR = \frac{q_S}{q_T} = \frac{42{,}520}{48{,}720} = 0.87$$

Air Conditions:

OA:	96°F DB	98 GRAINS	1,620 CFM
SA:	55°F DB	51 GRAINS	8,240 CFM
RA:	70°F DB	55 GRAINS	6,620 CFM
EA:			1,620 CFM

$$T_{MA} = \frac{96°F \times 1{,}620CFM + 70°F \times 6{,}620CFM}{8{,}240CFM}$$

$T_{MA} = 75.1°F$ DB, 63 GRAINS (From Psychrometric Chart)

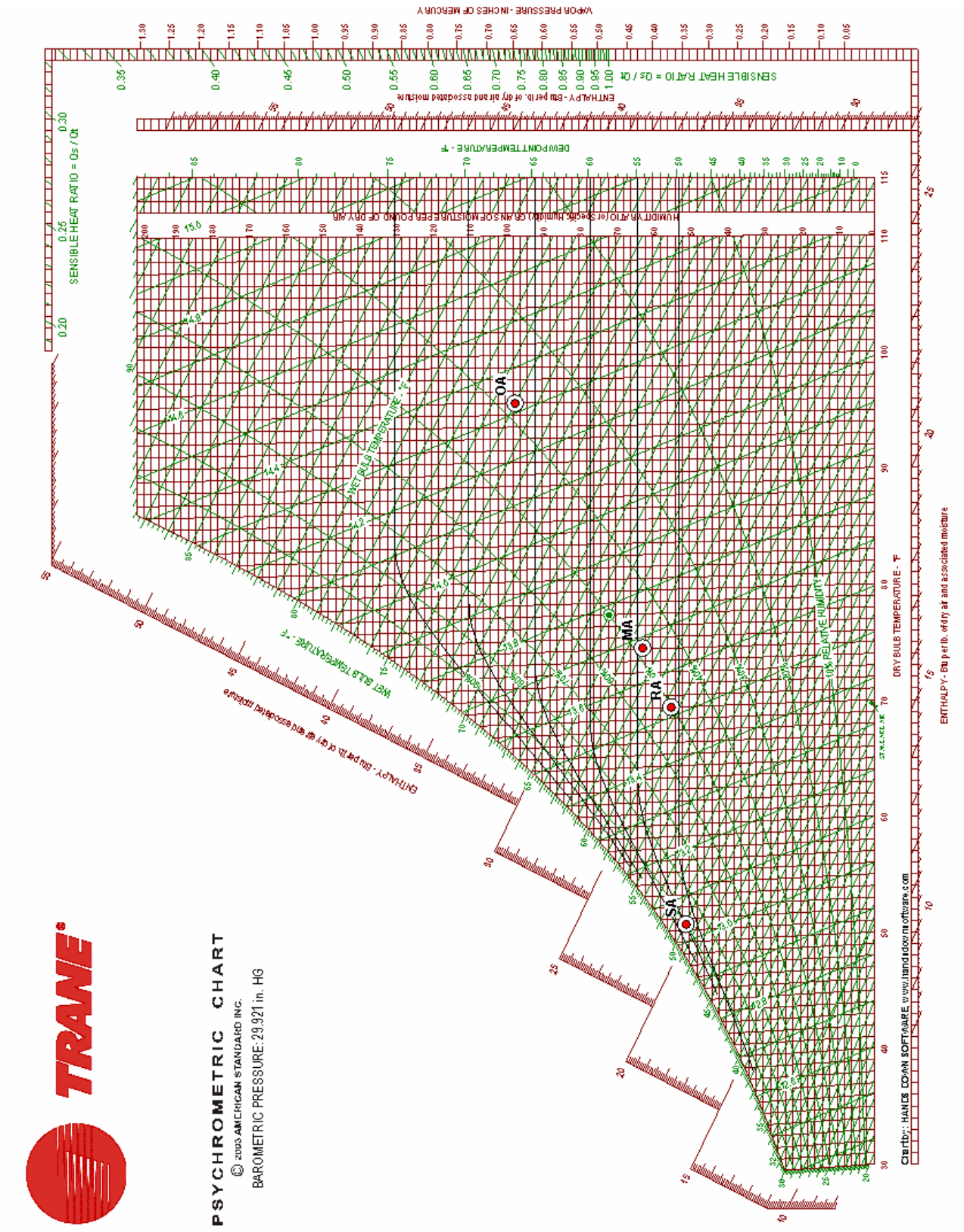
Unit Load Calculations:

Q_S = 1.08 x 8,240*CFM* x *(75.1°F – 51.5°F)* = 210,021 *Btuh*

Q_L = 0.69 x 8,240*CFM* x *(63G – 51G)* = 68,227 *Btuh*

Q_T = 210,021 *Btuh* + 68,227 *Btuh* = 278,248 *Btuh*

D.10 Psychrometric Chart: AHU-2



Appendix E - AHU Schedule & System Selections

E.1 AHU Schedule

AHU SCHEDULE

UNIT NUMBER	CFM	MIN. OA CFM	TOTAL S.P.	EXT. S.P.	CHILLED WATER COOLING COIL DATA								HOT WATER HEATING COIL DATA				FILTER DATA				REMARKS
					FACE VEL. MAX. (FPM)	SENSIBLE MBH	TOTAL MBH	EWT °F	LWT °F	EDB °F	EWB °F	LDB °F	LWB °F	EAT	LAT	BTU//HR	GPM 180°F HOT WATER (20°F ΔT)	TYPE	MERV RATING	CLEAN S.P. IN WG	DIRTY S.P. IN WG	
AHU - 1	3,900	1,250	3.81"	1.0"	500	113.7	162.2	42	52	78.5	64.5	51.5	50.0	47.2	110.0	264,500	26.5	PRE-FILTER	8	0.4	0.9	PROVIDE VFD RATED MOTORS
																		FINAL FILTER	14	0.6	1.2	
AHU - 2	8,240	1,620	3.54"	1.0"	500	210.0	278.2	42	52	75.1	62.1	51.5	50.0	56.0	110.0	480,600	48.1	PRE-FILTER	8	0.4	0.9	PROVIDE VFD RATED MOTORS
																		FINAL FILTER	14	0.6	1.2	

E.2 System Selection: AHU-1

SKYLINE AIR HANDLING UNIT TECHNICAL DATA Date Saved : 14/11/2007

JOB NAME	M2B275(YY.000)	**REP. OFFICE**	Thermal Components (KC)
JOB DESCRIPTION	KSU Project	**SALESPERSON**	TB
MODEL NUMBER	OAH008GDAC	**ENGINEER**	
UNIT TAGGING	AHU-1	**VERSION**	8.61

Unit configuration	Inline horizontal		
Drive (handing) location	Right		
	SUPPLY	**RETURN / EXHAUST**	
Air volume	3900		s cfm
Altitude	0		ft
Turning loss	0.00		in WC.
External static	1.00		in WC.
Total static	3.81		in WC.
External H x W	34 x 58 (Not including base rails)		ins

CASING DETAILS		
Outer panel	Painted standard G60 galv steel	
Liner	Galvanized steel (Unless noted per section)	
Insulation	R-13 Injected Foam (Unless noted per section)	
Frame	2 ins	
Base	Curb ready	
Sound baffles	None (unless noted per section)	
Roof curb kit	20.00	ins
Tread Plate floor liner	None (unless noted per section)	

1 MIXING BOX(20 ins)			SECTION 1
Drip pan	None	Drip side	-
	OUTSIDE AIR	**RETURN AIR**	
Length x Width	16.00 x 54.00	16.00 x 54.00	ins
Location	End	Bottom	
Dampers	UltraSeal Low Leak	UltraSeal Low Leak	
Actuation	-	-	
Rated cfm	3900	3900	cfm
Air pressure drop	0.09		in WC
Hoods	Fitted		

DOOR DATA				
Door location	Drive side		Window size	None
Door width	16	ins	Light	None
Door opening	Outward			

2 COMBINATION FILTER(22 ins) SECTION 2

Access	Side		Face velocity	479	fpm
Air volume	3900	cfm	Face area	8.1	ft2

	PRE-FILTER	FILTER	
Type	Pleated (MERV 8)	Varicel SH cartridge	
Efficiency	70	95	%
Clean air press. drop	0.38	0.54	ins WC
Mean air press. drop	**0.69**	**0.87**	**ins WC**
Dirty air press. drop	1.00	1.20	ins WC
Depth	2.00	12.00	ins

BANK ARRANGEMENT

No. of Filters	Size H x W	
2	24.00 x 20.00 x 2.00	ins
1	24.00 x 12.00 x 2.00	

DOOR DATA

Door location	Both sides	Window size	None	
Drive side door width	18 ins	Light	None	
Opp drv side door width	18 ins			
Door opening	Outward			

SPECIAL

Pre-filter Intersept Antimicrobial treatment

Tread Plate floor liner	None			
Liner	(As casing details)			
Insulation	(As casing details)			
Sound baffles	None			
Special static pressure	-	ins WC	Filter Gauge	None

3 HOT WATER COIL(16 ins) SECTION 3

Coil model	5WH1202B		Number of coils	1	
Capacity	270335	Btu/h	Number of rows	2	
			Fins per inch	12	
Air volume	3900	cfm			
Entering db	47.2	F	Entering water	180.0	F
Leaving db	110.6	F	Leaving water	159.6	F
Finned height x length	24 x 42	ins	Water flow rate	26.50	gpm
Face area	7.00	ft2	Water pressure drop	2.70	ftHD
Face velocity	557	ft/m	Water velocity	3.50	ft/s
Coil air pressure drop	0.26	ins WC	Piping vestibule	18	ins
			Fluid volume	3.0	gal
			Fluid weight	25.00	lb
Connection type	Threaded		Fin material	Aluminum (.0075)	
Connection Qty x size	2 x 2.50	ins	Tube material	Copper (.020)	
Connection location	Drive side		Header material	Copper	
Glycol type (%)	- (0 %)		Case material	Galvanized track	
Fouling Factor	0		Drip pan	None	
			Drip pan side	-	
			Turbospirals	None	
Coil code	5WH1202B		Electro-fin coat	None	

4 ACCESS SECTION(24 ins)					SECTION 4
Drip pan	None		Drip side	-	
DOOR DATA					
Door location	Drive side		Window size	None	
Door width	20	ins	Light	None	
Door opening	Outward				

5 CHILLED WATER COIL(20 ins)					SECTION 5
Coil model	5WH1206B		Number of coils	1	
Total capacity	163757	Btu/h	Number of rows	6	
Sensible capacity	120218	Btu/h	Fins per inch	12	
Air volume	3900	cfm			
Entering db/wb	78.5 / 64.5	F	Entering water	42.0	F
Leaving db/wb	50.3 / 49.9	F	Leaving water	52.1	F
Finned height x length	24 x 45	ins	Water flow rate	32.40	gpm
Face area	7.50	ft2	Water pressure drop	13.80	ftHD
Face velocity	520	ft/m	Water velocity	4.40	ft/s
Coil air pressure drop	0.89	ins WC	Piping vestibule	18	ins
			Fluid volume	6.0	gal
			Fluid weight	55.00	lb
Connection type	Threaded		Fin material	Aluminum (.0075)	
Connection Qty x size	2 x 1.50	ins	Tube material	Copper (.020)	
Connection location	Drive side		Header material	Copper	
Glycol type (%)	- (0 %)		Case material	Galv. steel	
Fouling Factor	0		Drain pan	Stainless steel	
			Drain pan side	Opp drive side	
			Turbospirals	None	
Coil code	5WH1206B		Electro-fin coat	None	

6 SUPPLY FAN SECTION(40 ins)				SECTION	6
Air volume	3900	cfm	Motor power	7.5	HP
External static pressure	1.00	ins WC	Motor type	ODP	
Total static pressure	3.81	ins WC	Frame size	213 T frame	
			Electrical supply	460/60/3	
Type	-		Motor efficiency	Premium	
Blade type/Class	Airfoil / 2		Motor speed	1750	rpm
Fan wheel diameter	13.22	ins	Motor pole	4	
Brake horsepower	4.48	HP	Full load current	10	A
Operating/Max speed	3232 / 4335	rpm	Lock rotor current	80	A
Orientation	Top horizontal		Motor supplier	Generic	
Air modulation	None		Actual drive service fac.	1.11	
Drip pan	None		Bearing type	Standard - L50 (200K)	
Drip pan side	-		Outlet velocity	1831	ft/m
Wheel guard	None		Inlet screen	None	
Belt guard	None		Outlet screen	None	
Inspection port	None				
DRIVES					
Fan sheave	2AK34H		Motor sheave	2AK64H	
Number of belts	2		Belt	AX30	
ANTI-VIBRATION MOUNTS / SPRINGS					
Type	Spring				
Seismic restraint	With snubbers				
DOOR DATA					
Door location	Drive side		Window size	None	
Door width	30	ins	Light	None	
Door opening	Outward				

7 PLENUM SECTION(18 ins)				SECTION	7
Drip pan	None		Drip side	-	
Opening location	Bottom		Opening size	14.00 x 54.00	ins
DOOR DATA					
Panel Location	Removable panels		Window size	None	
Panel Width	14	ins	Light	None	
Panel Opening	Outward				

NOTES

Supply fan performance is certified in accordance with the Central Station Air-Handling Unit Certification Program, which is based on ARI Standard 430.
As a standalone component, unit meets or exceeds requirements of ASHRAE 90.1 - 1999. The approving authority is responsible for compliance of multi-component building systems.
Piping vestibule shipping section length(s) not included in the total unit shipping section length. Vestibules are not listed as separate sections, although vestibule weight is included in the total unit weight.

SHIPPING SECTION DETAILS

	Length (inches)	Weight (lb)	
Section 1	20	573	
Section 2	22	287	
Section 3	16	294	
Section 4	24	217	
Section 5	20	482	
Section 6	40	694	
Section 7	18	207	
TOTALS	**160.00 (Lower level total)**	**2984 (Entire unit weight)**	

UNIT SOUND	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Radiated	79	81	75	71	62	53	37	28
Unit discharge	87	89	87	88	82	76	72	64
Unit return	84	86	81	81	70	60	49	40

E.3 System Selection: AHU-2

SKYLINE AIR HANDLING UNIT TECHNICAL DATA Date Saved : 14/11/2007

JOB NAME	M2B275(YY.002)	**REP. OFFICE**	Thermal Components (KC)
JOB DESCRIPTION	KSU Project	**SALESPERSON**	TB
MODEL NUMBER	OAH017GDAC	**ENGINEER**	
UNIT TAGGING	AHU-2	**VERSION**	8.61

Unit configuration	Inline horizontal		
Drive (handing) location	Right		
	SUPPLY	**RETURN / EXHAUST**	
Air volume	8240		s cfm
Altitude	0		ft
Turning loss	0.00		in WC.
External static	1.00		in WC.
Total static	3.54		in WC.
External H x W	46 x 80 (Not including base rails)		ins

CASING DETAILS		
Outer panel	Painted standard G60 galv steel	
Liner	Galvanized steel (Unless noted per section)	
Insulation	R-13 Injected Foam (Unless noted per section)	
Frame	2 ins	
Base	Curb ready	
Sound baffles	None (unless noted per section)	
Roof curb kit	20.00	ins
Tread Plate floor liner	None (unless noted per section)	

1 MIXING BOX(26 ins)			SECTION	1
Drip pan	None	Drip side	-	
	OUTSIDE AIR	**RETURN AIR**		
Length x Width	22.00 x 76.00	22.00 x 76.00		ins
Location	End	Bottom		
Dampers	UltraSeal Low Leak	UltraSeal Low Leak		
Actuation	-	-		
Rated cfm	8240	8240		cfm
Air pressure drop	0.08			in WC
Hoods	Fitted			
DOOR DATA				
Door location	Drive side	Window size	None	
Door width	22 ins	Light	None	
Door opening	Outward			

2 COMBINATION FILTER(22 ins)					SECTION 1
Access	Side		Face velocity	437	fpm
Air volume	8240	cfm	Face area	18.9	ft2
	PRE-FILTER		**FILTER**		
Type	Pleated (MERV 8)		Varicel SH cartridge		
Efficiency	70		95		%
Clean air press. drop	0.34		0.47		ins WC
Mean air press. drop	**0.67**		**0.84**		**ins WC**
Dirty air press. drop	1.00		1.20		ins WC
Depth	2.00		12.00		ins

BANK ARRANGEMENT		
No. of Filters	**Size H x W**	
6	20.00 x 24.00 x 2.00	ins

DOOR DATA				
Door location	Both sides	Window size	None	
Drive side door width	18	ins	Light	None
Opp drv side door width	18	ins		
Door opening	Outward			

SPECIAL				
Pre-filter Intersept Antimicrobial treatment				
Tread Plate floor liner	None			
Liner	(As casing details)			
Insulation	(As casing details)			
Sound baffles	None			
Special static pressure	-	ins WC	Filter Gauge	None

3 HOT WATER COIL(16 ins)					SECTION 1
Coil model	5WH1002B		Number of coils	1	
Capacity	501432	Btu/h	Number of rows	2	
			Fins per inch	10	
Air volume	8240	cfm			
Entering db	56.0	F	Entering water	180.0	F
Leaving db	111.6	F	Leaving water	159.2	F
Finned height x length	36 x 64	ins	Water flow rate	48.10	gpm
Face area	16.00	ft2	Water pressure drop	6.20	ftHD
Face velocity	515	ft/m	Water velocity	4.30	ft/s
Coil air pressure drop	0.20	ins WC	Piping vestibule	18	ins
			Fluid volume	5.0	gal
			Fluid weight	48.00	lb
Connection type	Threaded		Fin material	Aluminum (.0075)	
Connection Qty x size	2 x 2.50	ins	Tube material	Copper (.020)	
Connection location	Drive side		Header material	Copper	
Glycol type (%)	- (0 %)		Case material	Galvanized track	
Fouling Factor	0		Drip pan	None	
			Drip pan side	-	
			Turbospirals	None	
Coil code	5WH1002B		Electro-fin coat	None	

4 ACCESS SECTION(24 ins)				SECTION 1
Drip pan	None	Drip side	-	
DOOR DATA				
Door location	Drive side	Window size	None	
Door width	20	ins	Light	None
Door opening	Outward			

5 CHILLED WATER COIL(20 ins) SECTION 2

Coil model	5WL1106B		Number of coils	1	
Total capacity	283554	Btu/h	Number of rows	6	
Sensible capacity	223237	Btu/h	Fins per inch	11	
Air volume	8240	cfm			
Entering db/wb	75.1 / 62.1	F	Entering water	42.0	F
Leaving db/wb	50.3 / 49.8	F	Leaving water	52.2	F
Finned height x length	36 x 67	ins	Water flow rate	55.60	gpm
Face area	16.75	ft2	Water pressure drop	7.60	ftHD
Face velocity	492	ft/m	Water velocity	3.30	ft/s
Coil air pressure drop	0.74	ins WC	Piping vestibule	18	ins
			Fluid volume	14.0	gal
			Fluid weight	117.00	lb
Connection type	Threaded		Fin material	Aluminum (.0075)	
Connection Qty x size	2 x 2.50	ins	Tube material	Copper (.020)	
Connection location	Drive side		Header material	Copper	
Glycol type (%)	- (0 %)		Case material	Galv. steel	
Fouling Factor	0		Drain pan	Stainless steel	
			Drain pan side	Opp drive side	
			Turbospirals	None	
Coil code	5WL1106B		Electro-fin coat	None	

6 SUPPLY FAN SECTION(50 ins) SECTION 2

Air volume	8240	cfm	Motor power	10.0	HP
External static pressure	1.00	ins WC	Motor type	ODP	
Total static pressure	3.54	ins WC	Frame size	215 T frame	
			Electrical supply	460/60/3	
Type	-		Motor efficiency	Premium	
Blade type/Class	Airfoil / 1		Motor speed	1750	rpm
Fan wheel diameter	19.69	ins	Motor pole	4	
Brake horsepower	7.29	HP	Full load current	12.9	A
Operating/Max speed	1922 / 2000	rpm	Lock rotor current	106	A
Orientation	Top horizontal		Motor supplier	Generic	
Air modulation	None		Actual drive service fac.	1.30	
Drip pan	None		Bearing type	Standard - L50 (200K)	
Drip pan side	-		Outlet velocity	1749	ft/m
Wheel guard	None		Inlet screen	None	
Belt guard	None		Outlet screen	None	
Inspection port	None				

DRIVES

Fan sheave	2B5V52	Motor sheave	2BK62H
Number of belts	2	Belt	B47

ANTI-VIBRATION MOUNTS / SPRINGS

Type	Spring
Seismic restraint	With snubbers

DOOR DATA

Door location	Drive side		Window size	None
Door width	30	ins	Light	None
Door opening	Outward			

7 PLENUM SECTION(24 ins)				SECTION	2
Drip pan	None		Drip side	-	
Opening location	Bottom		Opening size	20.00 x 76.00	ins
DOOR DATA					
Panel Location	Removable panels		Window size	None	
Panel Width	20	ins	Light	None	
Panel Opening	Outward				

NOTES

Supply fan performance is certified in accordance with the Central Station Air-Handling Unit Certification Program, which is based on ARI Standard 430.
As a standalone component, unit meets or exceeds requirements of ASHRAE 90.1 - 1999. The approving authority is responsible for compliance of multi-component building systems.
Piping vestibule shipping section length(s) not included in the total unit shipping section length. Vestibules are not listed as separate sections, although vestibule weight is included in the total unit weight.

SHIPPING SECTION DETAILS			
	Length (inches)	**Weight (lb)**	
Section 1	88	1624	
Section 2	94	2221	
TOTALS	**182.00 (Lower level total)**	**4112 (Entire unit weight)**	

UNIT SOUND	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Radiated	80	82	76	72	63	54	38	29
Unit discharge	88	90	88	89	83	77	73	65
Unit return	85	87	82	82	71	61	50	41

Appendix F - First Cost Calculation Tables

F.1 First Cost Calculation Table: Upper-Room UVGI

HVAC UNIT	**AHU - 1**
SYSTEM	
Model	#WM-136
Number of UVGI Fixtures per space	2
Number of spaces with UVGI fixtures	14
LABOR	
Total number of fixtures	28
Cost per Labor-Hour	$42.35
Labor-Hours (per fixture)	1.5
Location Factor (KC, MO)	1.094
Labor Cost	*$1,946*
UVGI FIXTURE	
Total number of fixtures	28
UVGI Fixture Cost (each)	$824
Location Factor (KC, MO)	1.000
Total UVGI Fixture Cost	*$23,072*
Total Installed Cost	**$25,018**

General Notes:

1.) Labor data from 2006 RSMeans Building and Construction Cost Data

2.) UVGI fixture and cost data from Lumalier UV Air Disinfection

F.2 First Cost Calculation Table: UVGI in AHU

HVAC UNIT	**AHU - 1**
SYSTEM	
Model	#EXTV-60-1R4
LABOR	
Cost per Labor-Hour	$42.35
Labor-Hours	3
Location Factor (KC, MO)	1.094
Labor Cost	*$139*
UVGI SYSTEM	
UVGI System Cost	$1,428
Location Factor (KC, MO)	1.000
Material Cost	*$1,428*
Total Installed Cost	**$1,567**

General Notes:

1.) Labor cost data from 2006 RSMeans Building and Construction Cost Data

2.) UVGI fixture and cost data from Lumalier UV Air Disinfection

F.3 First Cost Calculation Table: Air Handling Units

HVAC UNIT	**AHU - 1**	**AHU - 2**
LABOR		
Crew	Q-6[A]	Q-7[B]
Cost per Labor-Hour	$40.18	$41.03
Labor-Hours	37.975	57.554
Location Factor (KC, MO)	1.054	1.054
Labor Cost	*$1,608*	*$2,489*
MATERIAL		
Material Cost	$9,950	$22,400
Location Factor (KC, MO)	0.999	0.999
Material Cost	*$9,940*	*$22,378*
Total Installed Cost	**$11,548**	**$24,867**

General Notes:

1.) Labor and Material data from 2006 RSMeans Building and Construction Cost Data

2.) Material cost includes standard controls, curb, and economizer

A.) Crew Q-6 includes 2 steamfitters and 1 steamfitter apprentice

B.) Crew Q-7 includes 1 steamfitter foreman, 2 steamfitters, and 1 steamfitter apprentice

F.4 First Cost Calculation Table: AHU-1 Ductwork

AHU - 1									
METAL DUCTWORK	Duct Size	Weight in Lb./Ft.	Duct Length in Ft.	Weight in Lb.	Material Cost per Lb. (*Ft.*)	Location Factor[A]	Labor Cost per Lb. (*Ft.*)	Location Factor	Installed Cost
	34 X 14	12.0	75	900	$0.50	0.999	$3.43	1.054	$3,703
	22 X 14	9.0	58	522	$0.50	0.999	$3.43	1.054	$2,148
	18 X 14	8.0	20	160	$0.50	0.999	$3.43	1.054	$658
	16 X 14	6.5	6	39	$0.50	0.999	$3.43	1.054	$160
	10 X 14	5.2	20	104	$0.50	0.999	$3.43	1.054	$428
	18 X 12	6.5	56	364	$0.50	0.999	$3.43	1.054	$1,498
	16 X 12	6.0	26	156	$0.50	0.999	$3.43	1.054	$642
	12 X 12	5.2	42	218	$0.50	0.999	$3.43	1.054	$899
	10 X 12	4.7	38	179	$0.50	0.999	$3.43	1.054	$735
	10 X 10	4.3	44	189	$0.50	0.999	$3.43	1.054	$779
	34 X 14 Elbow	N/A	N/A	53	$0.50	0.999	$3.43	1.054	$218
	34 X 14 Elbow	N/A	N/A	53	$0.50	0.999	$3.43	1.054	$218
	34 X 14 Elbow	N/A	N/A	53	$0.50	0.999	$3.43	1.054	$218
	8" Dia.	N/A	435	N/A	*$2.31*	0.999	*$3.03*	1.054	$2,393
	10" Dia.	N/A	30	N/A	*$2.86*	0.999	*$3.79*	1.054	$206
	8" Fittings	N/A	470	N/A	*$2.31*	0.999	*$3.03*	1.054	$2,586
	10" Fittings	N/A	40	N/A	*$2.86*	0.999	*$3.79*	1.054	$274
							Total Installed Metal Ductwork Cost:		*$17,762*
FLEXIBLE DUCTWORK	Duct Size	Insulation	Insulation Thickness	Length in Ft.	Material Cost per Ft.	Location Factor	Labor Cost per Ft.	Location Factor	Installed Cost
	8" Dia.	Yes	1"	85	$3.15	0.999	$3.37	1.054	$569
	10" Dia.	Yes	1"	15	$3.71	0.999	$4.34	1.054	$124
							Total Installed Flexible Ductwork Cost:		*$694*
INSULATION	Type	Thickness in Inches	Density in Lb.	Surface Area of duct in Ft.	Material Cost per Ft.	Location Factor	Labor Cost per Ft.	Location Factor	Installed Cost
	Blanket	1-1/2"	0.75	2345	$0.30	0.999	$1.76	1.054	$5,053
							Total Installed Insulation Cost:		*$5,053*
Total Installed Cost									**$23,509**

General Notes:

1.) Data from 2006 RSMeans Building and Construction Cost Data

2.) Galvanized steel assumed for metal ductwork

3.) Insulation surface area assumes 10% spare

4.) Spiral ductwork fittings calculated at an equivalent of 10 Ft. ductwork per fitting

A.) Location Factor for Kansas City, MO

F.5 First Cost Calculation Table: AHU-2 Ductwork

AHU - 2									
METAL DUCTWORK	Duct Size	Weight in Lb./Ft.	Duct Length in Ft.	Weight in Lb.	Material Cost per Lb. (*Ft.*)	Location Factor[A]	Labor Cost per Lb. (*Ft.*)	Location Factor	Installed Cost
	48 X 20	19.7	50	985	$0.50	0.999	$3.43	1.054	$4,053
	32 X 20	13.0	26	338	$0.50	0.999	$3.43	1.054	$1,391
	22 X 20	10.5	20	210	$0.50	0.999	$3.43	1.054	$864
	48 X 18	19.1	25	478	$0.50	0.999	$3.43	1.054	$1,965
	34 X 18	13.0	30	390	$0.50	0.999	$3.43	1.054	$1,605
	16 X 18	8.5	20	170	$0.50	0.999	$3.43	1.054	$700
	28 X 16	11.0	30	330	$0.50	0.999	$3.43	1.054	$1,358
	20 X 16	9.0	50	450	$0.50	0.999	$3.43	1.054	$1,852
	22 X 14	9.0	40	360	$0.50	0.999	$3.43	1.054	$1,481
	16 X 14	6.5	6	39	$0.50	0.999	$3.43	1.054	$160
	14 X 14	6.0	56	336	$0.50	0.999	$3.43	1.054	$1,383
	14 X 12	5.6	32	179	$0.50	0.999	$3.43	1.054	$737
	48 X 20 Elbow	N/A	N/A	94	$0.50	0.999	$3.43	1.054	$387
	48 X 20 Elbow	N/A	N/A	94	$0.50	0.999	$3.43	1.054	$387
	48 X 18 Elbow	N/A	N/A	91	$0.50	0.999	$3.43	1.054	$374
	12" Dia.	N/A	435	N/A	*$3.52*	0.999	*$5.05*	1.054	$3,845
	14" Dia.	N/A	30	N/A	*$4.07*	0.999	*$7.60*	1.054	$362
	12" Fittings	N/A	470	N/A	*$3.52*	0.999	*$5.05*	1.054	$4,154
	14" Fittings	N/A	40	N/A	*$4.07*	0.999	*$7.60*	1.054	$483
							Total Installed Metal Ductwork Cost:		*$27,541*
FLEXIBLE DUCTWORK	Duct Size	Insulation	Insulation Thickness	Length in Ft.	Material Cost per Ft.	Location Factor	Labor Cost per Ft.	Location Factor	Installed Cost
	12" Dia.	Yes	1"	85	$4.62	0.999	$6.05	1.054	$934
	14" Dia.	Yes	1"	15	$5.53	0.999	$7.76	1.054	$206
							Total Installed Flexible Ductwork Cost:		*$1,140*
INSULATION	Type	Thickness in Inches	Density in Lb.	Surface Area of duct in Ft.	Material Cost per Ft.	Location Factor	Labor Cost per Ft.	Location Factor	Installed Cost
	Blanket	1-1/2"	0.75	3270	$0.30	0.999	$1.76	1.054	$7,046
							Total Installed Insulation Cost:		*$7,046*
Total Installed Cost									**$35,727**

General Notes:

1.) Data from 2006 RSMeans Building and Construction Cost Data

2.) Galvanized steel assumed for metal ductwork

3.) Insulation surface area assumes 10% spare

4.) Spiral ductwork fittings calculated at an equivalent of 10 Ft. ductwork per fitting

A.) Location Factor for Kansas City, MO

F.6 First Cost Calculation Table: Exhaust Fans

EXHAUST FAN	**EF - 1**	**EF - 2**
MODEL	Cook VCR-D 120V15D	Cook VCR-D 135V15D
Design CFM	1250	1620
LABOR		
Crew	Q-20	Q-20
Cost per Labor-Hour	$38.74	$38.74
Labor-Hours	4.762	4.762
Location Factor	1.054	1.054
Labor Cost	*$194*	*$194*
MATERIAL		
Material Cost	*$540*	*$570*
Total Installed Cost	**$734**	**$764**

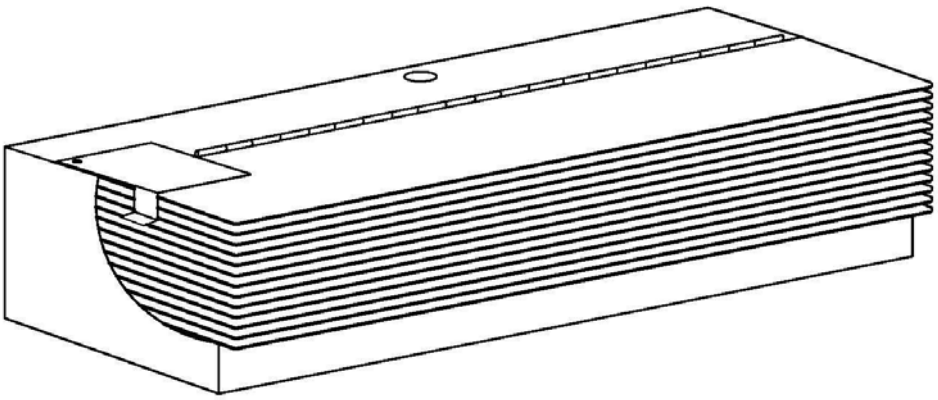
General Notes:

1.) Labor data from 2006 RSMeans Building and Construction Cost Data

2.) Material cost from Loren Cook Company - Upblast centrifugal exhaust ventilator

Appendix G - UVGI Data Sheets

G.1 Data Sheet: Upper-Room UVGI Fixture



DIMENSIONS: 18 1/4" L. x 8 1/2" EXT. x 4 3/4" H.

FINISHES: BRUSHED STAINLESS STEEL HOUSING &
FLAT BLACK LOUVERS

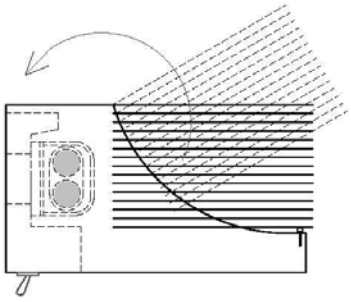
ELECTRICAL REQUIREMENTS: 120V THRU 277V/ 50-60Hz / 0.5A

LAMP: (1) 36W TWIN TUBE UV
UV WATTS: 12 UV WATTS
NOMINAL WATTS: 36 WATTS

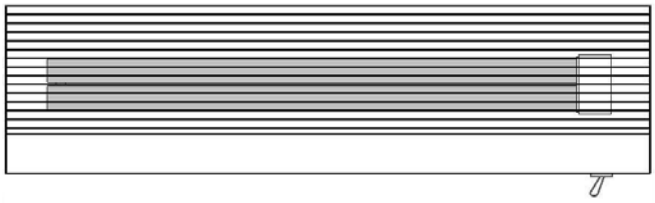
MINIMUM CEILING HEIGHT: 7' 9"
MOUNT NO LOWER THAN 7' 0" ABOVE FINISHED FLOOR.

WALL MOUNTED & HINGED LOUVER ASSEMBLY
FOR EASE OF MAINTENANCE.

4 3/4" HEIGHT; ON/OFF TOGGLE SWITCH & INTEGRAL SAFETY SWITCH



END VIEW

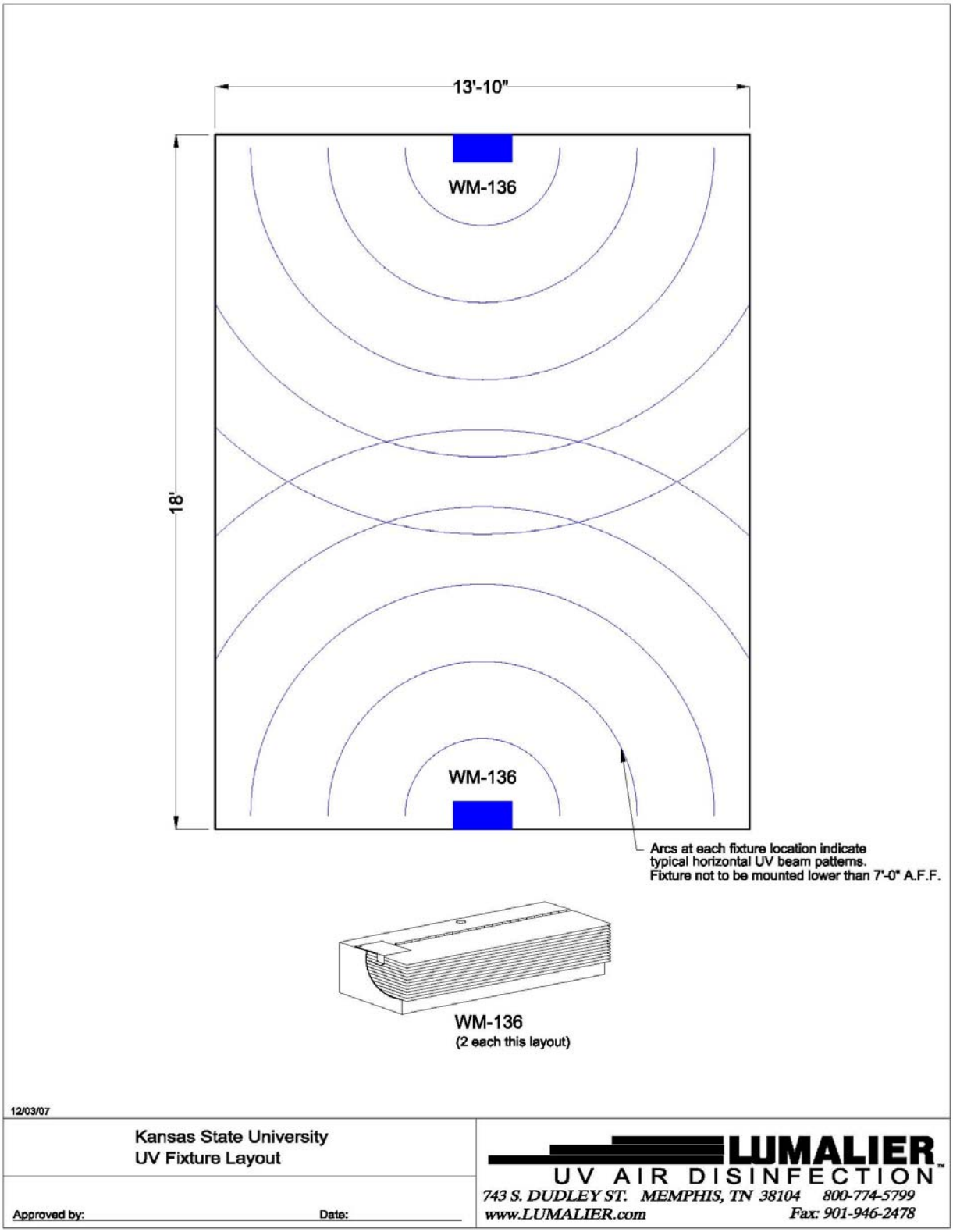


FRONT VIEW

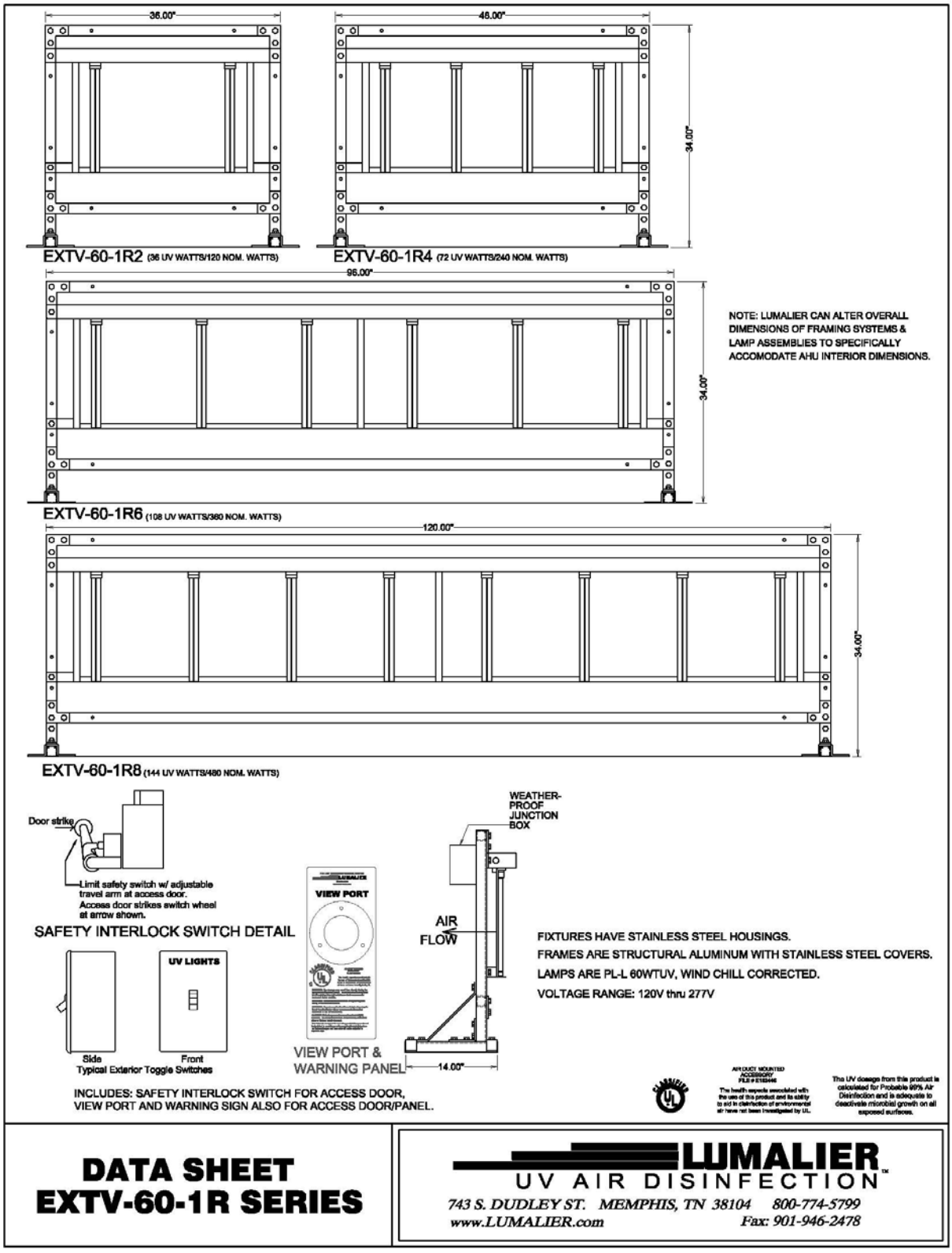
WM136
DATA SHEET

LUMALIER™
743 S. DUDLEY ST. MEMPHIS, TN 38104 800-774-5799
Fax: 901-946-2478 www.LUMALIER.com

G.2 Data Sheet: Upper-Room UVGI Fixture Layout



G.3 Data Sheet: UVGI in AHU



Appendix H - Fan Energy Calculations

H.1 Fan Energy Calculation Table

H.2 Fan Chart: AHU-1

H.3 Fan Chart: AHU-2

H.1 Fan Energy Calculation Table

HVAC UNIT	AHU - 1 (No UVGI)	AHU - 1 (With UVGI)	AHU - 2 (No UVGI)
CRITERIA			
Design Airflow (CFM)	3,900	3,900	8,240
Total Mean S.P. (in. WG)	4.31	3.81	3.80
Hours of Operation	8760	8760	8760
Fan Efficiency	0.522	0.522	0.629
Motor Efficiency	0.885	0.885	0.885
Total Fan Energy (KWH)	**37,446**	**33,102**	**57,888**

General Notes:

1.) Fan data from McQuay Skyline AHU selections

2.) Motor efficiency from Baldor Electric Company

Static Pressure Calculations:

- Assume 5% loss in CFM on systems without UVGI (as described in paper)
- Assume Total Mean Static Pressure (S.P.) by McQuay represents that of AHU - 1 (with UVGI)

- AHU - 1 (No UVGI):

  3,900CFM x 0.95 = 3,705CFM

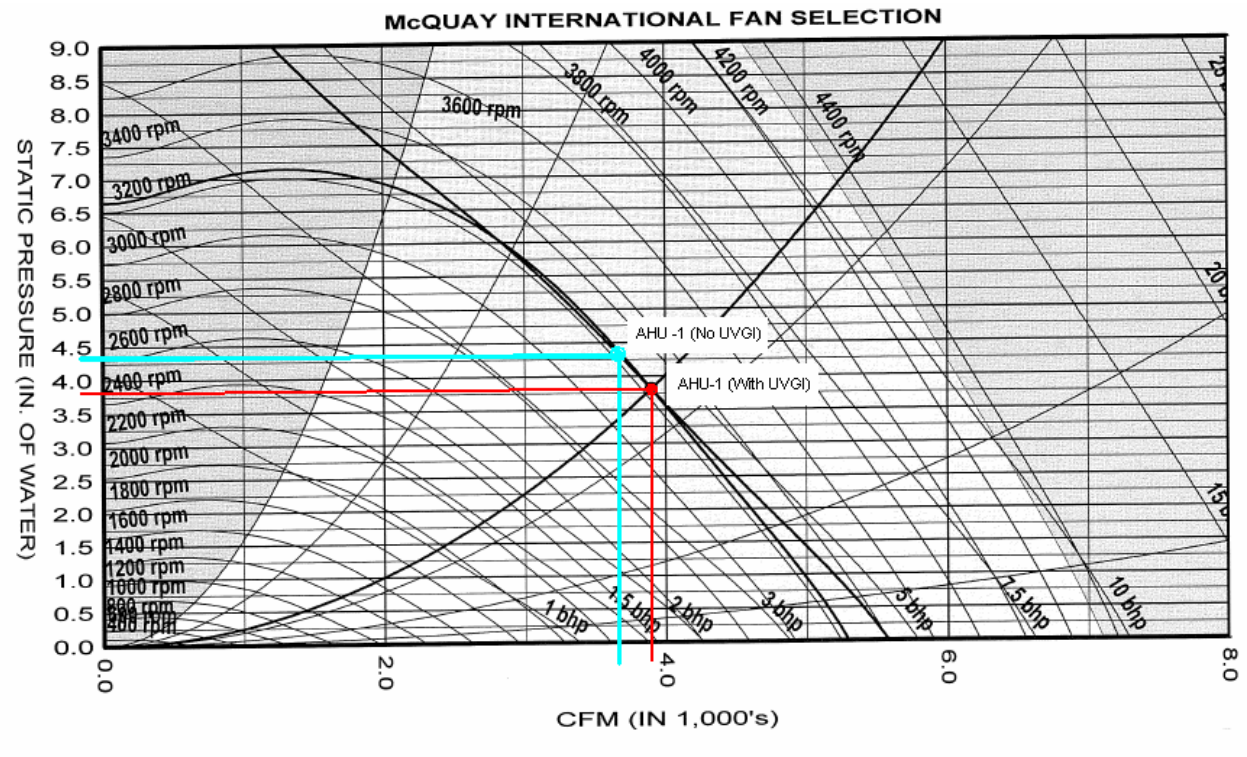
  Based on Fan Chart (Appendix H.2), Total Mean S.P. = 4.31 in. WG

- AHU - 2 (No UVGI):

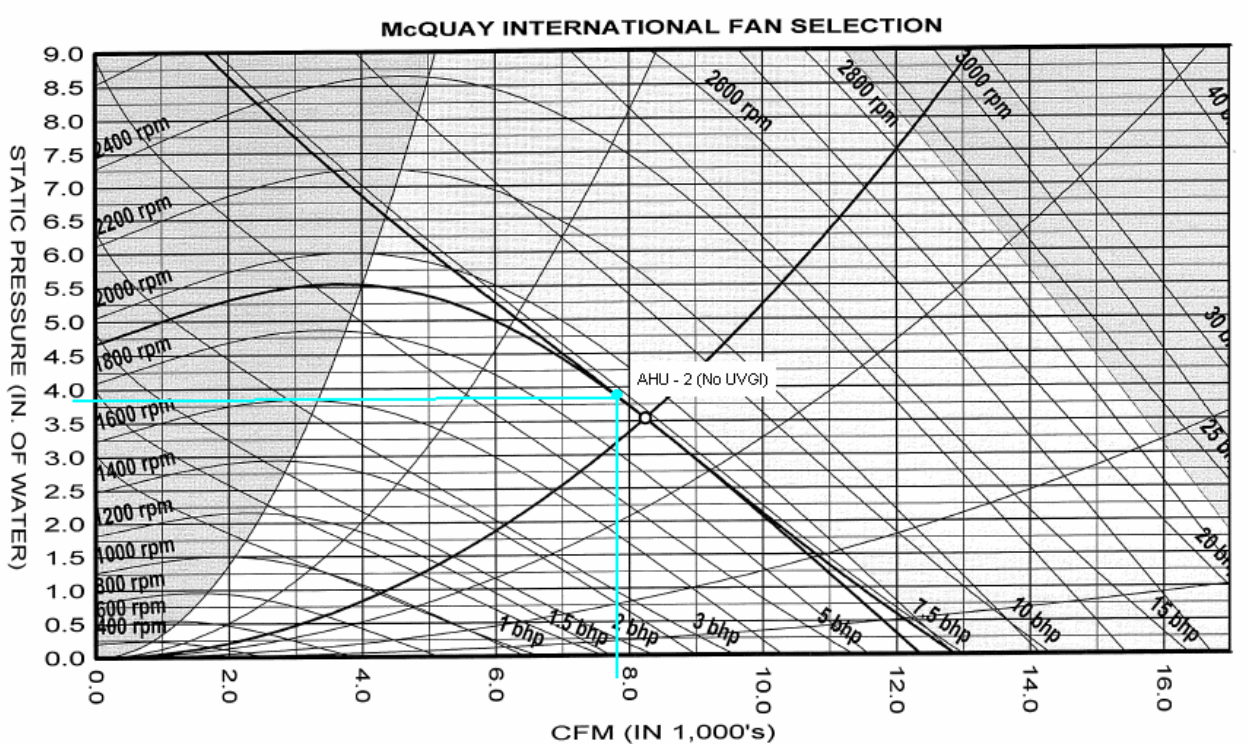
  8,240CFM x 0.95 = 7,828CFM

  Based on Fan Chart (Appendix H.3), Total Mean S.P. = 3.80 in. WG

H.2 Fan Chart: AHU-1



H.3 Fan Chart: AHU-2



Appendix I - Ductwork Sizing

Sizing Assumptions:

- Main ductwork: 0.10” S.P./100’
- Branch ductwork: 0.08” S.P./100’
- Return Air ductwork: 0.05” S.P./100’
- Exhaust Air ductwork: 0.08” S.P./100’

- Based on friction loss method of sizing
- S.P. = Static Pressure

Appendix J - Permission Releases

Date: Mon, 7 Jan 2008 11:19:57 -0500
From: Health Care Guidelines <Healthcareguidelines@aia.org>
To: jeremy@ksu.edu
Subject: RE: Republication Release of table from Guidelines for Design and Construction of Health Care Facilities

Thank you for inquiring about permission to publish Table 2.1-3 of the 2006 edition of the Guidelines in your research paper. I am told by the AIA general counsel's office that this use is generally acceptable under copyright rules.

The Health Guidelines Revision Committee (the multidisiciplinary, consensus body that updates the content of the Guidelines) would find the results of your research useful. We would appreciate it if you would share a copy of your finished paper for consideration by the committee.

Let me know if you have any questions about the Guidelines or its revision process.

Pamela James Blumgart
Development Editor
Knowledge Resources
The American Institute of Architects
1735 New York Avenue, NW
Washington, DC 20006
202.626.7367
fax 202.626.7425
pblumgart@aia.org

For more about the Guidelines, visit www.aia.org/aah_gd_hospcons or www.fgi-guidelines.org. An errata sheet for the 2006 edition is available on these sites, as well as much other information about the book and the revision process.

-----Original Message-----
From: jeremy@ksu.edu [mailto:jeremy@ksu.edu]
Sent: Sunday, January 06, 2008 5:04 PM
To: Health Care Guidelines
Subject: Republication Release of table from Guidelines for Design and Construction of Health Care Facilities

Dear AIA,

I am a Master's student at Kansas State University requesting the republication release of Table 2.1-3 (pg 133) from "Guidelines for Design and Construction of Health Care Facilities, 2006 edition" (ISBN 1-57165-013-X). The request is for education purposes of completing a Master of Science report with the possibility of publication.

Sincerely,

Jeremy Dreiling
Kansas State University
785.650.7394
jeremy@ksu.edu

Date: 8 Jan 2008 11:49:03 -0700
From: CDC-INFO <CDCINFO@cdc.gov>
To: jeremy@ksu.edu
Reply-to: cdcinfo@cdc.gov
Subject: RE: Republication release of figures from DHHS (NIOSH) Pub. No. 2003-136

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L2MN/5457/mr

[THREAD ID:1-RTM0Y] [SR No.:1-46738378]

-----Original Message-----

From: jeremy@ksu.edu
Sent: 1/7/2008 11:04:25 AM
To: cdcinfo@cdc.gov
Subject: Republication release of figures from DHHS (NIOSH) Pub. No. 2003-136

Dear NIOSH Publications,

I am a Master's student at Kansas State University requesting the release of figures from "Guidance for Filtration and Air-Cleaning Systems to Protect Building Environments from Airborne Chemical, Biological, or Radiological Attacks" - DHHS (NIOSH) Publication No. 2003-136.

The requested figures include Figure 3 (pg 10) and Figure 9 (pg 26).

The request is for educational purposes of a Master of Science report with the possibility of publication.

Sincerely,

Jeremy Dreiling
Kansas State University
785.650.7394
jeremy@ksu.edu

Date: 8 Jan 2008 12:08:23 -0700
From: CDC-INFO <CDCINFO@cdc.gov>
To: jeremy@ksu.edu
Reply-to: cdcinfo@cdc.gov
Subject: RE: Republication release of figure from DHHS (NIOSH) Pub. No. 2003-136

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For more information about building environments, please visit the CDC website:
http://www.cdc.gov/nceh/ehs/ETP/building.htm

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L3GZ-5457/mr

[THREAD ID:1-RTPK0] [SR No.:1-46744388]

-----Original Message-----

From: jeremy@ksu.edu
Sent: 1/7/2008 12:42:32 PM
To: "cdcinfo@cdc.gov" <cdcinfo@cdc.gov>
Subject: Republication release of figure from DHHS (NIOSH) Pub. No. 2003-136

Dear NIOSH Publications,

I am a Master's student at Kansas State University requesting the release of a figure from "Guidance for Filtration and Air-Cleaning Systems to Protect Building Environments from Airborne Chemical, Biological, or Radiological Attacks" - DHHS (NIOSH) Publication No. 2003-136.

The requested figure is Figure 4 (pg 11).

The request is for educational purposes of a Master of Science report with the possibility of publication.

Sincerely,

Jeremy Dreiling
Kansas State University
785.650.7394
jeremy@ksu.edu

Date: Wed, 09 Jan 2008 14:59:56 -0700
From: Jim Bolton <jim.bolton@iuva.org>
To: jeremy@ksu.edu
Cc: kathy.harvey@iuva.org
Subject: FW: Release of figures and tables from IUVA Draft Guidelines

Jeremy,

You have IUVA's permission to reproduce these figures and tables providing that you indicate thatyou properly cite the source of these items in your documents.

Jim

James R. Bolton, Ph.D.
Editor, IUVA News
Executive Director
International Ultraviolet Association
Home Office: 628 Cheriton Cres., NW, Edmonton, AB, Canada T6R 2M5
Tel: 780-906-1012 (cellular); Tel: 780-439-4709; Fax: 780-439-7792
Email: jim.bolton@iuva.org

==========

-----Original Message-----
From: Kathy Harvey [mailto:kathy.harvey@iuva.org]
Sent: Monday, January 07, 2008 8:29 AM
To: 'Jim Bolton'
Subject: FW: Release of figures and tables from IUVA Draft Guidelines

Jim,

Could you respond to this person?

Kathy

Kathy Harvey

Office Manager - Head Office
International Ultraviolet Association
P.O. Box 29060, Barrie, ON, Canada L4N 7W7
Tel: 705-812-2146; Fax: 705-812-2147
Email: Kathy.Harvey@iuva.org
Website: WWW.IUVA.ORG

-----Original Message-----
From: jeremy@ksu.edu [mailto:jeremy@ksu.edu]
Sent: January 6, 2008 4:41 PM
To: kathy.harvey@iuva.org; kevin.wright@kaizendenki.com
Subject: Release of figures and tables from IUVA Draft Guidelines

Dear IUVA,

I am a Master\'s student at Kansas State University requesting the release of figures and tables from \"IUVA Draft Guideline IUVA-G01A-2005\" and \"IUVA Draft Guideline IUVA-G03A-2005\" for use in my Master of Science report.

From \"IUVA Draft Guideline IUVA-G01A-2005,\" I am seeking release of Figure 3.1, Figure 3.8 and Table 9.1.

From \"IUVA Draft Guideline IUVA-G03A-2005,\" I am seeking release of Figure 2.1.

The request is for educational purposes with the possibility of publication.

Sincerely,

Jeremy Dreiling
Kansas State University
785.650.7394
jeremy@ksu.edu

Date: Thu, 3 Apr 2008 17:21:44 -0400
From: "Giometti, Tony" <giometti@ashrae.org>
To: jeremy@ksu.edu
Subject: ASHRAE HVAC Design Manual Reprint Request

2 unnamed text/html 4.24 KB

Dear Mr. Dreiling,

I am replying to your request via post to use Table F-1 from the ASHRAE HVAC Design Manual for Hospitals and Clinics in your master's report.

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Sincerely,

Tony Giometti

Tony Giometti, Manager of Communications and Programs
American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
Direct Line: 678-539-1155 Fax: 678-539-2155 eMail: Giometti@ashrae.org Web: www.ASHRAE.org

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