UVGI for Cooling Coil Disinfection and Air Treatment

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1. Executive Summary

This report reviews the history and current literature on ultraviolet germicidal irradiation (UVGI) systems used for air and surface disinfection applications. Three of the most promising applications are addressed in this report:

1) Cooling Coil Disinfection
2) Hospital Air & Surface Disinfection
3) Hotel Air & Surface Disinfection

Cooling coil disinfection has proved to be a most economical application and can produce a payback in terms of energy savings of about two years or less. These savings result from reduced coil cleaning maintenance costs and energy savings due to improved heat transfer and reduced pressure losses from airflow through the coils. The use of UVGI on cooling coils tends to restore them to original design conditions and will maintain them in a clean state for as long as the UVGI system is operated. This report summarizes the available information on laboratory and field testing of such installations. Information on the energy savings and payback period of cooling coil irradiation are provided along with an example of the computation of a typical payback period. Draft guidelines on cooling coil irradiation systems from the International Ultraviolet Association are reviewed.

Applications in hospital or other health care facilities include cooling coil cleaning, medical equipment, surface disinfection in unoccupied areas, direct surgical site disinfection during procedures, and air disinfection in operating rooms, procedure rooms, delivery rooms, isolation rooms, patient wards, and general areas. The problem of hospital-acquired (nosocomial) infections is one that has never been brought under complete control, and that causes an undue number of fatal infections annually in the US, with concomitant economic costs. UVGI may be able to reduce many types of nosocomial infections, especially those that have an airborne route of transmission. This paper explores some of the various applications for air and surface disinfection that may assist hospitals in reducing nosocomial infection rates.

Hotels may obtain significant economic benefits both from the use of UVGI to keep cooling coils clean and from improvements in air quality, which will provide a better environment for both guests and employees. The kinds of problems encountered in large hotels that are amenable to UVGI solutions are addressed in this report, and data is summarized from some previous applications.

2. Introduction and Background

The effects of ultraviolet light on microorganisms were discovered in the 1800s and several scientific studies on UV were published over a century ago. The first studies that attempted to quantify the effects of UV irradiation of microorganisms were published in the 1920s (Bedford 1927, Gates 1929). In these studies the disinfection rates for bacteria were determined in terms of the UV irradiance and dose. Luckiesh et al (1949) appears to have been the first to publish usable data on the irradiation of molds.

By 1950 it had been established that UV irradiation was effective at disinfecting both air and surfaces, and engineering applications were being developed. General Electric catalogs detailed many UV applications including various methods of installing UV lamps inside ducts and air conditioners (Buttolph and Haynes 1950, GE 1950). At this time it was not generally known that mold growth on cooling coils could cause respiratory problems. In 1954 it was demonstrated by Harstad et al (1954) that installation of UV lamps in air conditioners would reduce airborne contamination. It was further noted in this published study that microorganisms were impinging upon internal AHU surfaces.

It had been realized as early as 1958 that bacteria could grow on cooling coils (Walter 1969). The first evidence that air cooling equipment could actually cause respiratory infections was presented by Anderson (1959) when an air cooling apparatus was found to be contaminated with microbial growth. This very same concern had been raised in hospital environments since about 1944 but the possibility of growth of bacteria on air-conditioning cooling coils wasn't conclusively demonstrated until 1964 (Cole et al 1964). The growth of microbes on other equipment like filters and dust inside air-conditioning ducts was first demonstrated by Whyte (1968). The fact that microbes growing in air handling equipment could be disseminated by ventilation systems and cause respiratory infections became widely recognized in the late 1960s and early 1970s in both the medical and engineering fields (Banaszak et al 1970, Schicht 1972, Zeterberg 1973). It was widely known at this time that microbial growth could occur anywhere that air came into contact with moisture (Gunderman 1980, Ager and Tickner 1983, Spendlove and Fannin 1983).

The first UVGI system designed specifically for disinfecting the surfaces of air handling equipment, including humidifier water and filters, was detailed by Grun and Pitz (1974). Luciano (1977) published a book detailing many applications of UVGI, including health care applications in which the UV lamps are specifically placed upstream of the cooling coils and downstream of the filters.

By the late 1970s it was understood that UVGI could be used to control microbial growth inside air handling equipment. In 1985 Phillips published a design guide in which the first definitive description of applications of UV lamps for the control of microbial growth on cooling coils were presented (Philips 1985). This design guide, "Germicidal Lamps and Applications" provides details of how to locate lamps at specific distances form cooling coils, and referred to

installations that were already in operation at the time. Apparently, Europeans had been using such systems prior to 1985 but no publications exist to document such applications.

In January of 1996 the first UVGI system in the U.S. designed for controlling microbial growth on cooling coils was installed by Public Service of Omaha (PSO) in Tulsa. Tom McKain of PSO reports that the idea of irradiating their fouled cooling coils came both from Dr. Richard Shaughnessy of Tulsa University (TU), and from a European professor who could not be identified (Kowalski 2003). PSO hired Steril-Aire to implement the system, which was found to be highly effective after studies by TU researchers. Steril-Aire later filed a patent, claiming they had invented the application of UVGI to microbial growth control.

Table 1 summarizes the critical events described previously insofar as they can be assigned any specific dates.

Table 1: Chronology of UVGI Systems Development

Years	Event
1870 (circa)	Bactericidal Effects of UV light discovered
1877	First demonstration of UV water disinfection (AWWA 1971)
1909	First UV applications for water disinfection
1916	First USA applications of UV for water disinfection
1920s	First studies on air and surface disinfection with UV (Bedford 1927, Gates 1929)
1936	First hospital air disinfection application (Hart 1936)
1937	First school air disinfection application (Wells 1955)
1944	Concerns first raised about microbial growth on cooling coils in hospitals (Cole 1964)
1949	Luckiesh demonstrates UV disinfection of mold on surfaces
1950	GE catalogs recommend placing UV lamps inside air conditioning units (Buttolph and Haynes 1950, GE 1950)
1954	Harstad et al (1954) demonstrate effectiveness of UV inside air conditioners
1958	Microbial growth on air conditioners linked to respiratory problems (Anderson 1959, Walter 1969)
1968	Growth of microbes on filters and dust inside air-conditioning ducts was first demonstrated by Whyte (1968).
1970s	Microbial growth on cooling coils becomes widely recognized (Banaszak et al 1970, Schicht 1972, Zeterberg 1973)
1974	Grun and Pitz detail the use of UV for internal AHU surface disinfection
1977	Luciano details installation of UV lamps in air handling units downstream of filters and upstream of cooling coils
1980s	Conditions for microbial growth inside HVAC equipment quantified (Gunderman 1980, Ager and Tickner 1983, Spendlove and Fannin 1983)
pre-1985	First cooling coil disinfection systems installed in Europe
1985	Phillips catalog details cooling coil disinfection system installation
early 1990s	Disinfection of cooling coils is widely understood and discussed by researchers
1995	Dr. Richard Shaughnessy discusses cooling coil irradiation at a seminar, attended by Public Service of Oklahoma (PSO)
January, 1996	PSO contracts Steril-Aire to install cooling coil disinfection system based on recommendations from others
February, 1996	Steril-Aire makes claims to have invented cooling coil UV disinfection

3. Microbial Disinfection Model

A microbial population subject to UV exposure will tend to decay exponentially over time. The survival fraction at any time t after exposure can be defined by the following single stage exponential decay equation:

$$S = e^{-kt} \tag{1}$$

where k = UV rate constant, $cm^2/\mu J$

Figure 1 illustrates the exponential decay curve on a logarithmic scale with various values of k. The slope of the logarithmic decay curve (the slope of the line in Figure 1) is called the rate constant. The rate constant will determine how fast the population decreases under exposure. The value of the rate constant depends on both the species and the UV irradiance.

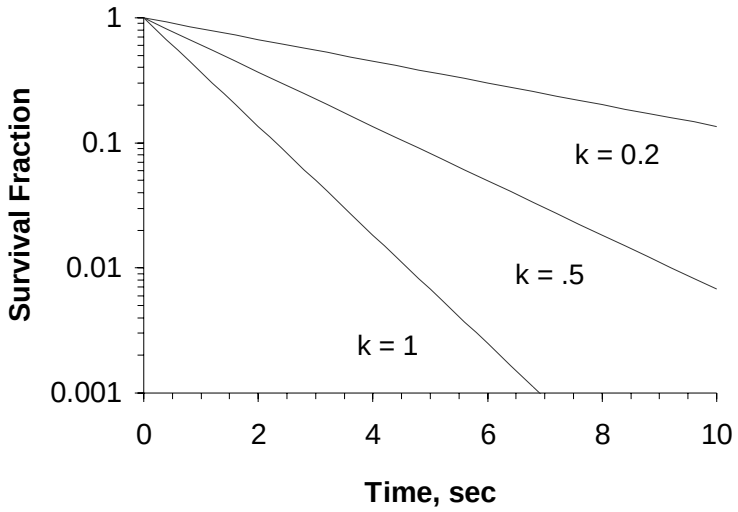

Figure 1: Survival curves for various rate constants.

The rate constant determines how fast the microbial population decays under the influence of UV. The UV irradiation may vary in intensity. The variation of irradiance is accounted for by a multiplier designated I. The classic exponential decay equation is then written as:

$$S = e^{-kIt} \tag{2}$$

In the form shown in equation (2), the rate constant k is known as the standard rate constant and it represents the susceptibility of the species for unit intensity only. In general, k is unique to each species. Often the quantity 'It' is combined into a single term called the dose. The dose can therefore be defined as:

$$D = It \tag{3}$$

When the dose is defined as in equation (3), the exponential decay equation is simply written as:

$$S = e^{-kD} \tag{4}$$

Sometimes a microbial population under UV exposure behaves as if it is two separate populations – one that succumbs rapidly and another that resists the factor. This effect has often been referred to as tailing or as nonlogarithmic survivor curves (Fujikawa and Itoh 1996, Moats et el 1971). Under these conditions the result is a two-stage decay curve. The two-stage curve is treated mathematically as if it were two distinct and separate populations that are simply added together. Each population has a unique rate constant, denoted by k_1 and k_2. The fraction of the population that is resistant is denoted by f, while the complementary fraction is denoted by (1-f), as follows:

$$S = (1 - f)e^{-k_1 It} + fe^{-k_2 It} \tag{5}$$

Figure 2 shows a survival curve fitted to equation (7.12) based on UVGI data for *Streptococcus pyogenes*. The curve was fitted by splitting equation (5) into two halves and fitting them individually to the split data set. The intercept of the second stage provided the population fraction.

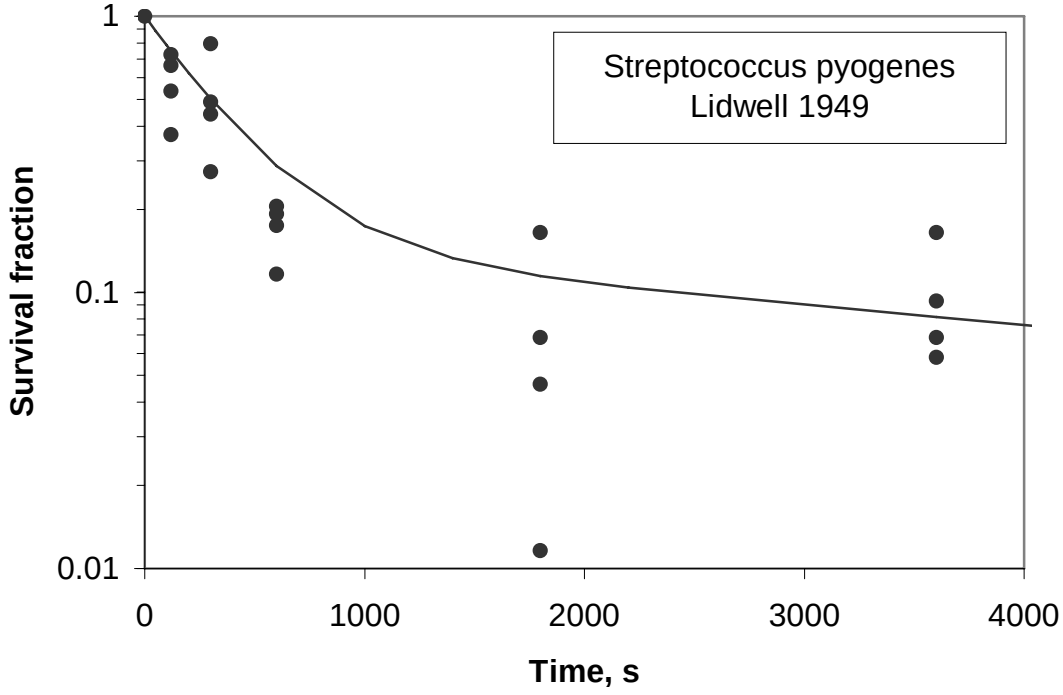

Figure 2: Survival of *Streptococcus pyogenes* under UVGI exposure. Two stage curve fitted to data from Lidwell (1949).

Data on two stage decay curves is limited and most of the available data for UVGI disinfection is for single stage curves only. A summary of microbial rate constants is provided in Appendix A.

4. Cooling Coil Disinfection Model

In typical cooling coil disinfection systems, a UV lamp, or array of UV lamps, is positioned so as to irradiate a coil surface. In the example shown in Figure 3 UV lamps are positioned so as to irradiate both the upstream and downstream sides of a cooling coil. Often, it is not possible to position lamps on both sides of a coil like this and only one side is irradiated. Lamps are often positioned in a crossflow arrangement in which the axis of the lamp runs perpendicular to the fins of the coil. The orientation of the lamp is not necessarily critical and lamps may be positioned horizontally, vertically, or at any angle relative to the coil surface. Lamp position will impact the irradiance levels at the coil surface but adjusting the total wattage, number of lamps, reflectivity, and other factors can compensate for less than optimum positioning of the lamp.

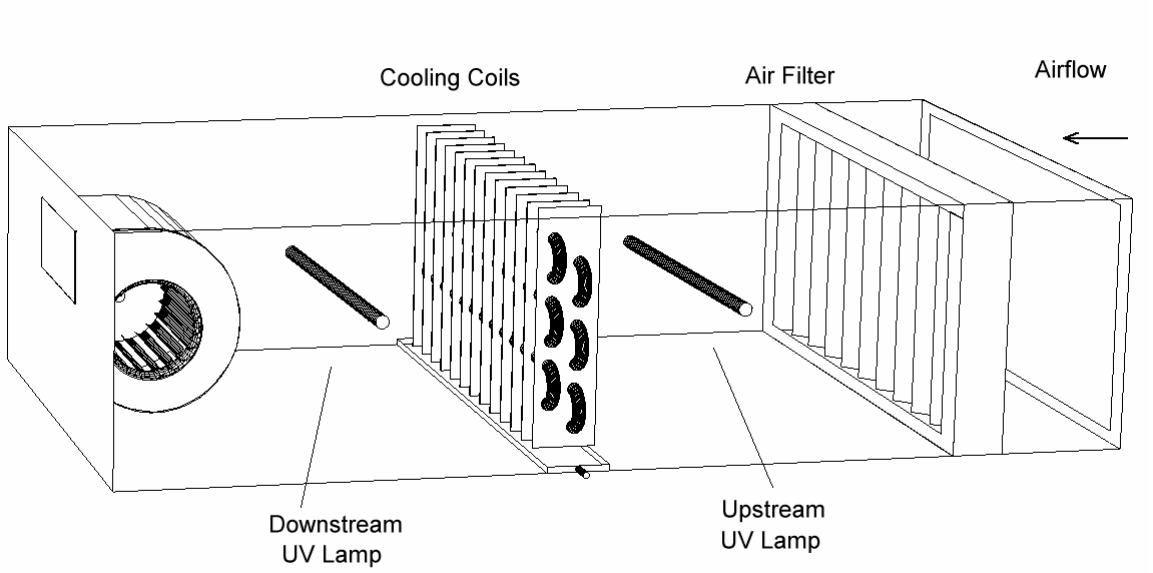

Figure 3: Air handling unit with UV lamps irradiating both upstream and downstream sides of the cooling coil.

When a single lamp is positioned with its axis parallel to the coil surface, the irradiance at any point on the coil surface can be determined using the view factor model of the lamp as a cylinder, as detailed by Kowalski et al (2000). Computer algorithms for this view factor model have been provided by Kowalski (2001 & 2003). The view factor model has been demonstrated to provide fairly accurate agreement with actual lamp irradiance measurements. Alternate lamp models have been proposed by others but there is either limited agreement with lamp data or a lack of quantitative data on the models (IESNA 2000, Krasnochub 2005). The view factor model can be used to generate irradiance profiles and contours such as those shown in Figure 4 and Figure 5, in which a single cylindrical lamp irradiates a rectangular cooling coil surface. The peak irradiance can be seen as a blunt outline of the cylindrical lamp.

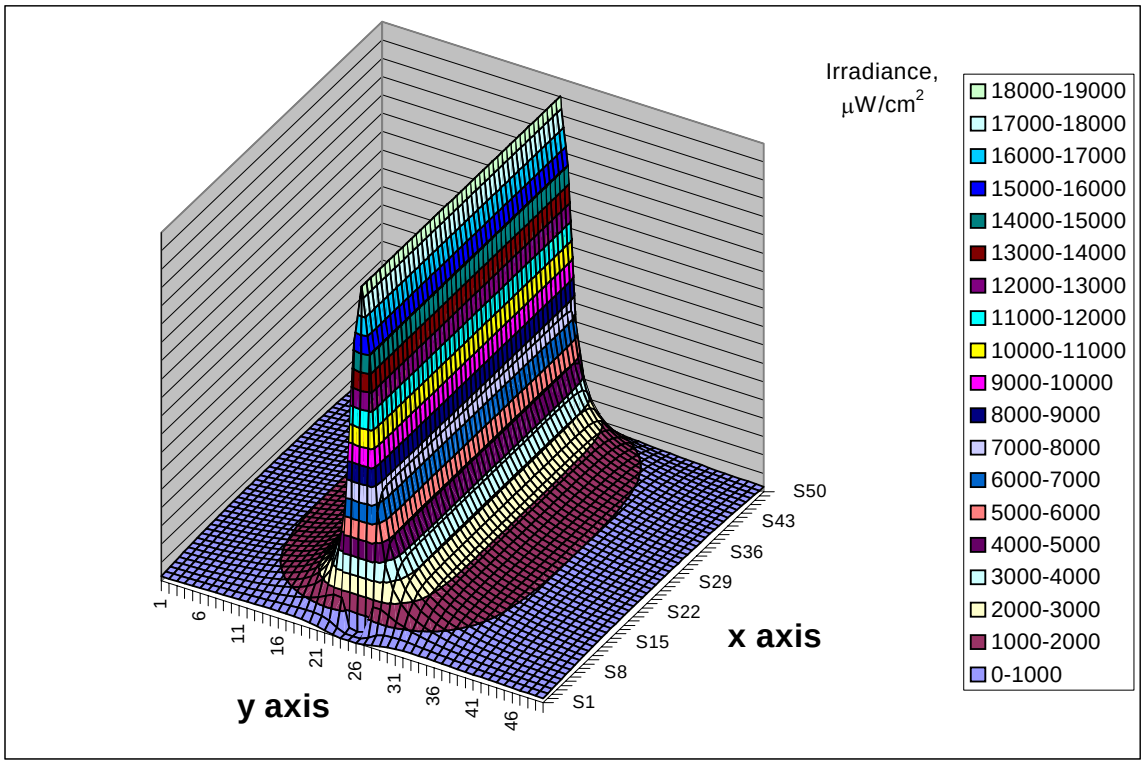

Figure 4: Example of irradiance profile on a cooling coil surface (x-y axes) from a single UV lamp located a short distance away.

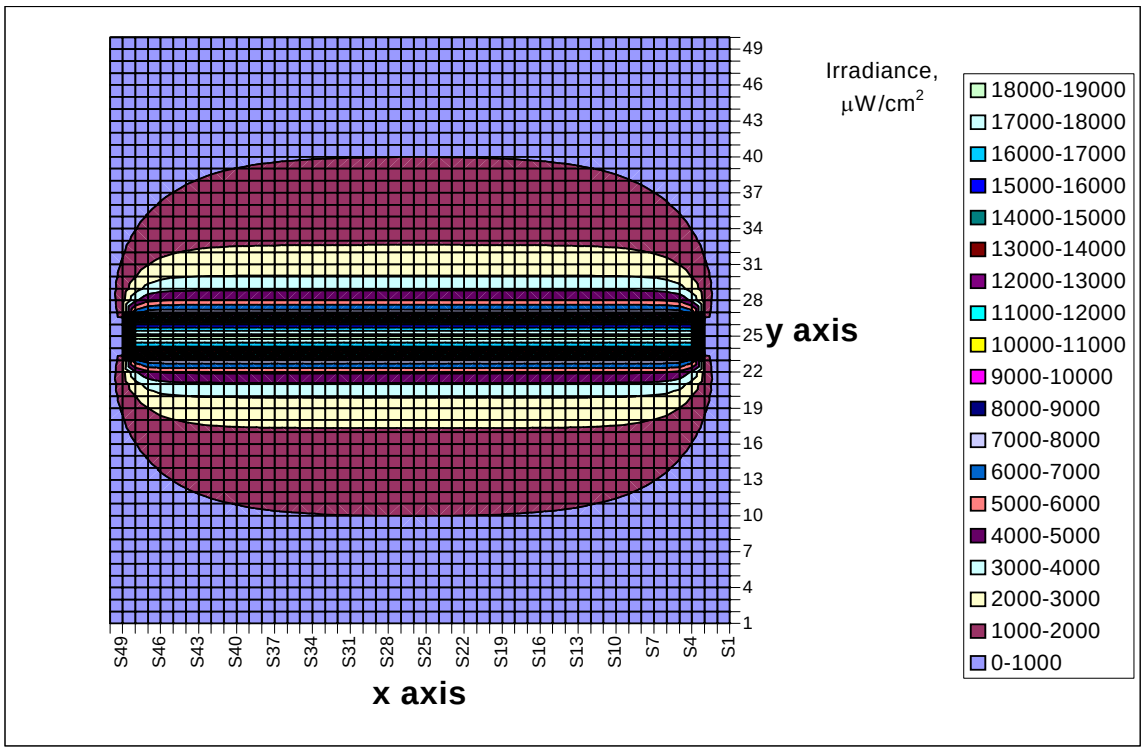

Figure 5: Irradiance contour on the cooling coil face (x-y axes) from the example in Figure 4.

Placing a UV lamp in front of a cooling coil entrance or exit plane will produce an irradiance contour on the leading edges or exit edges of the coil fins similar to that of Figure 5. Only the front surface (or back surface) irradiance levels can be predicted with certainty because determination of the irradiance within the cooling coil fins is an exceedingly complex problem that involves a limited field view factor and the reflective characteristics of the fins and coil tubes. At present, predictions of the surface irradiance must suffice as an indicator of the adequacy of UV exposure levels, but photometer measurements can also be used to confirm irradiance levels upstream and downstream. The ultimate confirmation of the adequacy of UV irradiance levels can only be obtained via surface sampling for spores. An alternative indicator of the effectiveness of UVGI may be coil performance, since the elimination of surface contamination should theoretically restore cooling coil performance to original design values.

Under UV exposure, the disinfection of cooling coil surfaces follows the basic mathematical decay models detailed in the previous section. Because the exposure times are extended in these types of surface disinfection systems, it is appropriate to use the two-stage decay equation to define the disinfection rates. The reason is that if a second stage does exist (i.e. for any mold or bacterial spore) it will likely become the only remaining stage after relatively brief initial exposure period. That is, the first stage will show rapid decay, after which only the second stage remains. Since the second stage becomes dominant in the long run, it is a better predictor than the single stage rate constant. However, few second stage rate constants are known with any certainty and predictive methods generally rely on theoretical values.

Figure 6 shows an example of a two stage decay curve of *Aspergillus niger* compared with predictions from a single stage model. The single stage model (in red) shows a log-linear decrease in microbial population over time, while the two-stage model (in blue) shows a second stage (a tail) becoming dominant after about 1000 seconds. It is clear that after extended exposure the single stage model will grossly overpredict the survival rate of the spores. This two stage behavior under prolonged exposure is typical for most microbes and indicates the need to use the two stage model when evaluating cooling coil surface disinfection. Data for the single stage is based on IESNA (2000) while the two stage curve is based on laboratory data from UVDI (2000).

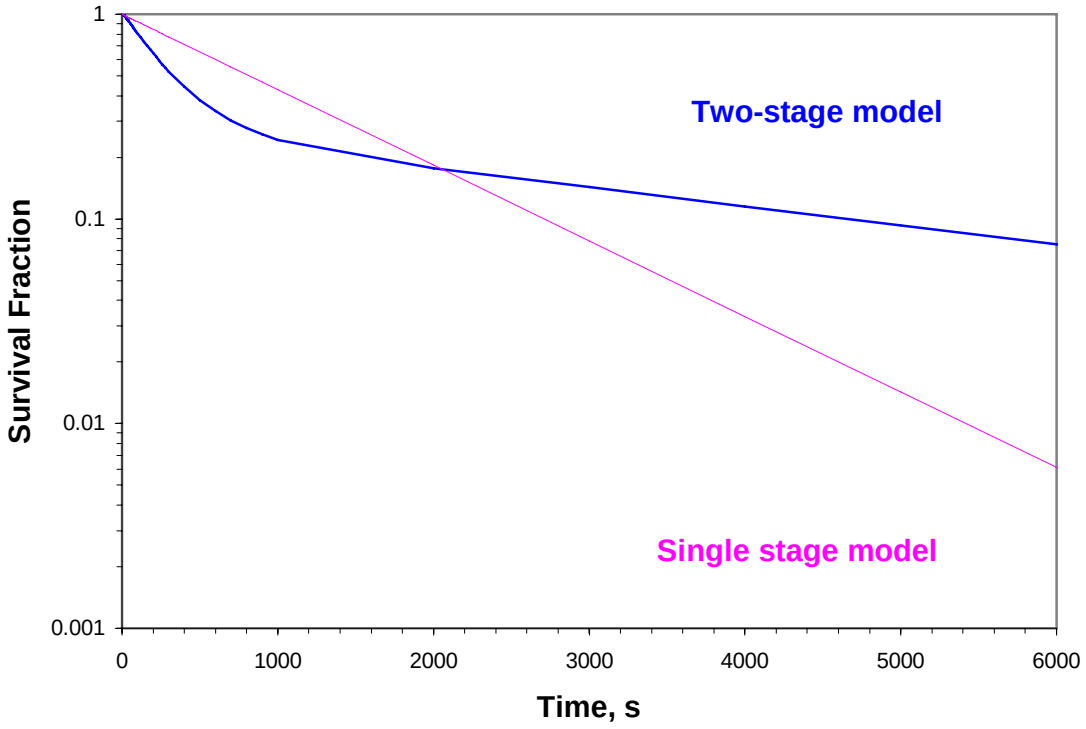

Figure 6: Comparison of a single stage model vs. a two stage model of the inactivation of *Aspergillus* spores under UV exposure of 50 μW/cm^2. The single stage model will underestimate the required dose for sterilization.

5. Performance of Cooling Coil Disinfection Systems

Although studies on the inactivation of mold spores and inhibition of mold growth by UV abound in the literature, information on the actual disinfection of cooling coils remains limited and reports of successful disinfection are primarily anecdotal, although some formal studies are underway (EPRI 2004, Shaughnessy et al 1999). There is, however, no reason to believe that the anecdotal reports are not accurate, and the indications are that disinfection of cooling coils with UV is so effective that payback periods of about 2-4 years are possible. That is, the cleaning of the coils under UV exposure proceeds so rapidly that fouled coils are restored to pristine condition and save energy and maintenance costs so effectively that the retrofit of a UV coil cleaning system pays for itself in about 2-4 years.

Theoretically, continuous exposure of cooling coil surfaces to UV should result in eradication of virtually all surface contamination within a few hours or days, depending on the irradiance levels. That is, any contamination on the exposed surface of the coils (entrance or exit respectively) should be sterilized rapidly. Figure 7 shows a system for which surface samples taken by the author indicated virtual sterilization of the leading edges after two weeks of operation.

Figure 7: A UVGI system installed in front (upstream) of a cooling coil that sterilized the front face of the coil after two weeks of operation.

Contamination on the internal surfaces of the cooling coil fins should also be sterilized over time, but it is difficult to predict how much time this might require. It does appear that, based on anecdotal field reports, that a few weeks or months is all that is required to restore coils to original design operating conditions, suggesting that internal coil contamination is sterilized in these time periods.

6. Economics of Cooling Coil Disinfection Systems

The economic savings that can result from the installation of a UV cooling coil disinfection system can be estimated by comparing the operating costs after installation with the operating costs before installation, minus the cost of installing and operating the UV system. Ideally, operating data would be drawn from field test results, but this necessitates installing such a system first. Little published data is available for installed systems but anecdotal evidence suggests that UV disinfection systems are fully capable of restoring a fouled cooling coil to approximately the original design operating conditions. The cost savings will then depend on how much coil fouling has occurred and how far the system capacity has been diminished in comparison with the original design conditions. Table 1 summarizes the basic costs and the basic savings of UV cooling coil disinfection systems.

Table 1: Costs vs. Savings of Cooling Coil Disinfection

Costs	Savings
First Cost of installation	Fan energy savings
Operating Cost of UVGI	Cooling energy savings
Maintenance costs of UVGI	Maintenance savings

The first cost of the UVGI system will always be known, as will the operating and maintenance costs, which consist of electrical energy consumption and lamp replacement. The heat added to the system by the lamps is generally negligible and can be ignored, and furthermore, in cold climates the heat becomes a credit but this will also be ignored. The energy savings will result from two effects, the first being the reduced pressure drop through the coils once the fouling is removed, and the second being the increased rate of heat transfer from the coils when the fouling film is gone. Both of these can be significant, as can the reduction or elimination of maintenance on the cooling coils. Since the coils will be maintained in a clean condition, there is likely to be no requirement for periodic cleaning of the coils. In fact, since the UV system will maintain the coils in pristine condition, the lifetime of the coil will likely be extended well beyond the normal lifespan of unirradiated cooling coils, but this aspect of the savings will be difficult to quantify until field data is accumulated from installations.

In order to estimate cost savings, it is necessary to assume that 1) the cooling coil is fouled, which is usually true if a system is being considered, and 2) the fouling will be completely eliminated and the coils restored to design condition, which is reportedly the usual case. Alternatively, a UV system may be installed on a brand new cooling coil, in which case the savings would have to be estimated based on the projected rate of fouling.

The cost savings in dollars of a UV cooling coil disinfection system can be written as:

$$Savings = \left(FE_F - FE_C\right) + \left(CE_F - CE_C\right) + \left(M_F - M_C\right) - FC_{uv} - OC_{uv} - MC_{uv} \qquad (1)$$

where FE_F = Fan Energy cost, Fouled ($)
FE_C = Fan Energy cost, Clean ($)
CE_F = Cooling Energy cost, Fouled ($)
CE_C = Cooling Energy cost, Clean ($)
M_F = Maintenance cost, Fouled ($)
M_C = Maintenance cost, Clean ($)
FC_{uv} = First Cost of UV ($)
OC_{uv} = Operating Cost of UV ($)
MC_{uv} = Maintenance Cost of UV ($)

The fan energy in kW is computed as follows:

$$FE = \frac{dP \cdot CFM}{6350(0.75 \cdot 0.75)} \cdot 0.7355 \quad (2)$$

where dP = pressure drop, in.w.g.
CFM = airflow, cfm
0.7355 = conversion factor from BHP to kW
0.75 = typical motor efficiency
0.75 = typical fan efficiency
6350 = conversion factor (in.w.g-cfm) to BHP

The fan energy savings is then the fan energy in the operating condition (fouled coils) minus the fan energy under design conditions.

The cooling energy savings in kW is computed as follows:

$$CE = \left(\frac{CL}{3412 \cdot COP} \right) \quad (3)$$

where CL = the capacity loss due to fouling, Btuh
COP = Coefficient of Performance
3412 = conversion from Btuh to kW

The COP can be computed as the seasonal energy efficiency ratio (SEER) divided by 3.412. The typical value for the SEER is about 9 or 10, and the respective COP would be about 2.64 – 2.93.

The maintenance cost Before, M_B, can vary and depends on local facility procedures. Cooling coil maintenance is typically a few hours of labor a year, and may vary from a few hundred to a few thousand dollars. A reasonable estimate for small cooling coil units might be about M_B = $500 a year. Presumably, there will be no maintenance cost After, or M_A = 0.

The first cost of the UV system, FCuv, will be established at the beginning of any project and no estimates can be provided. The operating cost, OC_{uv}, of the UV system is simply the electrical energy consumed by the lamp and ballast. The energy cost can be written as follows:

$$OC = \frac{W \cdot 8760}{1000} P_c \quad (4)$$

where W = total watts of power consumed by lamp fixture
P_c = power charge (typically 0.08 – 0.1 $/kWh)
8760 = hours of operation per year (continuous assumed)
1000 = conversion from kW to W

The maintenance cost of the UV system consists of the annual replacement of the UV lamps, which is simply the cost per lamp times the number of lamps. This cannot be estimated in advance and will depend on the particular project.

Application of the above equations can be demonstrated through an example of a typical cooling coil disinfection system. Consider a system with the following parameters:

- Airflow, cfm - 48,500CFM
- Cooling Coil leaving air temperature: 52 degrees F.
- Cooling Coil pressure drop, 0.75 in.w.g.
- UV wattage – 552W UVC output.
- UV lamp fixture first cost - $3,528 per total number of fixtures per coil.
- UV lamp installation labor cost, $1000.
- UV lamp replacement bulb cost - $1,800 annually.
- Annual hours of cooling – approximately 4,500 hours per year.
- Cost per kWh, $0.09.
- COP = 4.1 (typical for chilled water system)
- Cooling Load (design), 1,500,000 Btuh (assumed)

Keikavousi (2004) reports that a 27 year old system retrofitted with UV had a reduction in fan static pressure from 1.8 iwg to 0.7 iwg. The fan energy in our example above assumes only a fouled condition of 0.9 iwg, reducing to 0.75 after UV installation. The fan energy under design conditions is:

$$FE = \frac{0.75 \cdot 48{,}500}{6350(0.75 \cdot 0.75)} \cdot 0.7355 = 7.49 \text{ kW}$$

The fan energy under fouled conditions (assumed 0.9 in.w.g.) is:

$$FE = \frac{0.9 \cdot 48{,}500}{6350(0.75 \cdot 0.75)} \cdot 0.7355 = 8.988 \text{ kW}$$

The fan energy savings (Fouled-Clean) is:

$$FE_{F-C} = (8.988 - 7.49)4500 \cdot 0.09 = 607\,\$$$

The cooling energy (design operating conditions) is:

$$CE = \left(\frac{1{,}500{,}000}{3412 \cdot 4.1}\right) = 107.2\,\text{kW}$$

Assuming a 20% loss due to fouling, the energy savings would be:

$$CE_{F-C} = (0.20 \cdot 107.2) \cdot 4500 \cdot 0.09 = 8685\,\$$$

The operating costs are:

$$OC = \frac{552 \cdot 8760}{1000} 0.09 = 435\,\$$$

The total savings can then be summed up as follows, assuming $1000 in maintenance savings:

$$Savings = (607) + (8685) + (1000) - 3528 - 435 - 1800 = 4529\,\$$$

The payback (PB) period can be approximated by dividing the initial cost by the annual savings as follows:

$$PB = \frac{3528}{4529} = 0.8 \text{ years}$$

Some examples of estimates of the savings that might be accrued from the use of cooling coil disinfection systems in health care facilities are provided in Appendix D and Appendix E. In Appendix D summaries for six facilities are provided showing inpatient and outpatient occupancies, number of clinical procedure rooms and number of procedures performed. Appendix E provides estimated costs for cooling coil disinfection systems, in-duct UV systems, and operating room UV systems, along with estimated savings based on assumptions regarding nosocomial infection rates and operating costs. Although the available data on nosocomial infection rates due to airborne infections is not specific enough to isolate the true savings that might be anticipated, the ball-park figures provided in Appendix E clearly show the potential savings are great and that payback periods computed from these estimates would be in the range of 1-2 years or less, similar to the payback periods demonstrated previously.

7. Guidelines for Cooling Coil Disinfection Systems

Several guidelines have been recently introduced, or are in preparation that address the use of UV for either cooling coil disinfection or air disinfection (GSA 2003, NIOSH 2005, IUVA 2005). Based on the literature, including draft guidelines from IUVA (2005), and the analysis previously presented, certain basic design guidelines can be summarized. These are as follows:

- **Guidelines for Cooling Coil Disinfection**
- Minimum Filtration: MERV 6
- Recommended Filtration: MERV 8-11
- Maximum air velocity of between 400-500 fpm
- Maximum air temperature between 40^oF-110^oF
- Maximum ballast operating temperature of 40^oC or 50^oC (104^oF or 122^oF) depending on ballast
- Lamp placement: upstream, downstream, or both sides of coils
- Lamp distance from coil face: 1-4 feet (30-120 cm)
- **Exposed Coil Surface**:
    - Recommended coil average irradiance: 50-500 $\mu W/cm^2$
    - Minimum coil irradiance: 50 $\mu W/cm^2$
    - Minimum coil irradiance in any corner or side: 10 $\mu W/cm^2$
- **Opposite Coil Surface (if unexposed)**
    - Recommended coil average irradiance: 50-100 $\mu W/cm^2$
    - Minimum coil average irradiance: 10 $\mu W/cm^2$
    - Minimum coil irradiance in any corner or side: 1 $\mu W/cm^2$

The above recommendations are preliminary (per IUVA 2005) and should not be considered to be strict requirements as these matters are still under study. In addition to the above guidelines, it is recommended that UV lamp ballasts be placed externally if possible, or, if placed internally, be shielded from any heat sources. All electrical wiring should be in accordance with UL/ETL requirements. Alarms or disconnect switches should be included to disengage the UV lamps if an access door is opened. Warning signs should be placed in the vicinity and proper training given to maintenance personnel. UV lamps should be handled with care and used lamps disposed of in accordance with regulations regarding mercury content.

As verification of coil disinfection, surface sampling for fungi and/or bacteria could be performed before UV lamp installation, and then follow-up testing could be performed about 2 weeks or any time later. Major reductions in coil contaminants would suggest effective disinfection while the absence of all fungal contamination would indicate complete sterilization. As an alternative to microbiological testing, coil performance could be monitored over time to verify that the cooling coil heat transfer and pressure drop characteristics are being returned to design conditions, a process that requires an unknown amount of time, but for highly fouled coils it may require weeks or months.

8. Hospital Air & Surface Disinfection Systems

UVGI systems have been in use in some operating rooms since at least 1937 (Hart and Sanger 1939). Reductions in post-operative infection rates of about 24-44% have been reported (Goldner and Allen 1973). Duke University has successfully used overhead UVGI systems to maintain a low level of orthopedic infections (Lowell et al 1980). Upper room UVGI systems have been used at The New England Deaconess Hospital, The Infant and Children's Hospital in Boston, The Cradle in Evanston, and St. Luke's Hospital in New York, to reduce surgical site infections by a net average of 68%, and for the control of respiratory infections, which decreased by a net average of 50% (Overholt and Betts 1940, Del Mundo and McKhann 1941, Sauer et al 1942, Higgons and Hyde 1947). The Home for Hebrew Infants in New York successfully brought a halt to a Varicella epidemic using UVGI (Wells 1955). Limited mention is made in most health care literature of UVGI, although some recent guidelines have acknowledged its potential effectiveness (CDC 2003, ASHRAE 2003).

A growing list of anecdotal reports, and some clinical studies, have addressed the apparent effectiveness of UVGI systems in health care facilities. These reports address the usefulness of UVGI in disinfecting cooling coils, reducing energy costs associated with cooling coils, controlling respiratory infections and complaints, sterilizing sources of TB, SARS, and other bacteria and viruses, addressing bioterrorism concerns, and controlling mold in homes. A summary of these reports, culled from engineering trade magazines, journals, Internet and paper news media, and private reports has been included in Appendix F.

The use of UVGI to clean cooling coils in hospital ventilation systems has the same economic benefits as those addressed in the previous sections of this report. However, the removal of mold and bacterial slime from cooling coils is much more important in the hospital environment which should be kept cleaner than the average commercial office building. That is, environmental bacteria and mold spores may pose hazards to patients in hospitals, especially those with impaired immune systems or burn victims. Microbial levels on surfaces and in the air need to be lower in hospitals due to the higher risks of nosocomial infection. The disinfection of cooling coils is one way to reduce microbial loading in hospitals. In theory, the requisite levels of air filtration should keep microbial contamination from accumulating on cooling coils, which are typically downstream of the filters, but casual inspections of hospital cooling coils and ductwork typically show levels of biocontamination above and beyond what would be expected with such high efficiency filters installed. The reasons for the apparent penetration of the filters are unclear but may be due to poorly fitting filters, leaking filters "bypass factor", or the performance of filter change-outs while the ventilation system continues to operate. The installation of a UVGI cooling coil disinfection system should resolve such problems and contribute to net reductions of biocontamination in hospitals. The use of dual purpose UVGI systems that both clean coils and disinfect air, should also enhance the

reductions of microbial loading.

Nosocomial infections include many diverse diseases, the sources and etiology of which are uncertain at present. Table 3 summarizes nosocomial agents that have the potential to transmit by the airborne route. The majority of nosocomial agents are potentially airborne, although most of the actual transmission is probably through direct contact (Kowalski 2005). The degree to which a cooling coil disinfection system will decrease nosocomial infections is probably quite limited, although the cost savings alone should justify such systems in any health care facility. The degree to which air and surface disinfection systems can reduce nosocomial infections is much more quantifiable, and a number of studies have been performed in this regard.

Table 3: Nosocomial Agents with Airborne Transmission Potential

AIRBORNE PATHOGEN	TYPE	PRIMARY INFECTION CAUSED	Annual Cases	Annual Fatalities
Varicella-zoster virus	C	chickenpox	common	250
Streptococcus pyogenes	C	scarlet fever, pharyngitis	213,962	-
Streptococcus pneumoniae	C	lobar pneumonia, sinusitis, meningitis	500,000	50000
Staphylococcus aureus	E	staphylococcal pneumonia, opportunistic	2,750	-
Serratia marcescens	E	bacteremia, endocarditis, pneumonia.	479	-
SARS virus	C	Severe Acute Respiratory Syndrome	(10)	(?)
Rubella virus	C	rubella (German measles)	3,000	none
Rhizopus stolonifer	NC	zygomycosis, allergic reactions	rare	-
Respiratory Syncytial Virus	C	pneumonia, bronchiolitis	common	rare
Pseudomonas aeruginosa	NC	pneumonia	2,626	-
Pneumocystis carinii	NC	pneumocystosis	rare	rare
Parainfluenza virus	C	flu, colds, croup, pneumonia	common	-
Nocardia brasiliensis	NC	nocardiosis	uncommon	-
Nocardia asteroides	NC	nocardiosis	uncommon	rare
Mycobacterium tuberculosis	C	tuberculosis, TB	20,000	-
Mucor plumbeus	NC	mucormycosis, rhinitis	rare	rare
Moraxella	E	otitis media, opportunistic	rare	0
Measles virus	C	measles (rubeola)	500,000	rare
Legionella pneumophila	NC	Legionnaire's Disease, opportunistic	1,163	10
Klebsiella pneumoniae	E	opportunistic, pneumonia	1,488	-
Influenza A virus	C	flu, secondary pneumonia	2,000,000	20000
Histoplasma capsulatum	NC	histoplasmosis, fever, malaise	common	-
Haemophilus parainfluenzae	E	conjunctivitis, pneumonia, meningitis	common	-
Haemophilus influenzae	C	meningitis, pneumonia, endocarditis	1,162	-
Cryptococcus neoformans	NC	cryptococcosis, cryptococcal meningitis	high	rare
Corynebacterium diphtheriae	C	diphtheria, toxin produced.	10	-
Coccidioides immitis	NC	coccidioidomycosis, valley fever	uncommon	-
Chlamydia pneumoniae	C	pneumonia, bronchitis, pharyngitis	uncommon	-
Cardiobacterium	E	opportunistic infections, endocarditis	rare	-
Burkholderia pseudomallei	NC	meliodosis, opportunistic	rare	rare
Burkholderia mallei	NC	Glanders, fever, opportunistic	-	none
Bordetella pertussis	C	whooping cough	6,564	15
Blastomyces dermatitidis	NC	blastomycosis, Gilchrist's Disease	rare	-
Aspergillus	NC	aspergillosis, alveolitis, asthma	uncommon	-
Alcaligenes	E	opportunistic	rare	rare
Acinetobacter	E	opportunistic/septic, meningitis	147	-

Abbreviations: C = Communicable, NC = Noncommunicable, E=Endogenous.

SARS virus C Severe Acute Respiratory Syndrome

There are some aspects of the savings that could be expected in health care facilities that cannot be generalized or quantified exactly, such as the reduction in worker illness (nosocomial worker illnesses are an ongoing problem in health care facilities for which rates and costs are unknown at present), and possible reductions in insurance costs once such air cleaning systems are installed. The estimated costs in these examples, including the labor costs and energy costs, are based on assumptions and should not be construed to represent the actual costs for any specific installation, which need to be independently determined. The geographic area can also impact the energy

costs through climate. One related report, that addresses air cleaning and bioterrorism, is a guideline from FEMA on the subject of insurance costs that may also be used to address reductions of naturally occurring diseases and possible savings from UVGI (FEMA 2003). UVGI may also allow for the use of lower pressure drop filters (ACEEE 2005).

9. Hotel Air & Surface Disinfection Systems

Hotels are often unique in that the living quarters are typically small and do not always have direct supply air, only air conditioning or heaters under occupant control. Hotels will typically have one or more central air handling units providing air to the lobbies, hallways, restaurants, and other large areas. This supply air is intended to infiltrate into the individual hotel rooms. Sometimes the individual air conditioning units may have individual outside air dampers.

Although the central air handling units in hotels may have medium-to-low efficiency filters, the room air conditioners rarely have anything more than a simple dust filter fabric. As a result, these air conditioners tend to accumulate spores over time. With the presence of condensation, these spores may even amplify and lead to air quality problems in rooms.

Regular maintenance of room air conditioners normally involves removing the unit and cleaning with an acid or fungicide once a year. In a 200-400 unit hotel where only one or two units can be cleaned per day, this means that about half the units will have months of accumulation during the times of the year they need it most – summer and fall. As a result, hotel patrons often discover that when they turn on the air conditioner it produces a somewhat unpleasant odor.

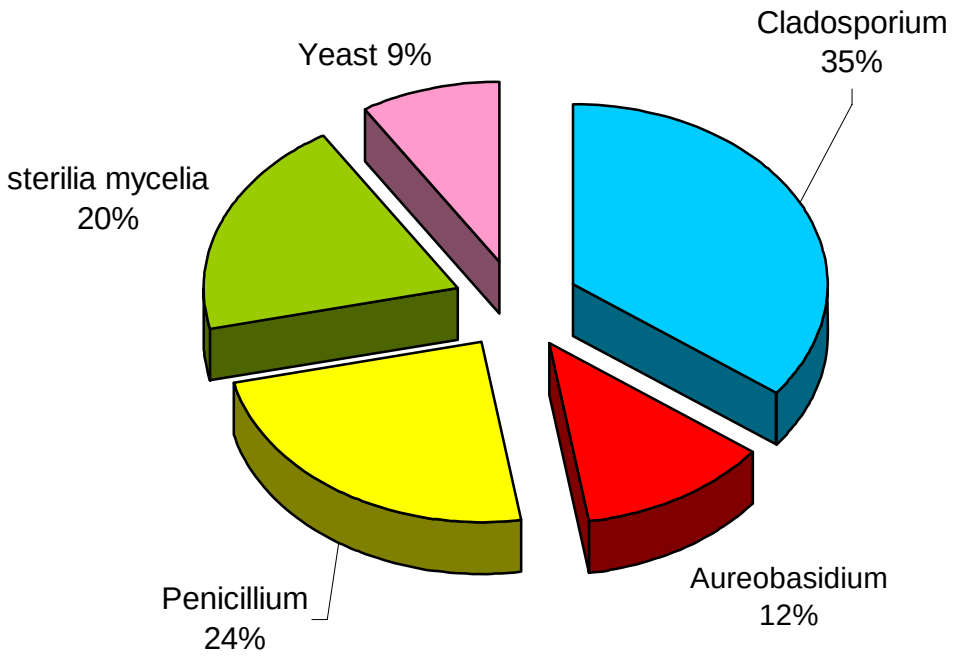

Figure 44: Fungal contamination of main air handling unit cooling coils of a large hotel. Based on author's data (Kowalski 2006).

Figure 30.6 shows the results of a survey taken by the author of the air in two hotel rooms in winter, in a hotel that had experienced water damage from a leaky roof. Although outdoor spore levels were less than 10 cfu/m^3, indoor spore levels in one of the rooms exceeded a few hundred cfu/m^3.

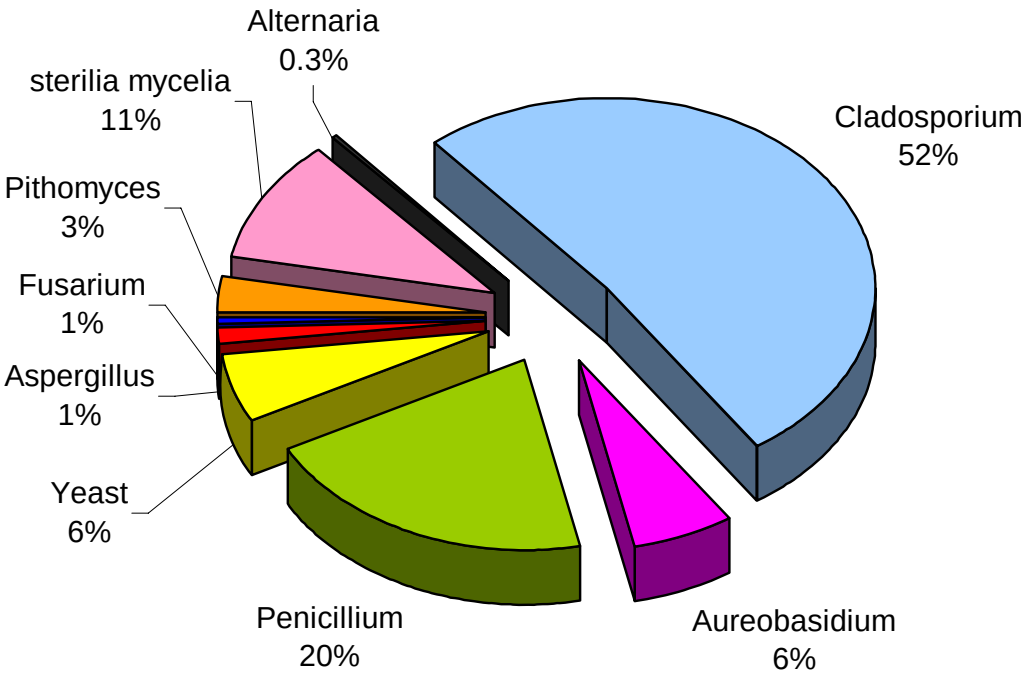

Figure 30.6: Airborne fungal spores in a hotel that had water damage. Based on average of two rooms from author's data (Kowalski 2006).

A UVGI lamp was installed in one room in the stand-alone A/C unit over the coils. Airborne fungal spores were measured before installation and after two weeks of operation. Figure SS shows the results, in which airborne levels dropped significantly. Although there was no filter, other than a dust filter, on the A/C unit, this modification appeared to greatly reduce fungal spore levels in the room. UVGI has a very limited effect on fungal spores, which tend to be resistant to UV exposure, but the constant recirculation of the room air through the unit produces a 'chronic dosing, effect – that is, if a 1% kill rate is produced by a single pass, then after several hundred passes the total kill rate will approach 99%.

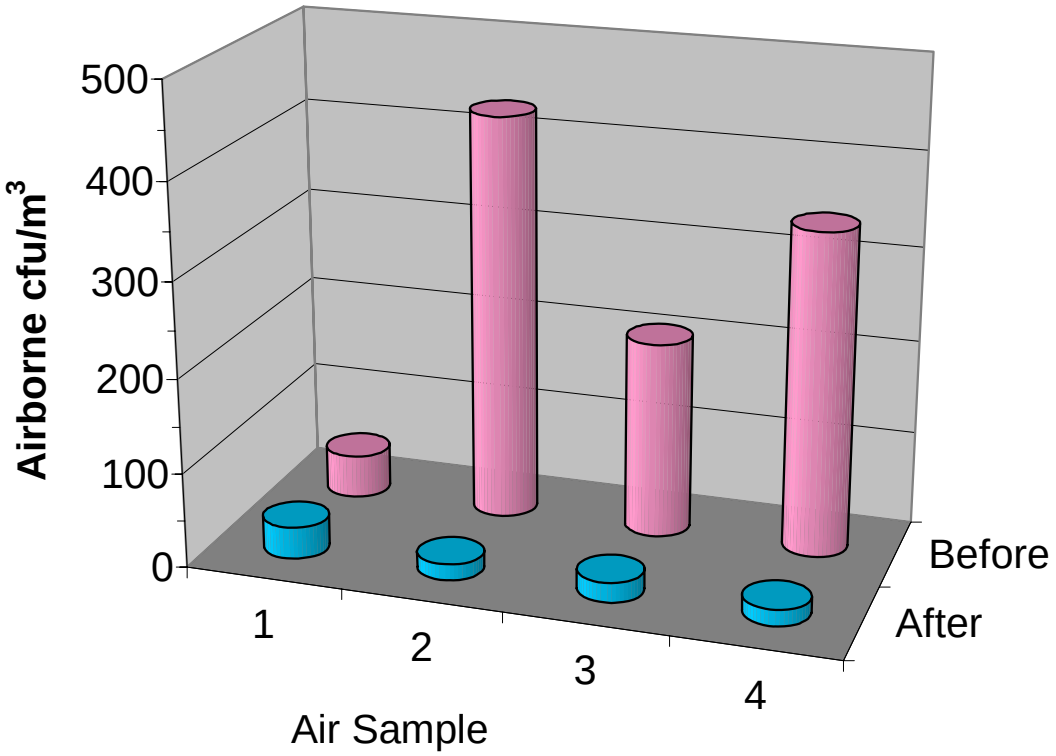

Figure: Airborne levels of fungi in a hotel room before and two weeks after UVGI installation. Based on author's data (Kowalski 2006).

One of the problems most frequently encountered in hotels is that the local room A/C units tend to accumulate mold spores on the coils and the dust filter. Condensation on the coils can then produce mold growth, which manifests itself as a foul smell when the A/C unit is turned on. These A/C units are typically subject to cleaning by maintenance personnel approximately once a year. Maintenance programs will often cycle through all the units in the hotel by removing them individually, cleaning them with steam or chemicals, and then reinstalling them. Such maintenance programs are not necessarily tied to the seasons, but may operate continuously throughout the year. What this means is that statistically up to one half of all A/C units will not have been cleaned in over six months, and if these six months are in the mold season (Spring through Fall) then up to one half the rooms may have moldy odors when the units are turned on. The odds are that many guests will experience moldy odors when they turn on the A/C units. Changes in maintenance programs may be one way to address the problem.

A more cost-effective way to control mold growth on local room A/C units, and also on central A/C units, is to install UVGI lamps around the cooling coils, provided there is sufficient space. This is relatively easy to accomplish for larger central air handling units with cooling coils, but can be problematic for local room A/C units due to the lack of space around the coils. Stand-alone A/C units

located in walls and overhead may have very limited space and UV lamps can be installed with appropriate reflectors to ensure coil exposure. Window A/C units may have no space to install UV lamps and might have to be modified to create such space, or else replaced with newer A/C units that can accommodate UV lamps.

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APPENDIX A: Microbial UV Rate Constants and D90 Doses

Microbe	Type	Media	RH %	UVGI k m^2/J	D90 J/m^2	Source
Acinetobacter	Bacteria	Water	100%*	0.00023	10964.7	Keller 1982
Adenovirus	Virus	Surface	-	0.0047	489.9	Rainbow 1973
Adenovirus	Virus	Air	-	0.055	41.9	Jensen 1964
Aeromonas	Bacteria	-	-	0.2031	11.3	Sako 1985
Aspergillus	Fungi	Air	-	0.0007	3289	Luckiesh 1946
Aspergillus amstelodami	Fungi	Air	67	0.000797	2890	Luckiesh 1949
Aspergillus amstelodami	Fungi	Surface	-	0.002063	1116	Luckiesh 1949
Aspergillus amstelodami	Fungi	-	-	0.003289	700	Jepson 1975
Aspergillus amstelodami	Fungi	Air	-	0.00344	669	Luckiesh 1946
Aspergillus flavus	Fungi	-	-	0.003838	600	Nagy 1964
Aspergillus fumigatus	Fungi	Surface	-	0.001028	2240	Chick 1963
Aspergillus fumigatus (vegetative)	Fungi	Surface	-	0.004112	560	Chick 1963
Aspergillus glaucus	Fungi	-	-	0.005233	440	Nagy 1964
Aspergillus niger	Fungi	Air	55	0.000128	17938	Luckiesh 1949
Aspergillus niger	Fungi	Surface	-	0.000385	5979	Luckiesh 1949
Aspergillus niger	Fungi	Surface	-	0.000514	4480	Chick 1963
Aspergillus niger	Fungi	-	-	0.001744	1320	Nagy 1964
Aspergillus niger	Fungi	-	-	0.002303	1000	Jepson 1975
Aspergillus niger	Fungi	Surface	-	0.00307	750	Gritz 1990
Aspergillus niger	Fungi	Surface	-	0.00731	315	Kowalski 2001
Aspergillus versicolor	Fungi	Air	55	0.003	768	vanOsdell 2002
Aspergillus versicolor	Fungi	Air	85	0.006	384	vanOsdell 2002
Bacillus anthracis spores	Bacteria	Surface	-	0.0031	742.8	Knudson 1986
Bacillus anthracis spores	Bacteria	-	-	0.028654	80.4	Jepson 1975
Bacillus anthracis spores	Bacteria	-	-	0.050942	45.2	Nagy 1964
Bacillus cereus spores	Bacteria	Surface	-	0.005638	408.4	Benoit 1990
Bacillus cereus spores	Bacteria	-	-	0.00863	266.8	Weinberger 1984
Bacillus cereus spores	Bacteria	Surface	-	0.010983	209.6	Weisova 1966
Bacillus cereus spores	Bacteria	Surface	-	0.019789	116.4	Germaine 1973
Bacillus subtilis (vegetative)	Bacteria	-	-	0.0324	71.1	IES 1981
Bacillus subtilis (vegetative)	Bacteria	-	-	0.0397	58	Nagy 1964
Bacillus subtilis (vegetative)	Bacteria	Water	100%*	0.0921	25.1	Lojo 1985
Bacillus subtilis (vegetative)	Bacteria	Air	-	0.168582	13.7	Nakamura 1987
Bacillus subtilis spores	Bacteria	Water	100%*	0.0136	171.8	Qualls 1983
Bacillus subtilis spores	Bacteria	-	-	0.015351	150	Chang 1985
Bacillus subtilis spores	Bacteria	-	-	0.019821	116.2	Sommer 1989
Bacillus subtilis spores	Bacteria	-	-	0.01985	116	Nagy 1964
Bacillus subtilis spores	Bacteria	Air	55-85	0.02	115.1	vanOsdell 2002
Bacillus subtilis spores	Bacteria	Surface	-	0.0203	113.4	Munakata 1972
Bacillus subtilis spores	Bacteria	Surface	-	0.0246	93.6	Rentschler 1941
Bacillus subtilis spores	Bacteria	Air	95	0.025	92.1	Peccia 2001
Bacillus subtilis spores	Bacteria	Water	100%*	0.0258	89.9	Horneck 1985
Bacillus subtilis spores	Bacteria	Air	50	0.027	85.3	Peccia 2001
Bacillus subtilis spores	Bacteria	Surface	-	0.0337	68.3	Munakata 1975
Bacillus subtilis spores	Bacteria	Air	45	0.0449	51.3	Kowalski 2001
Blastomyces dermatitidis (vegetative)	Fungi	Surface	-	0.016447	140	Chick 1963
Blastomyces dermatitidis (yeast)	Fungi	Surface	-	0.016447	140	Chick 1963
Burkholderia cenocepacia	Bacteria	Water	100%*	0.039563	58.2	Abshire 1981
Candida albicans (yeast)	Fungi	Surface	-	0.00307	750	Gritz 1990

APPENDIX A: Microbial UV Rate Constants and D90 Doses

Microbe	Type	Media	RH %	UVGI k m^2/J	D90 J/m^2	Source
Candida albicans (yeast)	Fungi	Water	100%*	0.005151	447	Abshire 1981
Candida albicans (yeast)	Fungi	Surface	-	0.008224	280	Chick 1963
Candida albicans (yeast)	Fungi	-	-	0.01	230	Dolman 1989
Cladosporium	Fungi	Air	-	0.00384	600	Luckiesh 1946
Cladosporium herbarum	Fungi	Air	53	0.000856	2691	Luckiesh 1949
Cladosporium herbarum	Fungi	Surface	-	0.002818	817	Luckiesh 1949
Cladosporium herbarum	Fungi	Air	-	0.0037	622	Luckiesh 1946
Cladosporium herbarum	Fungi	-	-	0.004605	500	Jepson 1975
Cladosporium sphaerospermum	Fungi	Air	-	0.0016	1439	vanOsdell 2002
Cladosporium trichoides	Fungi	Surface	-	0.002056	1120	Chick 1963
Cladosporium trichoides (vegetative)	Fungi	Surface	-	0.004112	560	Chick 1963
Cladosporium wernecki (vegetative)	Fungi	Surface	-	0.004112	560	Chick 1963
Cladosporium wernecki spores	Fungi	Surface	-	0.000514	4480	Chick 1963
Clostridium perfringens	Bacteria	Surface	-	0.017	135.4	Jepson 1975
Clostridium tetani	Bacteria	-	-	0.046992	49	Jepson 1975
Corynebacterium diphtheriae	Bacteria	-	-	0.068326	33.7	Nagy 1964
Corynebacterium diphtheriae	Bacteria	Surface	-	0.0701	32.8	Sharp 1939
Coxiella burnetii	Bacteria	Water	100%*	0.1535	15	Little 1980
Coxsackievirus	Virus	Water	100%*	0.02	127.9	Hill 1970
Coxsackievirus	Virus	Water	100%*	0.026837	85.8	Havelaar 1987
Coxsackievirus	Virus	Air	-	0.111	20.7	Jensen 1964
Cryptococcus neoformans	Fungi	Surface	-	0.0167	138	Wang 1994
Cryptococcus neoformans (yeast)	Fungi	Surface	-	0.008224	280	Chick 1963
Curvularia lunata (vegetative)	Fungi	Surface	-	0.004112	560	Chick 1963
Echovirus	Virus	Water	100%*	0.0219	106.1	Hill 1970
Enterobacter cloacae	Bacteria	Water	100%*	0.021419	107.5	Martiny 1988
Enterobacter cloacae	Bacteria	Water	100%*	0.03598	64	Zemke 1990
Escherichia coli	Bacteria	Surface	-	0.010502	219.2	Luckiesh 1949
Escherichia coli	Bacteria	Water	100%*	0.028322	81.3	Abshire 1981
Escherichia coli	Bacteria	-	-	0.06524	35.3	Jepson 1975
Escherichia coli	Bacteria	-	-	0.076753	30	Nagy 1964
Escherichia coli	Bacteria	-	-	0.08009	28.7	Harm 1980
Escherichia coli	Bacteria	-	-	0.095941	24	David 1973
Escherichia coli	Bacteria	Air	-	0.156114	14.7	Luckiesh 1949
Francisella tularensis	Bacteria	Air	-	0.01474	156.2	Beebe 1959
Fusarium oxysporum	Fungi	Surface	-	0.008856	260	Asthana 1992
Fusarium solani	Fungi	Surface	-	0.007349	313	Asthana 1992
Fusarium spp. (vegetative)	Fungi	Surface	-	0.002056	1120	Chick 1963
Fusarium spp. spores	Fungi	Surface	-	0.004112	560	Chick 1963
Haemophilus influenzae	Bacteria	Surface	-	0.0599	38.4	Mongold 1992
Histoplasma capsulatum (vegetative)	Fungi	Surface	-	0.016447	140	Chick 1963
Histoplasma capsulatum (yeast)	Fungi	Surface	-	0.016447	140	Chick 1963
Influenza A virus	Virus	Air	-	0.119	19.3	Jensen 1964
Kilham Rat Virus (parvovirus)	Virus	-	-	0.095941	24	Proctor 1972
Klebsiella pneumoniae	Bacteria	Water	100%*	0.023616	97.5	Martiny 1988
Klebsiella pneumoniae	Bacteria	Water	100%*	0.0548	42	Zemke 1990
Legionella pneumophila	Bacteria	Water	100%*	0.122805	18.8	Yamamoto 1987
Legionella pneumophila	Bacteria	Water	100%*	0.192979	11.9	Gilpin 1985
Legionella pneumophila	Bacteria	Surface	-	0.248493	9.3	Antopol 1979

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Microbe	Type	Media	RH %	UVGI k m^2/J	D90 J/m^2	Source
Legionella pneumophila	Bacteria	Surface	-	0.446126	5.2	Knudson 1985
Listeria monocytogenes	Bacteria	Surface	-	0.03	76.8	Kim 2002
Listeria monocytogenes	Bacteria	Air	-	0.2303	10	Collins 1971
Micrococcus	Bacteria	-	-	0.028782	80	Nagy 1964
Micrococcus candidus	Bacteria	-	-	0.038059	60.5	IES 1981
Micrococcus sphaeroides	Bacteria	-	-	0.023026	100	IES 1981
Moraxella-Acinetobacter	Bacteria	Water	100%*	0.00022	10964.7	Keller 1982
Mucor	Fungi	Air	-	0.0135	171	Luckiesh 1946
Mucor mucedo	Fungi	Air	63	0.000924	2491	Luckiesh 1949
Mucor mucedo	Fungi	Surface	-	0.002962	777	Luckiesh 1949
Mucor mucedo	Fungi	-	-	0.003838	600	Jepson 1975
Mucor mucedo	Fungi	Air	-	0.00399	577	Luckiesh 1946
Mucor racemosus	Fungi	-	-	0.013545	170	Nagy 1964
Mucor spp. (vegetative)	Fungi	Surface	-	0.008224	280	Chick 1963
Mucor spp. spores	Fungi	Surface	-	0.016447	140	Chick 1963
Mycobacterium avium-intracellulare	Bacteria	Surface	-	0.040634	56.7	David 1973
Mycobacterium bovis BCG	Bacteria	Air	-	0.1055	21.8	Collins 1971
Mycobacterium bovis BCG	Bacteria	Air	-	0.19	12.1	Peccia 2002
Mycobacterium bovis BCG	Bacteria	Air	50	0.242	9.5	Riley 1976
Mycobacterium flaviscens	Bacteria	Surface	-	0.019188	120	David 1973
Mycobacterium fortuitum	Bacteria	Surface	-	0.046052	50	David 1973
Mycobacterium kansasii	Bacteria	Surface	-	0.035424	65	David 1973
Mycobacterium marinum	Bacteria	Surface	-	0.038808	59.3	David 1973
Mycobacterium parafortuitum	Bacteria	Water	100%*	0.01	287.8	Peccia 2001
Mycobacterium parafortuitum	Bacteria	Air	95	0.1	23	Peccia 2001
Mycobacterium parafortuitum	Bacteria	Air	-	0.12	19.2	Xu 2003
Mycobacterium parafortuitum	Bacteria	Air	50	0.17	13.5	Peccia 2001
Mycobacterium phlei	Bacteria	Surface	-	0.036357	63.3	David 1973
Mycobacterium phlei	Bacteria	Air	50	0.0365	63.1	Riley 1976
Mycobacterium phlei	Bacteria	Air	50	0.1	23	Kethley 1973
Mycobacterium phlei	Bacteria	Air	50	0.14	16.4	Gillis 1974
Mycobacterium smegmatis	Bacteria	Surface	-	0.030701	75	David 1973
Mycobacterium smegmatis	Bacteria	Air	50	0.19	12.1	Gillis 1974
Mycobacterium smegmatis	Bacteria	Surface	-	0.23	10	Boshoff 2003
Mycobacterium tuberculosis	Bacteria	Surface	-	0.086347	26.7	David 1973
Mycobacterium tuberculosis	Bacteria	Air	-	0.2132	10.8	Collins 1971
Mycobacterium tuberculosis	Bacteria	Surface	-	0.33	7	Boshoff 2003
Mycobacterium tuberculosis	Bacteria	Air	50	0.4721	4.9	Riley 1976
Neisseria catarrhalis	Bacteria	-	-	0.052331	44	Nagy 1964
Newcastle Disease Virus (NDV)	Virus	-	-	0.361835	6.4	vonBrodorotti 1982
Nocardia asteroides (vegetative)	Bacteria	Surface	-	0.008224	280	Chick 1963
Parvovirus (Bovine)	Virus	-	-	0.0658	35	vonBrodorotti 1982
Penicillium chrysogenum	Fungi	Air	41	0.001005	2292	Luckiesh 1949
Penicillium chrysogenum	Fungi	Air	-	0.0014	1645	vanOsdell 2002
Penicillium chrysogenum	Fungi	Surface	-	0.00361	638	Luckiesh 1949
Penicillium chrysogenum	Fungi	Air	-	0.00434	531	Luckiesh 1946
Penicillium chrysogenum	Fungi	-	-	0.005756	400	Jepson 1975
Penicillium digitatum	Fungi	-	-	0.005233	440	Nagy 1964
Penicillium digitatum	Fungi	Surface	-	0.00718	321	Asthana 1992

APPENDIX A: Microbial UV Rate Constants and D90 Doses

Microbe	Type	Media	RH %	UVGI k m^2/J	D90 J/m^2	Source
Penicillium digitatum	Fungi	-	-	0.005233	440	Nagy 1964
Penicillium digitatum	Fungi	Surface	-	0.00718	321	Asthana 1992
Penicillium expansum	Fungi	-	-	0.017712	130	Nagy 1964
Penicillium italicum	Fungi	Surface	-	0.00718	321	Asthana 1992
Penicillium roquefortii	Fungi	-	-	0.017712	130	Nagy 1964
Penicillium spp. (vegetative)	Fungi	Surface	-	0.008224	280	Chick 1963
Penicillium spp. spores	Fungi	Surface	-	0.001028	2240	Chick 1963
Proteus vulgaris	Bacteria	-	-	0.076753	30	Nagy 1964
Proteus vulgaris	Bacteria	-	-	0.087219	26.4	IES 1981
Pseudomonas aeruginosa	Bacteria	-	-	0.041865	55	Zelle 1955
Pseudomonas aeruginosa	Bacteria	Water	-	0.0419	55	Antopol 1979
Pseudomonas aeruginosa	Bacteria	Water	100%*	0.066	36	Abshire 1981
Pseudomonas aeruginosa	Bacteria	Water	100%*	0.226921	10.1	Gilpin 1985
Pseudomonas aeruginosa	Bacteria	Air	-	0.2375	9.7	Collins 1971
Pseudomonas aeruginosa	Bacteria	Air	-	0.5721	4	Sharp 1940
Pseudomonas diminuta	Bacteria	Water	100%*	0.023911	96.3	Abshire 1981
Pseudomonas fluorescens	Bacteria	-	-	0.065788	35	Nagy 1964
Pseudomonas fluorescens	Bacteria	Air	-	0.935	2.5	vanOsdell 2002
Pseudomonas maltophilia	Bacteria	Water	100%*	0.032941	69.9	Abshire 1981
Pseudomonas putrefaciens	Bacteria	Water	100%*	0.026619	86.5	Abshire 1981
Reovirus	Virus	Water	100%	0.0132	174.4	Hill 1970
Reovirus	Virus	Water	100%	0.015082	152.7	Harris 1987 (Type 1)
Reovirus	Virus	-	-	0.033579	68.6	vonBrodorotti 1982
Rhizopus	Fungi	Air	-	0.00861	267	Luckiesh 1946
Rhizopus nigricans	Fungi	-	-	0.000768	3000	Jepson 1975
Rhizopus nigricans	Fungi	Air	62	0.001992	1156	Luckiesh 1949
Rhizopus nigricans	Fungi	-	-	0.002074	1110	Nagy 1964
Rhizopus nigricans	Fungi	Air	-	0.00861	267	Luckiesh 1946
Rhizopus nigricans	Fungi	Surface	-	0.0285	81	Kowalski 2001
Rhizopus oryzae	Fungi	Surface	-	0.000514	4480	Chick 1963
Rhodotorula spp. (yeast)	Fungi	Surface	-	0.002056	1120	Chick 1963
Rickettsia prowazekii	Bacteria	Surface	-	0.0292	78.9	Allen 1954
Scopulariopsis brevicaulis	Fungi	Air	79	0.000797	2890	Luckiesh 1949
Scopulariopsis brevicaulis	Fungi	Surface	-	0.002358	977	Luckiesh 1949
Scopulariopsis brevicaulis	Fungi	Air	-	0.00344	669	Luckiesh 1946
Scopulariopsis brevicaulis	Fungi	-	-	0.003542	650	Jepson 1975
Serratia marcescens	Bacteria	Water	100%*	0.01071	215	Martiny 1988
Serratia marcescens	Bacteria	Surface	-	0.02194	105	Harris 1993
Serratia marcescens	Bacteria	Air	95	0.065	35.4	Peccia 2001
Serratia marcescens	Bacteria	-	-	0.095148	24.2	Nagy 1964
Serratia marcescens	Bacteria	-	-	0.104663	22	Jepson 1975
Serratia marcescens	Bacteria	-	-	0.104663	22	Zelle 1955
Serratia marcescens	Bacteria	Air	-	0.1047	22	Sharp 1939
Serratia marcescens	Bacteria	Water	100%*	0.1049	22	Antopol 1979
Serratia marcescens	Bacteria	Air	-	0.1225	18.8	Rentschler 1941
Serratia marcescens	Bacteria	Air	-	0.2208	10.4	Collins 1971
Serratia marcescens	Bacteria	Air	25-57	0.2867	8	Kowalski 2001
Serratia marcescens	Bacteria	Air	60	0.2909	7.9	Peccia 2001
Serratia marcescens	Bacteria	Air	-	0.328941	7	Nakamura 1987

APPENDIX A: Microbial UV Rate Constants and D90 Doses

Microbe	Type	Media	RH %	UVGI k m^2/J	D90 J/m^2	Source
Serratia marcescens	Bacteria	Air	-	0.4449	5.2	Sharp 1940
Serratia marcescens	Bacteria	Air	50	0.45	5.1	Peccia 2001
Serratia marcescens	Bacteria	Air	22-33	0.58	4	Ko 2000
Serratia marcescens	Bacteria	Air	-	0.749	3.1	vanOsdell 2002
Serratia marcescens	Bacteria	Water	100%*	2.093259	1.1	Lai 2004
Serratia marcescens	Bacteria	Air	60	3.289407	0.7	Riley 1972
Serratia marcescens	Bacteria	Air	30	6.39607	0.4	Riley 1972
Serratia marcescens	Bacteria	Air	45	8.223518	0.3	Riley 1972
Sindbis virus	Virus	-	-	0.038645	59.6	vonBrodorotti 1982
Sporotrichum schenkii (yeast)	Fungi	Surface	-	0.008224	280	Chick 1963
Staphylococcus albus	Bacteria	-	-	0.12514	18.4	Nagy 1964
Staphylococcus aureus	Bacteria	Surface	-	0.014441	159.5	Luckiesh 1949
Staphylococcus aureus	Bacteria	Water	100%*	0.041339	55.7	Abshire 1981
Staphylococcus aureus	Bacteria	Surface	-	0.085314	27	Chang 1985
Staphylococcus aureus	Bacteria	-	-	0.088561	26	Jepson 1975
Staphylococcus aureus	Bacteria	-	-	0.088561	26	Nagy 1964
Staphylococcus aureus	Bacteria	Surface	-	0.0886	26	Sharp 1939
Staphylococcus aureus	Bacteria	Surface	-	0.1184	19.4	Gates 1929
Staphylococcus aureus	Bacteria	Air	-	0.222163	10.4	Luckiesh 1949
Staphylococcus aureus	Bacteria	Air	-	0.3476	6.6	Sharp 1940
Staphylococcus aureus	Bacteria	Air	-	0.962	2.4	Luckiesh 1946
Staphylococcus epidermis	Bacteria	Water	100%*	0.014329	160.7	Harris 1993
Staphylococcus epidermis	Bacteria	Air	85	0.08	28.8	vanOsdell 2002
Staphylococcus epidermis	Bacteria	Air	55	0.24	9.6	vanOsdell 2002
Streptococcus (alpha)	Bacteria	Air	-	0.361014	6.4	Luckiesh 1949
Streptococcus (beta)	Bacteria	Air	-	0.100456	22.9	Luckiesh 1949
Streptococcus faecalis	Bacteria	Water	100%*	0.019188	120	Abshire 1981
Streptococcus faecalis	Bacteria	Surface	-	0.062744	36.7	Chang 1985
Streptococcus faecalis	Bacteria	Water	100%*	0.075398	30.5	Harris 1987
Streptococcus hemolyticus	Bacteria	-	-	0.106601	21.6	Nagy 1964
Streptococcus lactis	Bacteria	-	-	0.03744	61.5	Nagy 1964
Streptococcus pneumoniae	Bacteria	-	-	0.055	41.9	Chang 1985
Streptococcus pyogenes	Bacteria	-	-	0.104663	22	Jepson 1975
Streptococcus pyogenes	Bacteria	Surface	-	0.6161	3.7	Lidwell 1950
Streptococcus viridans	Bacteria	-	-	0.115129	20	Nagy 1964
Torula bergeri (vegetative)	Fungi	Surface	-	0.000514	4480	Chick 1963
Trichophyton rubrum (vegetative)	Fungi	Surface	-	0.004112	560	Chick 1963
Trichophyton rubrum spores	Fungi	Surface	-	0.004112	560	Chick 1963
Ustilago zeae (yeast)	Fungi	Surface	-	0.002056	1120	Chick 1963
Ustilago zeae spores	Fungi	-	-	0.0658	35	Sussman 1966
Vaccinia virus	Virus	-	-	0.127921	18	Klein 1994
Vaccinia virus	Virus	Air	-	0.1528	15.1	Collier 1955
Vaccinia virus	Virus	Air	-	0.153	15	Jensen 1964
Vaccinia virus	Virus	Surface	-	0.348877	6.6	Galasso 1965
Varicella-zoster virus (VZV)	Virus	-	-	0.05862	39.3	Lytle 1971 (Herpes)
Yersinia enterolitica	Bacteria	-	-	0.081268	28.3	Carlson 1975
Yersinia enterolitica	Bacteria	-	-	0.204674	11.3	Butler 1987

Appendix B: Common Indoor Bacteria

PATHOGEN	GROUP	TYPE	DISEASE GROUP	BIOSAFETY LEVEL
Acinetobacter	Bacteria	Gram–	Endogenous	Risk Group 2
Actinomyces israelii	Bacteria	Gram+	Endogenous	Risk Group 2
Aeromonas	Bacteria	Gram–	Non-communicable	Risk Group 2
Alcaligenes	Bacteria	Gram–	Endogenous	Risk Group 2
Bacteroides fragilis	Bacteria	Gram–	Endogenous	Risk Group 2
Bordetella pertussis	Bacteria	Gram–	Communicable	Risk Group 2
Brucella	Bacteria	Gram–	Non-communicable	Risk Group 2-3
Burkholderia cepacia	Bacteria	Gram–	Non-communicable	Risk Group 1
Burkholderia mallei	Bacteria	Gram–	Non-communicable	Risk Group 3
Burkholderia pseudomallei	Bacteria	Gram–	Non-communicable	Risk Group 2-3
Cardiobacterium	Bacteria	Gram–	Endogenous	Risk Group 2
Chlamydia pneumoniae	Bacteria	Gram–	Communicable	Risk Group 2
Chlamydophila psittaci	Bacteria	Gram–	Non-communicable	Risk Group 2-3
Clostridium botulinum	Bacteria	Gram+	Non-communicable	Risk Group 2-4
Clostridium perfringens	Bacteria	Gram+	Non-communicable	Risk Group 2
Corynebacterium diphtheriae	Bacteria	Gram+	Communicable	Risk Group 2
Enterobacter cloacae	Bacteria	Gram–	Endogenous	Risk Group 1
Enterococcus	Bacteria	Gram+	Non-communicable	Risk Group 1-2
Enterococcus faecalis	Bacteria	Gram+	Endogenous	Risk Group 1
Francisella tularensis	Bacteria	Gram–	Non-communicable	Risk Group 2-3
Haemophilus influenzae	Bacteria	Gram–	Communicable	Risk Group 2
Haemophilus parainfluenzae	Bacteria	Gram–	Endogenous	Risk Group 2
Klebsiella pneumoniae	Bacteria	Gram–	Endogenous	Risk Group 2
Legionella pneumophila	Bacteria	Gram–	Non-communicable	Risk Group 2
Listeria monocytogenes	Bacteria	Gram+	Non-communicable	
Moraxella	Bacteria	Gram–	Endogenous	Risk Group 2
Mycobacterium avium	Bacteria	Gram+	Non-communicable	Risk Group 3
Mycobacterium kansasii	Bacteria	Gram+	Non-communicable	Risk Group 2
Mycobacterium tuberculosis	Bacteria	Gram+ (acid fast)	Communicable	Risk Group 2-3
Mycoplasma pneumoniae	Bacteria	no wall	Endogenous	Risk Group 2
Neisseria meningitidis	Bacteria	Gram–	Endogenous	Risk Group 2
Proteus mirabilis	Bacteria	Gram–	Endogenous	Risk Group 2
Pseudomonas aeruginosa	Bacteria	Gram–	Non-communicable	Risk Group 1
Rickettsia prowazeki	Bacteria	Gram-	Vector-borne	Risk Group 2-3
Rickettsia rickettsii	Bacteria	Gram-	Vector-borne	Risk Group 2-3
Salmonella typhi	Bacteria	Gram-	Food-borne	Risk Group 2
Serratia marcescens	Bacteria	Gram–	Endogenous	Risk Group 1
Shigella	Bacteria	Gram-	Food-borne	Risk Group 2
Staphylococcus aureus	Bacteria	Gram+	Endogenous	Risk Group 2
Staphylococcus epidermis	Bacteria	Gram+	Endogenous	Risk Group 1
Streptococcus pneumoniae	Bacteria	Gram+	Communicable	Risk Group 2
Streptococcus pyogenes	Bacteria	Gram+	Communicable	Risk Group 2
Vibrio cholerae	Bacteria	Gram-	Food-borne	Risk Group 2
Yersinia pestis	Bacteria	Gram–	Communicable	Risk Group 2-3
Coxiella burnetii	Bacteria / Rickettsiae	Gram–	Non-communicable	Risk Group 2-3
Bacillus anthracis	Bacterial Spore	Gram+	Non-communicable	Risk Group 2-3
Micromonospora faeni	Bacterial Spore	Micromonosporaceae	Non-communicable	-
Nocardia asteroides	Bacterial Spore	Nocardiaceae	Non-communicable	Risk Group 2
Nocardia brasiliensis	Bacterial Spore	Nocardiaceae	Non-communicable	Risk Group 2
Saccharopolyspora rectivirgula	Bacterial Spore	Micromonosporaceae	Non-communicable	Risk Group 2
Thermoactinomyces sacchari	Bacterial Spore	Micromonosporaceae	Non-communicable	Risk Group 2
Thermoactinomyces vulgaris	Bacterial Spore	Micromonosporaceae	Non-communicable	Risk Group 1
Thermomonospora viridis	Bacterial Spore	Micromonosporaceae	Non-communicable	Risk Group 1

Appendix C: Common Indoor Fungi

PATHOGEN	GROUP	PHYLUM	DISEASE GROUP	BIOSAFETY LEVEL
Absidia	Fungal Spore	Zygomycetes	Non-communicable	Risk Group 2
Acremonium	Fungal Spore	Hyphomycetes	Non-communicable	Risk Group 1-2
Alternaria alternata	Fungal Spore	Hyphomycetes	Non-communicable	Risk Group 1
Arthrinium phaeospermum	Fungal Spore	Hyphomycetes	Non-communicable	Risk Group 2
Aspergillus	Fungal Spore	Hyphomycetes	Non-communicable	Risk Group 2
Aureobasidium pullulans	Fungal Spore	Hyphomycetes	Non-communicable	Risk Group 1
Blastomyces dermatitidis	Fungal Spore	Hyphomycetes	Non-communicable	Risk Group 2-3
Botrytis cinerea	Fungal Spore	Hyphomycetes	Non-communicable	Risk Group 3
Candida	Fungal Spore	Hyphomycetes	Endogenous	Risk Group 1
Chaetomium globosum	Fungal Spore	Ascomycetes	Non-communicable	Risk Group 1
Cladosporium	Fungal Spore	Hyphomycetes	Non-communicable	Risk Group 1
Coccidioides immitis	Fungal Spore	Hyphomycetes	Non-communicable	Risk Group 3
Cryptostroma corticale	Fungal Spore	Hyphomycetes	Non-communicable	Risk Group 2
Curvularia	Fungal Spore	Hyphomycetes	Non-communicable	Risk Group 1
Drechslera	Fungal Spore	Hyphomycetes	Non-communicable	Risk Group 2
Emericella nidulans	Fungal Spore	Ascomycetes	Non-communicable	Risk Group 1
Epicoccum nigrum	Fungal Spore	Ascomycetes	Non-communicable	Risk Group 1
Eurotium	Fungal Spore	Ascomycetes	Non-communicable	Risk Group 1
Exophiala	Fungal Spore	Hyphomycetes	Non-communicable	Risk Group 2
Fusarium	Fungal Spore	Hyphomycetes	Non-communicable	Risk Group 1
Helminthosporium	Fungal Spore	Hyphomycetes	Non-communicable	Risk Group 1
Histoplasma capsulatum	Fungal Spore	Ascomycetes	Non-communicable	Risk Group 3
Mucor plumbeus	Fungal Spore	Zygomycetes	Non-communicable	Risk Group 1
Paecilomyces variotii	Fungal Spore	Hyphomycetes	Non-communicable	Risk Group 1
Paracoccidioides	Fungal Spore	Hyphomycetes	Non-communicable	Risk Group 2
Penicillium	Fungal Spore	Hyphomycetes	Non-communicable	Risk Group 1
Phialophora	Fungal Spore	Hyphomycetes	Non-communicable	Risk Group 2
Phoma	Fungal Spore	Coelomycetes	Non-communicable	Risk Group 1
Pneumocystis carinii	Fungal Spore	Protozoal	Communicable	Risk Group 1
Rhizomucor pusillus	Fungal Spore	Zygomycetes	Non-communicable	Risk Group 1
Rhizopus stolonifer	Fungal Spore	Zygomycetes	Non-communicable	Risk Group 2
Rhodoturula	Fungal Spore	Blastomycetes	Non-communicable	-
Scopulariopsis	Fungal Spore	Hyphomycetes	Non-communicable	Risk Group 2
Sporothrix schenckii	Fungal Spore	Hyphomycetes	Non-communicable	Risk Group 2
Stachybotrys chartarum	Fungal Spore	Hyphomycetes	Non-communicable	Risk Group 1-2
Trichoderma	Fungal Spore	Hyphomycetes	Non-communicable	Risk Group 1
Trichophyton	Fungal Spore	Hyphomycetes	Non-communicable	
Ulocladium	Fungal Spore	Hyphomycetes	Non-communicable	Risk Group 1
Ustilago	Fungal Spore	Basidiomycetes	Non-communicable	Risk Group 1
Verticillium	Fungal Spore	Hyphomycetes	Non-communicable	
Wallemia sebi	Fungal Spore	Hyphomycetes	Non-communicable	Risk Group 1
Cryptococcus neoformans	Fungal Yeast	Hyphomycetes	Non-communicable	Risk Group 2
Trichosporon cutaneum	Fungi/Yeast	Basidiomycetes	Non-communicable	

Appendix D: Health Care Facility Cost Estimates -- Part 1

Category	Facility 1	Facility 2	Facility 3	Facility 4	Facility 5	Facility 6
General Facility						
Age	21 years	13 years	31 years	40 years	63 years	27 years
Area	193,200 SF	353,000 SF	294,619 SF	134,988 SF	1,000,000 SF	364,400 SF
No. Licensed Beds	149	247	228	108	345	401
Conditions	Good	Good	Poor	Adequate	Poor	Fair
Inpatient						
No. Staffed Beds	172	187	204	74	303	340
Private	38	110	0	10	0	0
Semi-private	84	57	0	44	0	401
Ward	7	7pr.+ 13 NICU	204	20	345	0
Total Admissions	6,864	7,890	6,088	2,637	12,154	21,246
Inpatient Days	30,880	44,513	31,553	15,287	87,354	99,503
Average Daily Census	83	122	149	39	239	273
Percent Occupancy	57	65	73	52	79	80
Routine Beds	108	131	108	54	176	331
Special Care	22	56	22	10	169	46
Nursery	26	44	26	0	0	42
Outpatient						
No. of Exam Rooms	57	124	12	38	190	62
Clinic Visits	110,232	119,399	118,234	61,181	257,795	98,897
Visits per exam room	1,934	1,592	9,852	1,610	1,357	1,595
List of Clinics	13	7	12	23	13	2
ER Visits	57,390	41,822	76,875	42,287	95,951	81,890
ER Treatment Rooms	16	7	26	10	80	20
Facility Needs	Space	Space	Space	Space	Space	Space, toilets
Area	13,205 SF	36,000 SF	51,000 SF	6,715 SF	53,540 SF	
Visits per Room	3,587	5,975	2,956	4,229	1,194	4,095
Clinical						
No. Operating Rooms	4	10	5	4	16	12
O.R. Cases	2,424	3,068	4,780	2,202	11,189	8,959
Cases per O.R.	606	307	956	550	699	747
No. Delivery Rooms	3	3	3	0	0	9
Live Births	948	1,638	1,603	0	0	3,579
Births per Room	316	546	534	0	0	398
No. X-Ray Rooms	9	13	8	6	37	12
X-Ray Equpment	See attached	See attached	See attached	See attached	See attached	See attached
Estimated # of air handlers	23	23	17	23	200	17
Facility Adequacy	Adequate	Adequate	Inadequate	Adequate	Inadequate	Adequate
Major Needs	Labor & Delivery, NICU		Labor & Delivery, NICU, MRI	ER, Clinic, Parking, Storage	New Facility	Space, Privacy, CT Scanner

Appendix D: Health Care Facility Cost Estimates -- Part 2

Category	Facility 1	Facility 2	Facility 3	Facility 4	Facility 5	Facility 6	TOTALS
ESTIMATED COSTS							
Coil Irradiation	$ 38,318.00	$ 63,864.00	$ 54,603.00	$ 34,486.00	$ 178,819.00	$ 64,928.00	$ 435,018.00
Duct Treatment	$ 30,959.00	$ 56,565.00	$ 47,210.00	$ 21,631.00	$ 160,242.00	$ 58,392.00	$ 374,999.00
Operating Room	$ 56,000.00	$ 140,000.00	$ 70,000.00	$ 56,000.00	$ 224,000.00	$ 168,000.00	$ 714,000.00
TOTAL COSTS	$ 125,277.00	$ 260,429.00	$ 171,813.00	$ 112,117.00	$ 563,061.00	$ 291,320.00	$ 1,524,017.00
Annual Cost	$ 20,044.32	$ 41,668.64	$ 27,490.08	$ 17,938.72	$ 90,089.76	$ 46,611.20	$ 243,842.72
ANNUAL MAINTENANCE							
ESTIMATED SAVINGS							
PATIENTS							
Nosocomial Infections	$ 154,400.00	$ 222,565.00	$ 157,765.00	$ 76,435.00	$ 436,770.00	$ 497,515.00	$ 1,545,450.00
Operating Infections	$ 12,120.00	$ 15,340.00	$ 23,900.00	$ 11,010.00	$ 55,945.00	$ 44,795.00	$ 163,110.00
Clinic Infections	$ 220,464.00	$ 238,798.00	$ 236,468.00	$ 122,362.00	$ 515,590.00	$ 197,794.00	$ 1,531,476.00
STAFF							$ -
Nosocomial Infections	3% reduction*	3% reduction*	3% reduction*	3% reduction*	3% reduction*	3% reduction*	$ -
Health Care	20% reduction*	20% reduction*	20% reduction*	20% reduction*	20% reduction*	20% reduction*	$ -
Illness Absentee rate	20% reduction*	20% reduction*	20% reduction*	20% reduction*	20% reduction*	20% reduction*	$ -
COIL & DUCT CLEANING	$ 1,725.00	$ 1,725.00	$ 1,275.00	$ 1,725.00	$ 15,000.00	$ 1,275.00	$ 22,725.00
ENERGY SAVINGS	10 - 14%*	10 - 14%*	10 - 14%*	10 - 14%*	10 - 14%*	10 - 14%*	$ -
EXTENDED LIFE OF UNITS	10%*	10%*	10%*	10%*	10%*	10%*	$ -
							$ -
TOTAL SAVINGS YEAR 1	$ 388,709.00	$ 478,428.00	$ 419,408.00	$ 211,532.00	$ 1,023,305.00	$ 741,379.00	$ 3,262,761.00
TOTAL SAVINGS YEAR 2	$ 388,709.00	$ 478,428.00	$ 419,408.00	$ 211,532.00	$ 1,023,305.00	$ 741,379.00	$ 1,708,560.00
TOTAL SAVINGS YEAR 3	$ 388,709.00	$ 478,428.00	$ 419,408.00	$ 211,532.00	$ 1,023,305.00	$ 741,379.00	$ 1,708,560.00
LIFETIME SAVINGS 10 YRS	$ 3,887,090.00	$ 4,784,280.00	$ 4,194,080.00	$ 2,115,320.00	$ 10,233,050.00	$ 7,413,790.00	$ 32,627,610.00

Note: Above estimates are based on SSI rate of 3% (NNIS 2000) and an assumed nosocomial infection rate of 0.5% for airborne pathogens.

**(Savings may vary based on local utility rates, age of equipment, and actual measured before and after results).*

APPENDIX F: Reports from articles and new sources on UVC effectiveness for improving IAQ and realizing savings from reduced energy and maintenance costs

A recent laboratory study has shown that ultraviolet (UV) light can effectively kill the Severe Acute Respiratory Syndrome (SARS) virus, according to FP Technologies. The company, an engineering firm that uses UV radiation to sterilize air and surfaces, designed the SARS testing. Tests were performed at ZeptoMetrix Inc., a biotechnology lab.[1]

Florida Hospital has been installing high-output ultraviolet C-band (UVC) lights in its air-handling units (AHUs), and found that this has reduced or, in some cases, eliminated coil-cleaning programs. The lights also offer IAQ and infection control benefits.

The air handler was essentially returned to its original performance specifications. The coil and drain pan areas have maintained their clean condition, and eliminating the necessity for routine cleaning. [2]

Exposing cooling coils to UVC will eventually kill all mold, and keep the drain pan clean, and keeping the coil clean will increase equipment efficiency, up to the design rating of the equipment." [3]

PSO installed UV lights in 1996-97 to eliminate a persistent mold and IAQ problem in the majority of its HVAC systems. The firm found that, by bathing the coil and drain pan areas from the downstream side was able to eradicate the microbial growth and its related problems. The lights eliminated most of the customary coil cleaning maintenance. It translated into a big energy consumption reduction." [4]

Placing a UV light close to the air conditioning coil can prevent microbes from breeding in this typically moist area, keeping the coil clean and preventing that yeasty odor that accompanies the growth of these microorganisms. [5]

UVC light can penetrate the cellular wall of a microbe and damage DNA. UVC renders bacteria and spores unable to spread. Application of UVC at a distance of 12 inches for 15 minutes resulted in a 74 percent spore count reduction as compared to the control sample. [6]

UVC lights can significantly reduce annual cleaning of evaporator coils and condenser coils and can significantly minimize the maintenance staff's exposure to a variety of chemicals. [7]

Sickness among office workers in industrialized countries could be reduced by using ultraviolet lamps to kill germs in ventilation systems. Ultraviolet germicidal irradiation, or UVGI, is sometimes used in hospital ventilation systems to disinfect the air but is rarely incorporated into office or other building ducts. In a study published this week in The Lancet medical journal, Canadian scientists found that the technique reduced overall worker sickness by about 20%, including a 40% drop in breathing problems. The cost of UVGI installations could prove cost-effective compared with the yearly losses from absenteeism. [8]

In one example, after a few weeks of UVC operation, static pressure over the coil decreased from 1.8 in.wg to just 0.7 in. wg. Air velocity over the coil more than doubled, from 230 fpm to 520 fpm. The coil and drain pan areas had no visible evidence of mold. The air exit wet bulb temperature decreased significantly, from 57° F (before UVC) to 53° (with UVC). It was estimated a total of $4,867 in savings accrued for this one unit. This hospital is saving approximately 15% in HVAC energy costs. Results from this and other studies indicate that just a one-micron buildup of dirt or debris on coil surfaces can lead to a 15% loss in efficiency.

The ability of UVC to inactivate all types of bacteria and viruses is well documented. And, by destroying microbes trapped on cooling coils or in air filters, UVC light may increase the service life of these components and may facilitate safer changeout. [9]

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[1] Testing Shows UV Effective At Killing SARS Virus /08/16/2004
[2] Retrofits Boost IAQ, Save Energy /Barb Checket-Hanks / Service, Maintenance and Troubleshooting Editor /08/16/2004
[3] Mechanical Inspectors Learn From IAQ Pro /by John R. Hall / Business Management Editor /09/24/2004
[4] UV technology sheds light on IAQ problems. Ultraviolet lights clear the air, reduce costs. /07/01/2000
[5] Contractor puts UV lighting system to the test. /by Ed Bas / Special Editor. /08/03/2000
[6] UVC Light: A Tool For Fighting Airborne Contaminants. /by John R. Hall / Business Management Editor. /07/17/2002
[7] IAQ Where We Work, Shop, And Save. /by Barb Checket-Hanks / Service/Maintenance and Troubleshooting Editor. /03/14/2003
[8] UV Lamps could reduce worker sickness. LONDON (AP) /11/28/2003
[9] UVC: Florida Hospital Puts HVAC Maintenance Under A New Light. Firouz Keikavousi - a mechanical engineer in charge of facilities management for Florida Hospital. /02/24/2004