# UV Cooling Coil Disinfection

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## 1. Executive Summary

This report reviews the history and current literature on ultraviolet germicidal irradiation (UVGI) cooling coil disinfection and 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. Guidelines on cooling coil irradiation systems are summarized for use.

Reports in the literature and from sources in the industry indicate that the disinfection of cooling coils with UV is so effective that pay back periods of about 2-4 years are possible. That is, the cleaning action of UV on fouled coils is so effective that the reduced maintenance costs and the savings in energy are so significant that the retrofit of a UV cooling coil cleaning system typically pays for itself in about 2-4 years. The energy savings results from two effects – the first being the reduced pressure loss through the coils once the fouling is removed, and the second being the increased rate of heat transfer in the coils when the fouling film is gone. Both of these can be significant, as can the reduction or elimination of maintenance for 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.

The elimination of microbiological fouling of the cooling coils can be demonstrated through surface sampling before and after installation of the UV system. 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.

## 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:

$$S = e^{-kt}$$

(1)

where k = UV rate constant, cm$^2$/μJ

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.
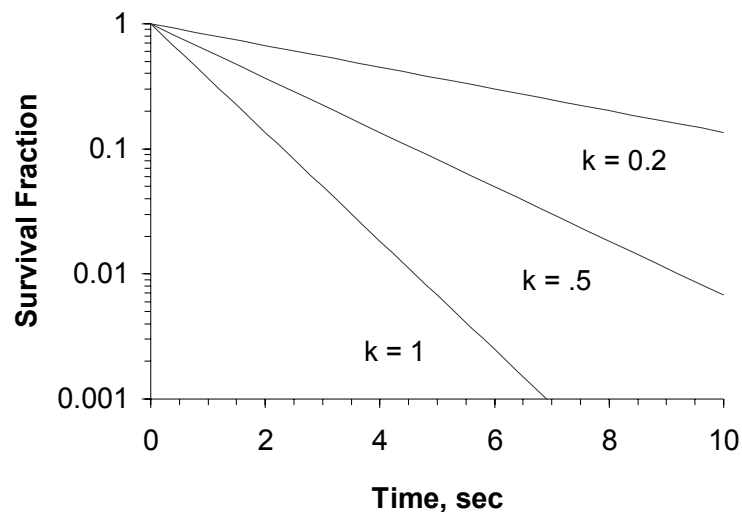
Figure 1: Survival curves for various rate constants.

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:

$$S = e^{-kIt}$$

(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:

$$D = It$$

(3)

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

$$S = e^{-kD}$$

(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:

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

(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.
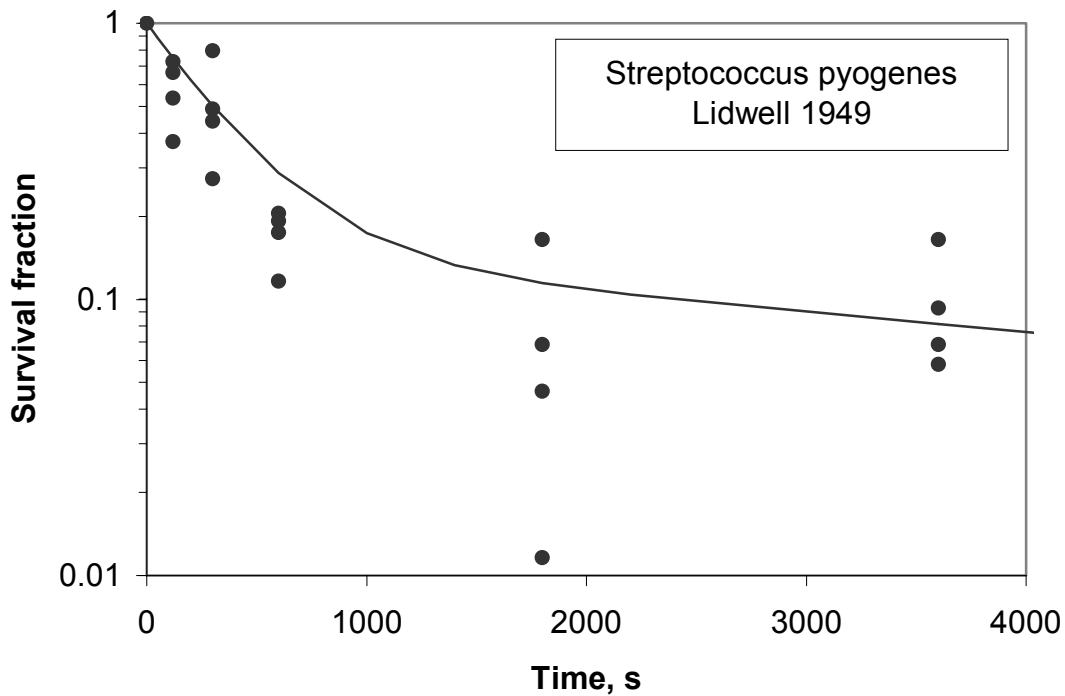


Figure 2: Survival of *Streptococcus pyogenes* under UVGI exposure. Two stage curves fitted to data from Lidwell (1949).

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.
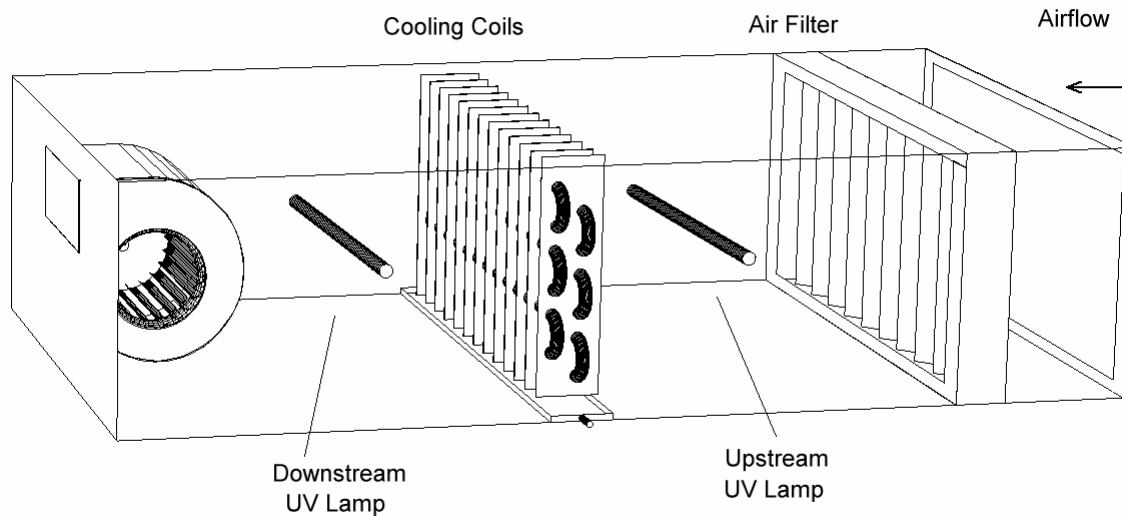


Figure 3: Air handling unit with UV lamps irradiating both upstream and downstream sides of the cooling coil.

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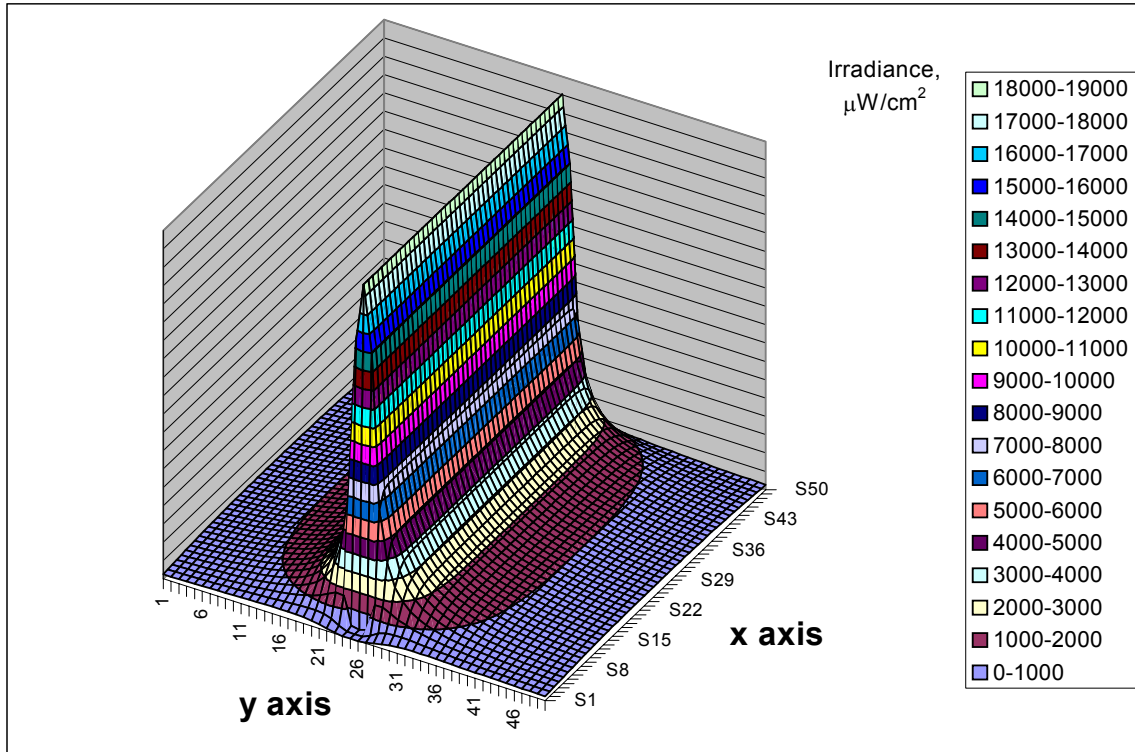
Figure 4: Example of irradiance profile on a cooling coil surface (x-y axes) from a single UV lamp located a short distance away.
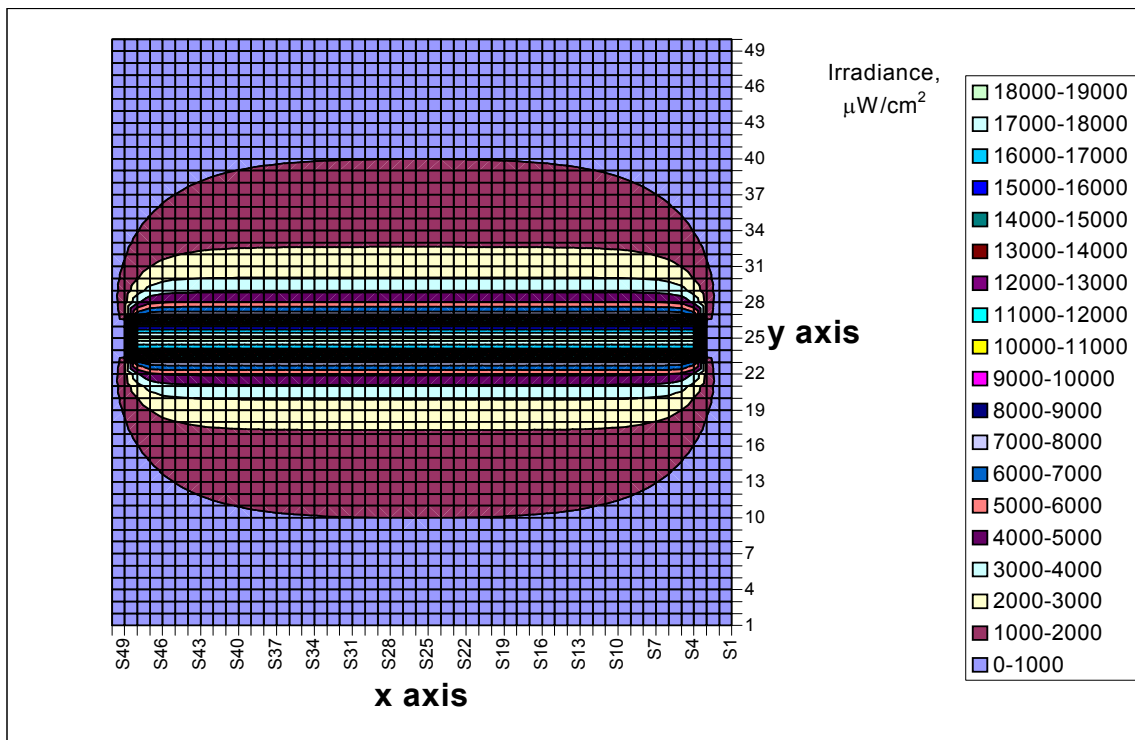


Figure 5: Irradiance contour on the cooling coil face (x-y axes) from the example in Figure 4.

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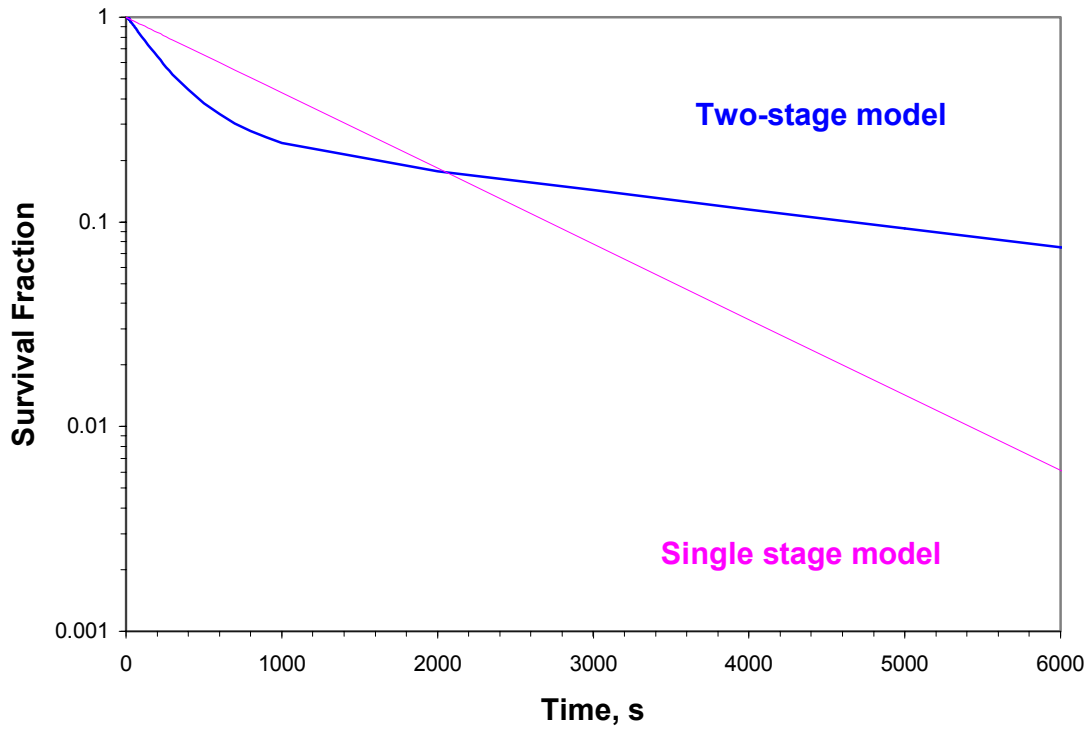
Figure 6: Comparison of a single stage model vs. a two stage model of the inactivation of *Aspergillus* spores under UV exposure of $50\mu W/cm^2$. The single stage model will underestimate the required dose for sterilization.

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

The fan energy in kW is computed as follows:

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

where dP = pressure drop, in.w.g.
$\qquad$ CFM = airflow, cfm
$\qquad$ 0.7355 = conversion factor from BHP to kW
$\qquad$ 0.75 = typical motor efficiency
$\qquad$ 0.75 = typical fan efficiency
$\qquad$ 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:

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

where CL = the capacity loss due to fouling, Btuh
$\qquad$ COP = Coefficient of Performance
$\qquad$ 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:

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

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.

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 UV (FEMA 2003). UV may also allow for the use of lower pressure drop filters (ACEEE 2005).

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 |
|---|---|---|

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 UV 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.

## 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$^o$F-110$^o$F
- Maximum ballast operating temperature of 40$^o$C or 50$^o$C (104$^o$F or 122$^o$F) 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.

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## Appendix A: UVGI Rate Constants for Pathogens.

| Microorganism | Reference | Test Medium Air/Plt/Wtr | Test Irradiance μW/cm² | Rate Constant cm²/μJ |
|---|---|---|---|---|
| Adenovirus | Jensen 1964 | A | 8749 | 0.000546 |
| Adenovirus Type 2 | Rainbow 1973 | P | 800 | 0.004700 |
| Vaccinia | Jensen 1964 | A | 8749 | 0.001528 |
| | Galasso 1965 | P | 33 | 0.001542 |
| Coxsackievirus B-1 | Jensen 1964 | A | 8749 | 0.001108 |
| | Hill 1970 | W | 83 | 0.002817 |
| Coxsackievirus A-9 | Hill 1970 | W | 83 | 0.001621 |
| Influenza A | Jensen 1964 | A | 8749 | 0.001187 |
| | Westinghouse data | | 1 | 0.001047 |
| Echovirus | Hill 1970 | W | 83 | 0.003033 |
| Reovirus Type 1 | Hill 1970 | W | 83 | 0.001849 |
| Staphylococcus aureus | Sharp 1939 | P | 1 | 0.000886 |
| | Sharp 1940 | A | 1 | 0.003476 |
| | Gates 1929 | P | 110 | 0.001184 |
| | Abshire 1981 | P | 100 | 0.000419 |
| Streptococcus pyogenes | Lidwell 1949 | P | 2.6 | 0.006161 |
| | Mitscherlich (T45) | A | 1 | 0.001066 |
| Mycobacterium tuberculosis | David 1973 | A | 4 | 0.024530 |
| | Riley 1961 | A | 1 | 0.077309 |
| | Collins 1971 | A | 40 | 0.002132 |
| | Westinghouse data | | 1 | 0.000691 |
| Mycobacterium kansasii | David 1973 | A | 4 | 0.035829 |
| Mycobacterium avium-intra. | David 1973 | A | 4 | 0.038841 |
| E. coli (reference) | Sharp 1939 | P | 1 | 0.000927 |
| | Sharp 1940 | A | 1 | 0.003759 |
| | Abshire 1981 | W | 100 | 0.000284 |
| | Zelle (Antopol 1979) | W | 1 | 0.001091 |
| Corynebacterium diptheriae | Sharp 1939 | P | 1 | 0.000683 |
| Moraxella-Acinetobacter | Keller 1982 | W | 2200 | 0.000002 |
| Haemophilus influenzae | Mongold 1992 | P | 800 | 0.000656 |
| Pseudomonas aeruginosa | Collins 1971 | A | 40 | 0.002555 |
| | Westinghouse data | | 1 | 0.000658 |
| | Abshire 1981 | W | 100 | 0.000465 |
| | Sharp 1940 | A | 1 | 0.005721 |
| | Zelle (Antopol) | W | 1 | 0.000419 |
| Legionella pneumophila | unidentified Figure | | 1 | 0.002047 |
| | Antopol 1979 | W | 50 | 0.002503 |
| | Westinghouse data | | 1 | 0.001818 |
| Serratia marcescens | Collins 1971 | A | 40 | 0.002208 |
| | Zelle (Antopol) | W | 1 | 0.001047 |
| | Riley (1972) | A | 1 | 0.049900 |
| | Sharp 1940 | A | 1 | 0.004449 |
| | Sharp 1939 | A | 1 | 0.001047 |
| | Rentschler 1941 | A | 1 | 0.001225 |
| Bacillus anthraci (w / spores) | Sharp 1939 | P | 1 | 0.000509 |
| Bacillus anthraci (spores) | Westinghouse data | | 1 | 0.000794 |
| Cryptococcus neoformans | Wang 1994 | P | 1 | 0.000102 |
| Mucor racemosus spores | Scheir 1996 | | 1 | 0.000135 |
| Penicillium expensum spores | Scheir 1996 | | 1 | 0.000177 |
| Aspergillus niger spores | Scheir 1996 | | 1 | 0.000017 |
| Aspergillus flavus spores | Scheir 1996 | | 1 | 0.000038 |
| Aspergillus glaucus spores | Scheir 1996 | | 1 | 0.000052 |
| Rhizopus nigricans spores | Scheir 1996 | | 1 | 0.000021 |
| Fusarium oxysporum | Asthana 1999 | P | 170 | 0.000112 |
| Fusarium solani | Asthana 1999 | P | 170 | 0.000071 |
| Penicillium italicum | Asthana 1999 | P | 170 | 0.000126 |
| Penicillium digitatum | Asthana 1999 | P | 170 | 0.000072 |
| Cladosporium | Westinghouse data | | 1 | 0.000038 |
| Scopulariopsis | Westinghouse data | | 1 | 0.000029 |

## 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 | $ 77,200.00 | $ 111,282.50 | $ 78,882.50 | $ 38,217.50 | $ 218,385.00 | $ 248,757.50 | $ 772,725.00 |
| Operating Infections | $ 36,360.00 | $ 46,020.00 | $ 71,700.00 | $ 33,030.00 | $ 167,835.00 | $ 134,385.00 | $ 489,330.00 |
| Clinic Infections | $ 110,232.00 | $ 119,399.00 | $ 118,234.00 | $ 61,181.00 | $ 257,795.00 | $ 98,897.00 | $ 765,738.00 |
| Aspergillius | NEED INFO | | | | | | $ - |
| STAFF | | | | | | | $ - |
| Nosocomial Infections | NEED INFO | | | | | | $ - |
| Health Care | NEED INFO | | | | | | $ - |
| Illness Absentee rate | NEED INFO | | | | | | $ - |
| 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 | NEED INFO | | | | | | $ - |
| EXTENDED LIFE OF UNITS | NEED INFO | | | | | | $ - |
| | | | | | | | $ - |
| TOTAL SAVINGS YEAR 1 | $ 80,195.68 | $ (23,671.14) | $ 70,788.42 | $ 4,097.78 | $ 5,864.24 | $ 145,383.30 | $ 282,658.28 |
| TOTAL SAVINGS YEAR 2 | $ 205,472.68 | $ 236,757.86 | $ 242,601.42 | $ 116,214.78 | $ 568,925.24 | $ 436,703.30 | $ 1,806,675.28 |
| TOTAL SAVINGS YEAR 3 | $ 205,472.68 | $ 236,757.86 | $ 242,601.42 | $ 116,214.78 | $ 568,925.24 | $ 436,703.30 | $ 1,806,675.28 |
| LIFETIME SAVINGS 10 YRS | $1,929,449.80 | $2,107,149.60 | $2,254,201.20 | $1,050,030.80 | $ 5,126,191.40 | $4,075,713.00 | $ 16,542,735.80 |

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

## 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]

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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]

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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]

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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]

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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]

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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]

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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]

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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]

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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]

[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