Residential Application of the Viratech Model UV 400 Portable Air Purification Unit

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Introduction

This report address the application of the Viratech Model UV 400 Portable Air Purification Unit to residential environments, including houses and apartments. The UV 400 unit employs three low-pressure mercury UV lamps each rated for 24 Watts of UV output. The lamps are housed inside a cartridge that is coated with the photocatalyst TiO2, which accelerates the breakdown of organic compounds like VOCs (volatile organic compounds) and reduces the concentration of the odors they cause. Air passes through the cartridge and is disinfected by the UV lamps and the air then flows through a carbon-treated gross particulate capture screen that removes large particles. Airflow is driven through the unit by a 210 cfm fan.

Independent laboratory testing has been conducted to determine the efficacy and safety of the UV 400 unit. Inactivation tests on bacteria, viruses, and reduction of odors and VOCs were completed at Northeast Laboratories in Berlin, CT, in accordance with EPA and FDA guidelines. The ViraTech UV400 model air cleaner has a demonstrated ability to disinfect air and inactivate a wide range of bacterial pathogens including *Staphylococcus aureus* (MRSA), *Pseudomonas*, and *Klebsiella* as has been conclusively demonstrated in independent laboratory tests. The UV400 produces a germicidal UV exposure dose of 41 J/m^2, as independently verified by biodosimetric testing, which is sufficient to reduce pathogenic bacterial populations by at least 99%. The UV exposure dose of 41 J/m^2 correlates with a UVGI Rating Value of URV 15. ETL certification utilizing the UL 507 Standard for Electric Fans was conducted by Intertek Testing Services in Cortland, NY.

In this report the various bacteria, fungi and viruses that may occur inside residences are identified along with their physical characteristics that determine their removal rates. These microbes are used as a basis to evaluate the performance of the UV 400 and to evaluate the performance of comparable air disinfection units on the market today for both residential and health care applications.

Residential Airborne Pathogens

Pathogens in residential homes include viruses and bacteria that come from occupants, including fungal spores that come from the environment and that may grow inside the house, and environmental bacteria. Table 1, Standard Test Array for Air Disinfection Systems, summarizes all the major airborne pathogens that may occur inside houses and apartments and the diseases or infections they may cause. Cold and flu viruses like Influenza and Rhinoviruses are commonly and seasonally released by occupants by coughing and sneezing and these become aerosolized inside homes. Transmission of these viruses can occur by inhalation or by contact with fomites left on surfaces (i.e. from sneezing), followed by self-inoculation of the eyes, nose, or mouth. Stomach viruses like Norwalk Virus can become aerosolized but more often produce fomites on surfaces that lead to hand contamination. Other common viruses like Measles and Mumps, that primarily affect children, can also spread inside residential environments via the airborne route.

Human pathogenic bacteria like *Corynebacterium diphtheria* and *Neisseria meningitis* can also become aerosolized and transmit inside homes by the airborne route by inhalation and also via fomites. Outdoor environmental bacteria like *Legionella* and *Pseudomonas* are well-established as airborne pathogens and can enter a home through air currents. A variety of fungal spores are common in outdoor air and these can enter a home by various routes, including air currents and on clothes or shoes. Once indoors, fungal spores may settle into rugs and become re-aerosolized to drift throughout a house along the floors.

All of the pathogens in Table 1, both common and uncommon, are susceptible, to varying degrees, to ultraviolet radiation. Table 1 shows the removal rates for UV air disinfection systems rated URV 6 through URV 15. URV stands for UVGI Rating Value and the UV dose ranges for these URV systems are shown in Appendix A, which also provides matching filter recommendations. The UV 400 unit qualifies as an URV 15 system and this rating is highlighted in the final column of Table 1. The URV 15 column represents the single-pass removal rates of these pathogens through the UV 400.

The Standard Test Array is used for evaluating the performance of air disinfection systems and includes pathogens likely to occur indoors in homes, but excludes various pathogens that are unique to health care, agriculture, and other non-residential facilities. Included in this list is the emerging pathogen MERS (Middle East Respiratory Syndrome) virus, which is physiologically identical to the Coronavirus (or SARS virus) and which is likely to be just as susceptible to UV irradiation as the Coronavirus, which is here used as a surrogate for UV inactivation. The single pass removal rate for MERS is 33%, which means that after four passes, or about one hour of operation, the removal rate will be 99%.

The average UV rate constant for each of the microbial groups is 0.0742 m^2/J for viruses, 0.1768 m^2/J for bacteria, and 0.0109 m^2/J for fungal spores. These representative values will be used for the simulation of the model room.

Table 1: Standard Test Array of Residential Pathogens for UV Air Disinfection

Microbe	Type	Disease or Infection	Dia. μm	UVGI k m^2/J	UV 400 Removal %
Acinetobacter baumannii	Bacteria	Opportunistic infections, meningitis	1.225	0.12800	99
Adenovirus	Virus	Colds, fever, pharyngitis, ARD, pneumonia	0.079	0.03900	79
Aeromonas	Bacteria	Non-respiratory opportunistic infections, gastroenteritis, bacteremia.	2.098	0.20310	100
Aspergillus niger	Fungal Spore	Aspergillosis, alveolitis, asthma, allergic fungal sinusitis, ODTS, toxic reactions	3.354	0.00058	2
Avian Influenza virus	Virus	Bird flu	0.098	0.10600	99
Bacillus anthracis spores	BacteriaS	Anthrax, woolsorter's disease	1.118	0.01988	55
Blastomyces dermatitidis	Fungi	Blastomycosis, Gilchrist's Disease, Chicago disease	11.000	0.01645	48
Burkholderia cenocepacia	Bacteria	Opportunistic infections.	0.707	0.03956	79
Candida albicans	Fungi	Candidamycosis, candidiasis, bronchitis, pneumonitis, onychomycosis	4.899	0.00515	19
Cladosporium herbarum	Fungal Spore	Chromoblastomycosis, allergic reactions, rhinitis, asthma	8.062	0.00370	14
Clostridium perfringens	Bacteria	Sepsis, toxic reactions, food poisoning	5	0.04699	85
Coronavirus (MERS)	Virus	MERS	0.113	0.01000	33
Coronavirus (SARS)	Virus	SARS, colds	0.113	0.01000	33
Corynebacterium diphtheriae	Bacteria	Diphtheria, toxin produced	0.698	0.07010	94
Coxiella burnetii	Bacteria	Q fever	0.283	0.15350	100
Coxsackievirus	Virus	Colds, Acute Respiratory Disorder (ARD).	0.027	0.11100	99
Cryptococcus neoformans	Fungal Spore	Cryptococcosis, cryptococcal meningitis, pneumonia possible	4.899	0.01670	49
Echovirus 1	Virus	Colds, meningitis possible	0.024	0.02878	68
Enterobacter cloacae	Bacteria	Opportunistic infections, pneumonia possible	1.414	0.03598	76
Francisella tularensis	Bacteria	Tularemia, pneumonia, fever	0.2	0.00900	30
Fusarium oxysporum	Fungal Spore	Allergic alveolitis, allergic fungal sinusitis, toxic reactions, MVOCs	11.225	0.00886	30
Haemophilus influenzae	Bacteria	Meningitis, pneumonia, endocarditis, otitis media, and flu	0.285	0.17700	100
Influenza A virus	Virus	Flu, secondary pneumonia	0.098	0.11900	99
Klebsiella pneumoniae	Bacteria	Opportunistic infections, pneumonia, ozena, rhinoscleroma	0.671	0.05480	89
Legionella pneumophila	Bacteria	Legionnaire's Disease, Pontiac fever, opportunistic infections, pneumonia	0.52	0.19298	100
Listeria monocytogenes	Bacteria	Food poisoning.	0.707	0.01480	45
Measles virus	Virus	Measles (rubeola), Hard measles, Red measles, Morbilli	0.329	0.10510	99
Mucor mucedo	Fungal Spore	Mucormycosis, rhinitis, pneumonia	7.071	0.00384	14
Norwalk Virus	Virus	Gastroenteritis	0.032	0.03040	70
Mycobacterium tuberculosis	Bacteria	Tuberculosis, TB, pneumonia possible	0.637	0.47210	100
Mycoplasma pneumoniae	Bacteria	Pneumonia, PPLO, walking pneumonia	0.177	0.27910	100

Table 1: Standard Test Array of Residential Pathogens for UV Air Disinfection

Microbe	Type	Disease or Infection	Dia. μm	UVGI k m^2/J	UV 400 Removal %
Neisseria meningitis	Bacteria	Meningitis, pharyngitis	0.177	0.05233	88
Nocardia asteroides	Bacteria	Nocardiosis, pneumonia	1.118	0.00822	28
Parainfluenza virus	Virus	Flu, colds, croup, pneumonia	0.194	0.20900	100
Parvovirus H-1	Virus	Fifth disease, anemia, fever.	0.022	0.09200	97
Penicillium chrysogenum	Fungal Spore	Alveolitis, rhinitis, asthma, allergic reactions, irritation, ODTS, toxic reactions, VOCs produced	3.262	0.00434	16
Proteus mirabilis	Bacteria	Opportunistic infections, pneumonia possible	0.494	0.28900	100
Pseudomonas aeruginosa	Bacteria	Pneumonia, toxic reactions	0.494	0.57210	100
Reovirus	Virus	Colds, fever, pneumonia, rhinorrhea	0.075	0.00940	31
Rhinovirus	Virus	Colds	0.023	0.02530	64
Rhizopus nigricans	Fungal Spore	Zygomycosis, allergic reactions, pneumonia, mucormycosis.	6.928	0.00861	29
Rickettsia prowazekii	Bacteria	Epidemic typhus, Louse-borne typhus fever, Brill-Zinsser disease	0.6	0.17600	100
Scopulariopsis brevicaulis	Fungal Spore	Allergic reactions, onychomycosis, skin lesions.	5.916	0.00344	13
Serratia marcescens	Bacteria	Opportunistic infections, bacteremia, endocarditis, pneumonia.	0.632	0.28670	100
Stachybotrys chartarum	Fungal Spore	Allergic reactions, stachybotritoxicosis, irritation, toxic reactions	5.623	0.00041	2
Staphylococcus aureus	Bacteria	Staphylococcal pneumonia, opportunistic infections (esp. MRSA)	0.866	0.11300	99
Staphylococcus epidermis	Bacteria	Opportunistic infections, bacteremia	0.866	0.16210	100
Streptococcus pyogenes	Bacteria	Scarlet fever, pharyngitis, toxic reactions	0.894	0.81100	100
Trichophyton rubrum	Fungal Spore	Skin and nail infections	4.899	0.00411	15
Ustilago zeae	Fungal Spore	Rhinitis, asthma, allergic reactions	5.916	0.06580	93
Vaccinia virus	Virus	Cowpox	0.307	0.16040	100
Yersinia pestis	Bacteria	Plague, bubonic plague, pneumonic plague, sylvatic plague.	0.707	0.15351	100

NOTES: B: Bacteria, BS: Bacterial Spore, V: Virus, F: Fungi, FS: Fungal Spore

A Model Residential Room

In order to evaluate the performance of the UV 400, and other air disinfection units, it is necessary to define a model residential room that includes standard airflow characteristics. Typical modern houses and apartments include forced air ventilation that may result in several air changes per hour. Naturally ventilated houses have unknown airflow rates that depend on the wind, leakage, and number of open windows. In this report we only address houses with forced ventilation.

Assuming that the model room has 210 sq. ft. of floor area, we would expect a typical forced air system to provide about 4 air changes per hour. With an 8 foot ceiling this equates to a volume of 1680 cu.ft. (47.6 m^3) and there will be 4 x 47.6 = 190 m^3 per hour of air exchanged or 3.17 m^3/min (112 cfm). A nominal outside air of 25% produces 28 cfm of fresh air. The UV 400 unit has an airflow of 210 cfm or 5.95 m^3/min for an ACH of 7.5. Figure 1 illustrates the model room with a UV 400 placed inside.

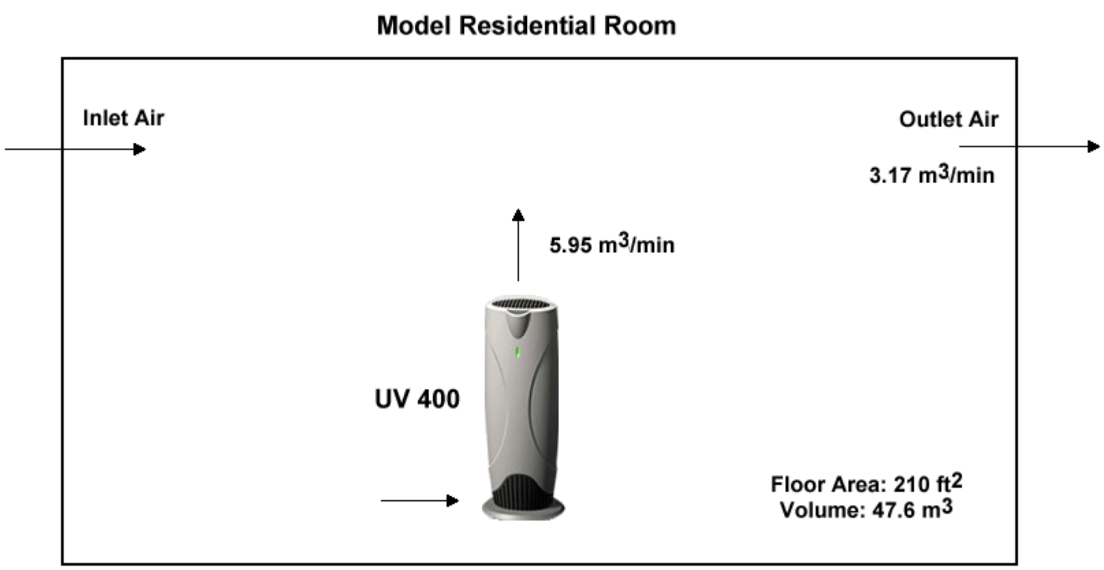

Figure 1: A model residential room with 210 ft^2 of floor area and an 8 ft ceiling.

In order to determine how well the UV 400 unit performs in this model environment it is necessary to assume some initial level of microbial contamination in the air, both inside and outside. Indoor microbial contamination hails from the occupants, pets, and from accumulated mold spores that may be embedded in rugs and furnishings or that may be growing in damp areas or in ducts. Outdoor contamination consists of fungal spores and environmental bacteria that are brought in with the outdoor air.

Let us assume an initial concentration of 1000 cfu/m^3 of bacteria and 1000 cfu/m^3 of fungal spores. These values are similar to actual measured values inside homes and the bacterial value is a suggested upper limit for indoor contamination (Kowalski 2003).

For the Outside Air model, let us assume 25% of the outside air is fresh and the rest recirculated. We will assume that outdoor air had 600 cfu/m^3 of fungal spores and 100 cfu/m^3 of environmental bacteria. There are no viruses in the outdoor air. We will also assume that Table 1 represents the mixture of indoor pathogens and that the bacteria and fungi in Table 1 represents the mixture of outdoor microbes.

Table 2 summarizes the input data for the residential room model, including input data for the full recirculation model (no outside air) and the simulation with a total room airflow (not counting the UV 400) of 112 cfm and 25% outside air.

Table 2: Input Data for Residential Room Model

Viratech UV 400	UV Dose	41	J/m^2
	Airflow	5.94657	m^3/min
	Airflow	210	cfm
	ACH	7.5	
Model Room	Floor Area	210	ft2
	Height	8	ft
	Volume	1680	ft3
	Volume	47.6	m^3
	Total Airflow	112	cfm
	Total Airflow	3.171504	m^3/min
	OA %	25	
	OA Flowrate	28	cfm
	OA Flowrate	0.792876	m^3/min
	ACH	4	
	OA ACH	1.0	
Indoor Microbes (Initial Concentration)	Bacteria	1000	cfu/m^3
	Viruses	10,000	cfu/m^3
	Fungi	1000	cfu/m^3
Outdoor Microbes	Bacteria	100	cfu/m^3
	Viruses	0	cfu/m^3
	Fungi	600	cfu/m^3
Average k Value	Bacteria	0.1768	m^2/J
	Viruses	0.0742	m^2/J
	Fungi	0.0109	m^2/J
Average Kill Rate (UV 400 Single Pass)	Bacteria	99.9	%
	Viruses	95.2	%
	Fungi	36.1	%

Two simulations will be performed using the UV 400 unit operating in the room, one without any outside air, and one with outside airflows as detailed in Table 2.

In-Place Performance in a Model Residential Room

The previous Table 2 showed the input data for the first room model, in which there is no outside air and the air cleaning is entirely performed by the UV 400 unit. It is also assumed the rooms are unoccupied and no internal generation of microbes occurs. A minute-by-minute analysis was performed using the assumption of complete mixing of air, which is reasonable for open areas. **Results show the initial microbial concentrations are reduced to zero within about 3 hours**. Figure 2 illustrates the rate at which airborne microbial concentrations are reduced over time for each of the three microbial groups. The summation of the three groups, the Total Microbes, decreases to unitary values after about 2.5 hours. Bacteria and viruses are removed at similar rates while the hardier fungal spores are removed more slowly due to their inherent resistance to UV irradiation. Because the air is exchanged through the UV 400 at about 7.5 air changes per hour, fungal spores may experience some 20 passes through the unit after 2.5 hours and this is sufficient to reduce their population to single digits. For a tabulation of the computations for Figure 2 see Appendix B, which shows the first 60 minutes of the simulation. In larger rooms, the number of passes (the ACH) would be reduced by a proportional amount, thus increasing the amount of time to disinfect the air - that is to say, the ACH is an inverse function of the time to disinfect the air and any decrease in ACH will increase the time for complete room disinfection proportionally (Kowalski 2009).

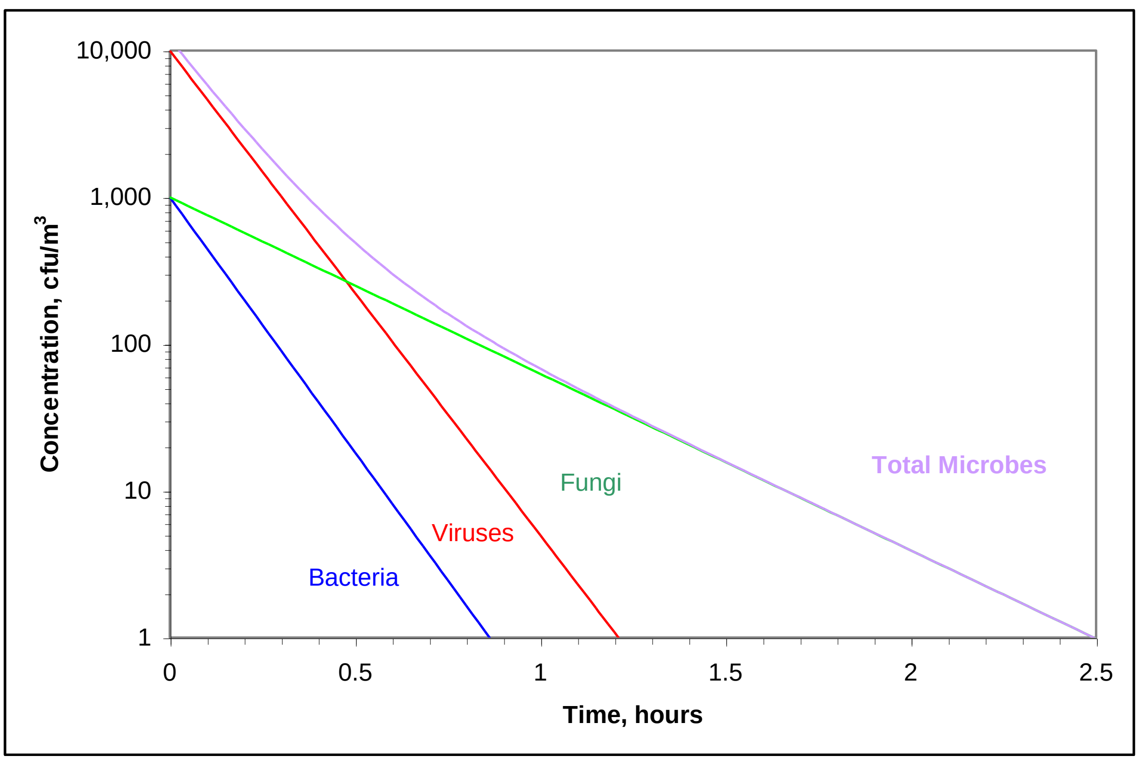

Figure 2: In-place performance of the UV 400 in a 210 ft^2 room with no outside air and initial concentrations of microbes as indicated.

The previous simulation ignored the addition of microbes to the room, which may occur from outside air and building leakage, and also from occupants and internal generation of mold spores (i.e. in problem buildings). In the next simulation it is assumed that the outside air contains environmental bacteria and fungal spores that are brought into the room unfiltered. With 112 cfm total airflow assumed and 25% outside air, this equates to 28 cfm of fresh air.

Figure 3 illustrates the results of the model room simulation. Since fungi and bacteria are continually being added to the room form unfiltered outside air, there is a steady-state limit to which indoor levels can be reduced. The steady-state condition will leave about 13 cfu/m^3 of bacteria and 222 cfu/m^3 of fungi, neither of which are considered hazardous levels. Since no viruses come from outdoor air, these values are reduced to unitary values from the initial condition. For a tabulation of the computations for Figure 3 see Appendix C, which shows the first 60 minutes of the simulation

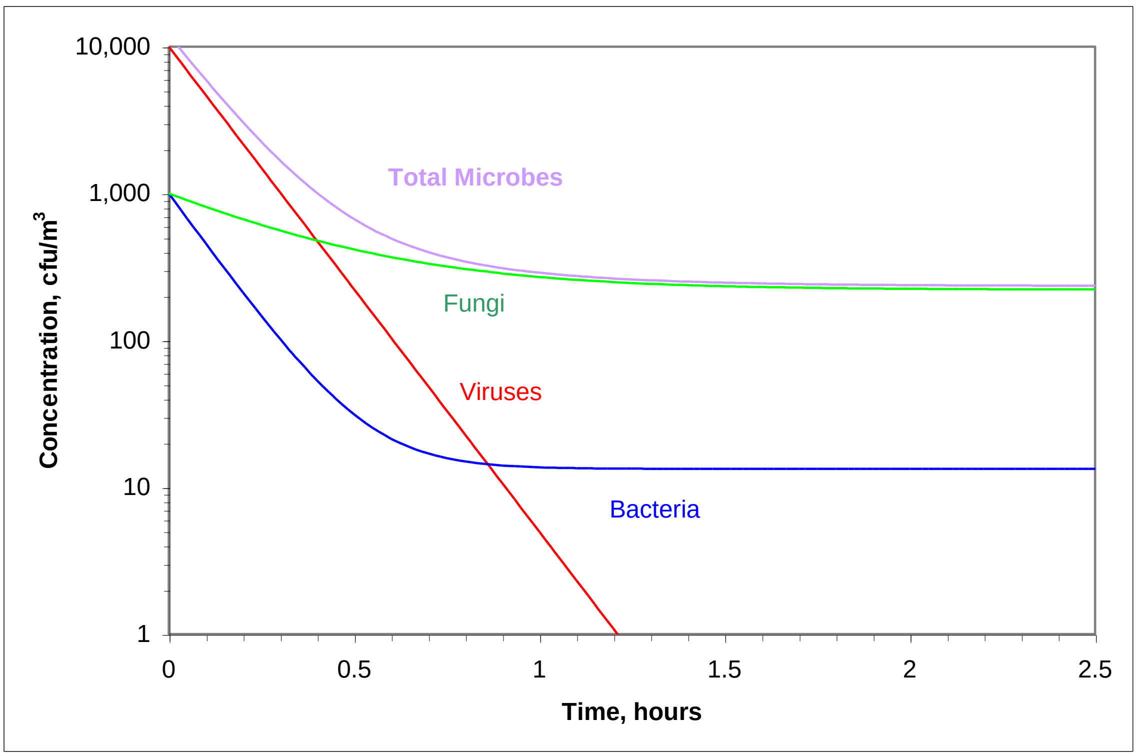

Figure 3: In-place performance of the UV 400 in a 210 ft^2 room with 25% outside air and initial concentrations of microbes as indicated.

Table 3 summarizes the results from the previous analysis and graphs, and includes the multiple pass removal rates up to one hour of operation.

Table 3: Summary of Analysis Results for Viratech UV 400

Condition / Unit	Virus	Bacteria	Fungi
Single Pass Removal Rates	%	%	%
Viratech UV 400	99.93	95.23	36.10
Time to Drawdown Airborne Concentrations, hrs	pfu/m^3	cfu/m^3	cfu/m^3
Viratech UV 400	1.2	0.85	2.5
Steady State Concentrations	pfu/m^3	cfu/m^3	cfu/m^3
Viratech UV 400	0	13	222
Multiple Pass Removal Rates			
2 passes	99.929	95.461	76.933
3 passes	99.999	99.957	99.917
4 passes (at 1 hour)	100.000	100.000	100.000

Comparison with Traditional Air Disinfection Units

A review of some thirty different air disinfection units intended for health care or residential environments that include germicidal UV lamps has been conducted by Kowalski (2009). **Only two of these units were FDA-approved, including the Viratech UV 400.** Eight of these units included PCO or carbon filters for odor control, including the Viratech UV 400. None of these devices employed electrostatics or charged media.

Ten of these units include final filters, rated MERV or HEPA. Three of these units include HEPA filters, but HEPA filters are generally regarded as overkill in such applications as they provide little additional improvement in performance over MERV filters and at considerably higher expense (Kowalski 2006). In addition, the use of HEPA filters in conjunction with UVGI renders the UV redundant. Furthermore, when filters are used in air cleaning devices they may become clogged or contaminated and require regular change-out and maintenance. Neglecting filter maintenance can result in higher energy costs and diminished airflow. The Viratech UV 400 uses no filters and its internal components are self-cleaning by virtue of the UV lamps and the PCO screen. **The Viratech unit is virtually maintenance free except for the changing of the UV lamps every 8400 hours**.

The same simulation performed in the previous section was also performed for the other high-end air disinfection units mentioned previously. Some of these units employed air filtration, and the filter performance was evaluated separately (and combined with UV performance) based on the filter performance data in Appendix D. **Analysis of the performance of the air disinfection units shows that the Viratech unit performs at the high end and has one of the highest clean air delivery rates (CADR). Over one half of the units evaluated had such low total airflows that they would not be suitable for a 200 ft^2 room.**

Of the eight units that include PCO, the Viratech unit has the highest single pass removal rate for viruses. In terms of the time required to draw down airborne concentrations to unitary values (see Figure 2), the Viratech unit outperforms all other PCO units for removal of viruses and bacteria. In terms of the residual steady state concentrations in rooms with outside air, the Viratech has the best performance against bacteria. In comparison with the majority of air disinfection units which do not utilize PCO or carbon filters, the Viratech unit will be able to remove odors and VOCs that the other non-PCO units will not. This can be an advantage in residential environments that are often subject to odors from mold, pets, and other sources of smells and organic contamination.

Many of the air disinfection units evaluated are so compact and have such low airflows that they appear to be styled for consumer sales and novelty rather than true effectiveness and performance. Indeed, the top selling unit has no fan at all and uses a novel 'ionic wind' technology that captures consumers' attention more effectively than it captures airborne pathogens. The device was given a 'fail' by Consumer Reports for its' lack of a sufficient CADR and concerns were voiced about its' ozone

generation, which puts this contaminant into the room air. The Viratech UV 400 unit, however, is designed for performance and uses proven, reliable technologies to accomplish room air disinfection, and generates no detectable ozone.

Summary and Discussion

The Viratech UV 400 is capable of superior air disinfection performance and although it is designed for residential applications its performance characteristics are comparable with the best air disinfection units that are available to day in the hospital and health care industries. The UV 400 can operate in any room of approximately 210 ft^2 to effectively decontaminate indoor air of any and all bacteria, viruses, or fungi that would conceivably occur in occupied indoor environments.

The Viratech UV 400 produces a UV dose of 41 J/m^2 as verified by biodosimetric testing performed by an independent laboratory. This rates an URV 15 by the proposed rating standard in Appendix A and is the highest rating recommended for indoor or health care environments. Higher URV ratings produce diminishing returns at considerable cost while ratings between the range of URV 10 and URV 15 are perfectly adequate for cleansing the air in normal indoor environments, provided airflows are also adequate. Since the Viratech unit recirculates room air, multiple passes are obtained and analysis shows better than 99% of pathogens, including all viruses, bacteria, and fungal spores can be removed after four passes, or about one hour, of operation.

Comparison of the Viratech UV 400 with some thirty air disinfection units on the market today for both residential and health care applications shows that it ranks among the top units in terms of performance and among the lowest in terms of maintenance and operating cost, and that it accomplishes this without the use of filters. Filters, it must be noted, will become contaminated or clogged over time and add to the cost of fan power. The Viratech UV 400 provides higher air flow rates than most of the units examined by virtue of not having a filter and has therefore, one of the highest clean air delivery rates (CADR) of all the units evaluated. The Viratech unit is also one of very few units that has obtained FDA clearance and that has documented test results to prove claims.

In addition, the Viratech UV 400 de-odorizes the air through the use of Photocatalytic oxidation (PCO), which removes odors and volatile organic compounds (VOCs). Of the eight air disinfection units employing PCO for odor control, the Viratech unit performs as good or better at also removing airborne pathogens, especially against viruses and bacteria.

The Viratech UV 400 will serve equally well in hospital environments as it will in residential homes. Some of the most common and dangerous infections in hospitals, such as *Mycobacterium tuberculosis*, MRSA, SARS, and *Clostridium difficile* spores are susceptible to inactivation by the UV 400 and can be removed, after multiple passes, to harmless airborne levels or, as in the case of TB bacilli, can be completely eradicated.

In conclusion, no other air purifier among those evaluated combined an FDA Clearance with the highest CADR, lowest maintenance costs, and the ability to remove odors and VOCs. Considering the ability of the UV 400 to kill all bacteria, viruses, and fungal spores in a typical sized room, it is clearly among the "Best in Class" of all devices evaluated.

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Appendix A: UVGI Rating Values (URV) and Matching Filters

URV	Dose J/m^2	Dose μW-s/cm^2	Mean Dose, J/m^2	MERV Filter Recommendation	Notes
1	0.01	1	0.055	6	
2	0.10	10	0.15	6	
3	0.20	20	0.25	6	
4	0.30	30	0.4	6	
5	0.50	50	0.63	6	
6	0.75	75	0.88	6	
7	1.0	100	1.25	7	
8	1.5	150	2	8	
9	2.5	250	3.75	9	
10	5	500	7.5	10	Normal Design Range
11	10	1000	12.5	11	
12	15	1500	17.5	12	
13	20	2000	25	13	
14	30	3000	35	14	
15	40	4000	45	15	
16	50	5000	55	15	
17	60	6000	70	15	
18	80	8000	90	15	
19	100	10000	150	15	
20	200	20000	250	15	
21	300	30000	350	15	
22	400	40000	450	15	
23	500	50000	750	15	
24	1000	100000	1500	15	
25	2000	200000	2500	15	

Appendix B: Residential Model with Complete Mixing, No Outside Air

Time		Microbes in Room				Indoor Concentrations				Microbes removed by UV 400		
min	hr	Viruses #	Bacteria #	Fungi #	Total microbes	Virus pfu/m^3	Bacterial cfu/m^3	Fungi cfu/m^3	Total cfu/m^3	Virus pfu	Bacterial cfu	Fungi cfu
0	0	476000	47600	47600	571,200	10,000	1000	1000	12,000	56664	5946	2148
1	0.02	419336	41654	45452	506,442	8,810	875	955	10,640	49919	5203	2051
2	0.03	369417	36451	43401	449,269	7,761	766	912	9,438	43976	4553	1958
3	0.05	325440	31898	41443	398,781	6,837	670	871	8,378	38741	3984	1870
4	0.07	286699	27914	39573	354,186	6,023	586	831	7,441	34129	3487	1786
5	0.08	252569	24427	37788	314,784	5,306	513	794	6,613	30067	3051	1705
6	0.10	222503	21376	36083	279,961	4,674	449	758	5,882	26487	2670	1628
7	0.12	196016	18706	34455	249,176	4,118	393	724	5,235	23334	2337	1555
8	0.13	172681	16369	32900	221,950	3,628	344	691	4,663	20556	2045	1484
9	0.15	152125	14324	31415	197,865	3,196	301	660	4,157	18109	1789	1417
10	0.17	134015	12535	29998	176,548	2,815	263	630	3,709	15954	1566	1354
11	0.18	118062	10969	28644	157,676	2,480	230	602	3,313	14054	1370	1292
12	0.20	104007	9599	27352	140,959	2,185	202	575	2,961	12381	1199	1234
13	0.22	91626	8400	26118	126,144	1,925	176	549	2,650	10907	1049	1178
14	0.23	80719	7351	24939	113,009	1,696	154	524	2,374	9609	918	1125
15	0.25	71110	6433	23814	101,356	1,494	135	500	2,129	8465	804	1075
16	0.27	62645	5629	22740	91,013	1,316	118	478	1,912	7457	703	1026
17	0.28	55187	4926	21714	81,827	1,159	103	456	1,719	6570	615	980
18	0.30	48618	4311	20734	73,662	1,021	91	436	1,548	5788	538	936
19	0.32	42830	3772	19798	66,400	900	79	416	1,395	5099	471	893
20	0.33	37731	3301	18905	59,937	793	69	397	1,259	4492	412	853
21	0.35	33240	2889	18052	54,180	698	61	379	1,138	3957	361	815
22	0.37	29283	2528	17237	49,048	615	53	362	1,030	3486	316	778
23	0.38	25797	2212	16460	44,469	542	46	346	934	3071	276	743
24	0.40	22726	1936	15717	40,379	477	41	330	848	2705	242	709
25	0.42	20021	1694	15008	36,722	421	36	315	771	2383	212	677
26	0.43	17637	1482	14331	33,450	371	31	301	703	2100	185	647
27	0.45	15538	1297	13684	30,519	326	27	287	641	1850	162	617
28	0.47	13688	1135	13067	27,890	288	24	275	586	1629	142	590
29	0.48	12059	993	12477	25,529	253	21	262	536	1435	124	563
30	0.50	10623	869	11914	23,406	223	18	250	492	1265	109	538
31	0.52	9358	761	11376	21,496	197	16	239	452	1114	95	513
32	0.53	8244	666	10863	19,773	173	14	228	415	981	83	490
33	0.55	7263	583	10373	18,219	153	12	218	383	865	73	468
34	0.57	6398	510	9905	16,813	134	11	208	353	762	64	447
35	0.58	5637	446	9458	15,541	118	9	199	326	671	56	427
36	0.60	4966	390	9031	14,387	104	8	190	302	591	49	407
37	0.62	4375	342	8624	13,340	92	7	181	280	521	43	389
38	0.63	3854	299	8235	12,387	81	6	173	260	459	37	372
39	0.65	3395	262	7863	11,520	71	5	165	242	404	33	355
40	0.67	2991	229	7508	10,728	63	5	158	225	356	29	339
41	0.68	2635	200	7170	10,005	55	4	151	210	314	25	323
42	0.70	2321	175	6846	9,343	49	4	144	196	276	22	309
43	0.72	2045	153	6537	8,735	43	3	137	184	243	19	295
44	0.73	1801	134	6242	8,178	38	3	131	172	214	17	282
45	0.75	1587	117	5961	7,665	33	2	125	161	189	15	269
46	0.77	1398	103	5692	7,192	29	2	120	151	166	13	257
47	0.78	1232	90	5435	6,756	26	2	114	142	147	11	245
48	0.80	1085	79	5190	6,353	23	2	109	133	129	10	234
49	0.82	956	69	4955	5,980	20	1	104	126	114	9	224
50	0.83	842	60	4732	5,634	18	1	99	118	100	8	214
51	0.85	742	53	4518	5,313	16	1	95	112	88	7	204
52	0.87	654	46	4314	5,014	14	1	91	105	78	6	195
53	0.88	576	40	4120	4,736	12	1	87	99	69	5	186
54	0.90	507	35	3934	4,476	11	1	83	94	60	4	178
55	0.92	447	31	3756	4,234	9	1	79	89	53	4	169
56	0.93	394	27	3587	4,008	8	1	75	84	47	3	162
57	0.95	347	24	3425	3,796	7	0	72	80	41	3	155
58	0.97	305	21	3271	3,597	6	0	69	76	36	3	148
59	0.98	269	18	3123	3,410	6	0	66	72	32	2	141
60	1.00	237	16	2982	3,235	5	0	63	68	28	2	135

Appendix C: Residential Model with Complete Mixing, 25% Outside Air

Time		Microbes in Room				Indoor Concentrations				Microbes removed by UV 400		
		Viruses	Bacteria	Fungi	Total	Virus	Bacterial	Fungi	Total	Virus	Bacterial	Fungi
min	hr	#	#	#	microbes	pfu/m^3	cfu/m^3	cfu/m^3	cfu/m^3	pfu	cfu	cfu
0	0	476000	47600	47600	571,200	10,000	1000	1000	12,000	56664	5946	2148
1	0.02	419336	41803	46345	507,483	8,810	878	974	10,661	49919	5222	2091
2	0.03	369417	36730	45146	451,293	7,761	772	948	9,481	43976	4588	2037
3	0.05	325440	32291	44002	401,733	6,837	678	924	8,440	38741	4033	1985
4	0.07	286699	28406	42909	358,014	6,023	597	901	7,521	34129	3548	1936
5	0.08	252569	25007	41865	319,441	5,306	525	880	6,711	30067	3124	1889
6	0.10	222503	22032	40869	285,403	4,674	463	859	5,996	26487	2752	1844
7	0.12	196016	19428	39917	255,361	4,118	408	839	5,365	23334	2427	1801
8	0.13	172681	17150	39009	228,840	3,628	360	820	4,808	20556	2142	1760
9	0.15	152125	15157	38141	205,423	3,196	318	801	4,316	18109	1893	1721
10	0.17	134015	13412	37312	184,740	2,815	282	784	3,881	15954	1675	1684
11	0.18	118062	11886	36521	166,469	2,480	250	767	3,497	14054	1485	1648
12	0.20	104007	10550	35766	150,323	2,185	222	751	3,158	12381	1318	1614
13	0.22	91626	9381	35045	136,052	1,925	197	736	2,858	10907	1172	1581
14	0.23	80719	8358	34356	123,432	1,696	176	722	2,593	9609	1044	1550
15	0.25	71110	7463	33698	112,271	1,494	157	708	2,359	8465	932	1520
16	0.27	62645	6679	33070	102,394	1,316	140	695	2,151	7457	834	1492
17	0.28	55187	5994	32471	93,651	1,159	126	682	1,967	6570	749	1465
18	0.30	48618	5394	31898	85,909	1,021	113	670	1,805	5788	674	1439
19	0.32	42830	4869	31351	79,050	900	102	659	1,661	5099	608	1415
20	0.33	37731	4409	30829	72,970	793	93	648	1,533	4492	551	1391
21	0.35	33240	4007	30331	67,578	698	84	637	1,420	3957	501	1369
22	0.37	29283	3655	29855	62,793	615	77	627	1,319	3486	457	1347
23	0.38	25797	3348	29400	58,545	542	70	618	1,230	3071	418	1327
24	0.40	22726	3078	28966	54,770	477	65	609	1,151	2705	385	1307
25	0.42	20021	2842	28552	51,415	421	60	600	1,080	2383	355	1288
26	0.43	17637	2636	28156	48,429	371	55	592	1,017	2100	329	1270
27	0.45	15538	2456	27778	45,771	326	52	584	962	1850	307	1253
28	0.47	13688	2298	27417	43,403	288	48	576	912	1629	287	1237
29	0.48	12059	2159	27072	41,290	253	45	569	867	1435	270	1222
30	0.50	10623	2038	26743	39,405	223	43	562	828	1265	255	1207
31	0.52	9358	1933	26429	37,720	197	41	555	792	1114	241	1193
32	0.53	8244	1840	26129	36,214	173	39	549	761	981	230	1179
33	0.55	7263	1759	25843	34,865	153	37	543	732	865	220	1166
34	0.57	6398	1688	25569	33,655	134	35	537	707	762	211	1154
35	0.58	5637	1626	25308	32,570	118	34	532	684	671	203	1142
36	0.60	4966	1571	25059	31,596	104	33	526	664	591	196	1131
37	0.62	4375	1524	24820	30,719	92	32	521	645	521	190	1120
38	0.63	3854	1482	24593	29,929	81	31	517	629	459	185	1110
39	0.65	3395	1446	24376	29,217	71	30	512	614	404	181	1100
40	0.67	2991	1414	24168	28,573	63	30	508	600	356	177	1091
41	0.68	2635	1386	23970	27,991	55	29	504	588	314	173	1082
42	0.70	2321	1362	23781	27,464	49	29	500	577	276	170	1073
43	0.72	2045	1340	23601	26,986	43	28	496	567	243	167	1065
44	0.73	1801	1322	23428	26,552	38	28	492	558	214	165	1057
45	0.75	1587	1305	23264	26,156	33	27	489	550	189	163	1050
46	0.77	1398	1291	23107	25,796	29	27	485	542	166	161	1043
47	0.78	1232	1279	22957	25,467	26	27	482	535	147	160	1036
48	0.80	1085	1268	22813	25,166	23	27	479	529	129	158	1029
49	0.82	956	1258	22676	24,890	20	26	476	523	114	157	1023
50	0.83	842	1250	22546	24,637	18	26	474	518	100	156	1017
51	0.85	742	1242	22421	24,405	16	26	471	513	88	155	1012
52	0.87	654	1236	22302	24,191	14	26	469	508	78	154	1006
53	0.88	576	1230	22188	23,994	12	26	466	504	69	154	1001
54	0.90	507	1225	22079	23,812	11	26	464	500	60	153	996
55	0.92	447	1221	21976	23,643	9	26	462	497	53	153	992
56	0.93	394	1217	21877	23,487	8	26	460	493	47	152	987
57	0.95	347	1214	21782	23,343	7	26	458	490	41	152	983
58	0.97	305	1211	21692	23,208	6	25	456	488	36	151	979
59	0.98	269	1209	21605	23,083	6	25	454	485	32	151	975
60	1.00	237	1206	21523	22,966	5	25	452	482	28	151	971

Appendix D: Standard Test Array for Air Filtration Systems

Microbe	Type	Dia.	Filter Removal %							
		µm	MERV 6	MERV 8	MERV 10	MERV 11	MERV 12	MERV 13	MERV 14	MERV 15
Parvovirus H-1	V	0.022	21	37	35	52	72	84	95	98
Echovirus 1	V	0.024	20	35	34	50	69	83	95	98
Coxsackievirus	V	0.027	19	33	31	47	66	80	94	97
Murine Norovirus (MNV)	V	0.032	17	30	28	43	62	76	92	95
Reovirus	V	0.075	9	16	15	24	37	52	75	78
Adenovirus	V	0.079	9	15	14	23	36	50	73	76
Influenza A virus	V	0.098	7	13	12	19	31	44	68	71
Avian Influenza virus	V	0.098	7	13	12	19	31	44	68	71
Coronavirus (SARS)	V	0.113	6	12	10	18	28	41	64	68
Coronavirus (MERS)	V	0.113	0	0	0	0	0	0	0	0
Mycoplasma pneumoniae	B	0.177	5	9	8	14	23	37	58	64
Neisseria catarrhalis	B	0.177	5	9	8	14	23	37	58	64
Francisella tularensis	B	0.2	4	9	8	14	23	37	58	66
Newcastle Disease Virus	V	0.212	4	9	8	14	23	37	59	67
Coxiella burnetii	B	0.283	4	9	8	15	25	43	64	75
Haemophilus influenzae	B	0.285	4	9	8	16	25	43	64	75
Proteus vulgaris	B	0.291	4	9	8	16	25	43	65	76
Vaccinia virus	V	0.307	5	10	9	16	26	45	66	78
Measles virus	V	0.329	5	10	9	17	27	47	69	80
Proteus mirabilis	B	0.494	7	15	14	25	39	64	84	94
Pseudomonas aeruginosa	B	0.494	7	15	14	25	39	64	84	94
Legionella pneumophila	B	0.52	7	16	15	27	41	66	86	95
Rickettsia prowazekii	B	0.6	9	19	18	31	47	73	90	97
Serratia marcescens	B	0.632	9	20	19	33	49	75	92	98
Mycobacterium tuberculosis	B	0.637	9	21	19	33	49	75	92	98
Klebsiella pneumoniae	B	0.671	10	22	20	35	52	78	93	99
Corynebacterium diphtheriae	B	0.698	10	23	21	37	54	79	94	99
Burkholderia cenocepacia	B	0.707	11	24	22	37	54	80	94	99
Listeria monocytogenes	B	0.707	11	24	22	37	54	80	94	99
Yersinia enterocolitica	B	0.707	11	24	22	37	54	80	94	99
Staphylococcus aureus	B	0.866	14	30	28	45	64	87	97	100
Staphylococcus epidermis	B	0.866	14	30	28	45	64	87	97	100
Streptococcus pyogenes	B	0.894	14	31	29	47	66	88	97	100
Bacillus anthracis spores	BS	1.118	19	40	38	57	76	92	99	100
Nocardia asteroides	B	1.118	19	40	38	57	76	92	99	100
Acinetobacter baumannii	B	1.225	21	44	42	61	80	94	99	100
Enterobacter cloacae	B	1.414	24	51	49	68	85	95	99	100
Aeromonas	B	2.098	35	66	68	83	95	96	99	100
Penicillium chrysogenum	FS	3.262	44	75	84	91	99	96	99	100
Aspergillus niger	FS	3.354	45	76	85	92	99	96	99	100
Candida albicans	F	4.899	49	77	91	94	99	96	99	100
Cryptococcus neoformans	FS	4.899	49	77	91	94	99	96	99	100
Trichophyton rubrum	FS	4.899	49	77	91	94	99	96	99	100
Clostridium tetani	B	5	49	77	91	94	99	96	99	100
Stachybotrys chartarum	FS	5.623	49	77	92	94	99	96	99	100
Scopulariopsis brevicaulis	FS	5.916	50	77	92	94	99	96	99	100
Ustilago zeae	FS	5.916	50	77	92	94	99	96	99	100
Rhizopus nigricans	FS	6.928	50	77	93	94	99	96	99	100
Mucor mucedo	FS	7.071	50	77	93	94	99	96	99	100
Cladosporium herbarum	FS	8.062	50	77	93	94	99	96	99	100
Blastomyces dermatitidis	F	11.000	50	77	93	94	99	96	99	100
Fusarium oxysporum	FS	11.225	50	77	93	94	99	96	99	100
Average Removal Rate	%		21	37	40	49	61	73	86	90

ADDENDUM: Pet Pathogens and Allergens

Homes with pets such as cats, dogs, birds, or rodents may be subject to exposure to additional pathogens and allergens from these animals. Table 3 summarizes all potentially airborne pet allergens and pathogens along with the disease caused, the particular animal that may be afflicted (D for Dog, C for Cat, B for Bird, or R for Rodent), and the microbial group to which it belongs (bacteria, virus, or fungi). The UV susceptibility is used to compute the final column, the single pass kill rate for the Viratech UV 400, which is 41 J/m2.

A number of these potentially airborne pathogens can be transmitted to humans and, in fact, several of these microbes appear in the list of human pathogens presented in Table 1 and these tables may be compared to find the pathogens common between humans and their pets. Such pathogens often transmit both ways, and humans infected with a disease may transmit it to their pets (Kowalski and Learned 2011, Kowalski 2013).

Pet pathogens behave much the same indoors as ordinary human pathogens, and they may transmit via inhalation or by contact with hands followed by inoculation (of eyes, nose, or mouth). Among pets these diseases often transmit via direct contact (i.e. nose to nose) but can also be inhaled. These pathogens, especially the fungi, can insinuate themselves in carpets and furnishings which the pets frequent and any air treatment employed may also require regular cleaning of surfaces.

All of the pet pathogens in Table 3 are subject to removal by the same technologies that control human pathogens. They can be purged and replaced with fresh air (except for those pathogens that hail from the environment or outside air), they can be filtered and removed from the airstream, or they can be killed or inactivated by ultraviolet radiation to disinfect the airstream. The performance of the Viratech UV 400 against these pet pathogens will be similar to its performance against human pathogens. That is, the overall removal rates of the pathogens in Table 3 could be expected to be very similar to the removal rates for comparable pathogens in Table 1. The Viratech UV 400 unit will perform as well against pet pathogens as it does against human pathogens.

Table 3: Potentially Airborne Pet Pathogens and Allergens

PATHOGEN or DISEASE	CDB	GROUP	DISEASE	UV400 Kill % per pass
Histoplasma capsulatum	DCB	Fungal spore	URD	49.06
Infectious Bronchitis Virus (IBV)	B	Virus	bronchitis	100.00
Infectious Laryngotracheitis	B	Virus	respiratory disease	99.11
Influenza A virus	DCBR	Virus	flu, secondary pneumonia	98.41
Kyasanur Forest virus	R	Virus	viral disease	unk
Listeria monocytogenes	DCR	Bacteria	Listeriosis	40.59
Louping Ill (LIV)	DR	Virus	Encephalomyelitis	12.62
Lymphocytic choriomeningitis (LCMV)	DR	Virus	Armstrong's disease	91.63
Marek's Disease Virus (Herpesvirus)	B	Virus	Marek's disease	92.52
Microsporum spp.	DCR	Fungal Spore	Dermatophyopsis	unk
Mycobacterium avium	CBR	Bacteria	Paratuberculosis	83.45
Mycobacterium bovis	DCR	Bacteria	Tuberculosis	99.94
Mycobacterium tuberculosis	DC	Bacteria	Tuberculosis	100.00
Mycoplasma spp.	CBR	Bacteria	infectious anemia, eye disease	100.00
Newcastle Disease Virus (NDV)	B	Virus	NDV	99.88
Nipah virus	DCR	Virus	respiratory syndrome	100.00
Omsk hemorrhagic fever	R	Virus	hemmorrhagic fever	unk
Papilloma virus	B	Virus	wart-like tumors	64.99
Parainfluenza virus	DR	Virus	flu, colds, croup, pneumonia	98.84
Pneumocystis carinii	DC	Fungal Spore	pneumocystosis	unk
Polyomavirus	B	Virus	paralysis, diarrhea	15.40
Pseudomonas aeruginosa	B	Bacteria	infection	99.47
Pseudomonas diminuta	R	Bacteria	rhinitis	99.47
Pseudorabies (PRV)	DCR	Virus	Aujeszky's Disease	93.74
Psittacine Beak and Feather Disease	B	Virus	beak & feather infections	24.95
Rabies virus	DCR	Virus	rabies	99.99
Reovirus	BR	Virus	colds, fever, pneumonia	48.11
Salmonella enteritidis	BR	Bacteria	Salmonellosis	94.35
Salmonella typhi	BR	Bacteria	Salmonellosis	99.76
Spirillus minus	DCR	Bacteria	Rat Bite Fever	unk
Sporothrix schenckii	DCR	Fungal Spore	Sporotrichosis	unk
Staphylococcus aureus	DCBR	Bacteria	MRSA, various infections	100.00
Streptobacillus moniliformis	DCR	Bacteria	Rat Bite Fever	unk
Streptococcus pneumoniae	R	Bacteria	pneumonia	18.27
Streptococcus pyogenes	DCR	Bacteria	fever	100.00
Swine Influenza	DC	Virus	H1N1 flu	98.20
Trichophyton spp.	DCR	Fungal Spore	Dermatophyopsis	unk
Yersinia pestis	DCR	Bacteria	Bubonic & Pneumonic Plague	98.70
Yersinia pseudotuberculosis	R	Bacteria	pseudotuberculosis	98.70
Corynebacterium bovis	R	Bacteria	hyperkeratosis	94.35
Corynebacterium kutscheri	R	Bacteria	pseudotuberculosis	94.35
Coxsackievirus	R	Virus	colds	68.71
Echovirus	R	Virus	colds	68.09
Guineapig adenovirus	R	Virus	colds	10.11
Junin virus	R	Virus	hemorrhagic fever	92.06
Klebsiella orthinolytica	R	Bacteria	pneumonia	83.77
Klebsiella oxytoca	R	Bacteria	pneumonia	83.77
Klebsiella planticola	R	Bacteria	pneumonia	83.77
Klebsiella pneumoniae	R	Bacteria	pneumonia	83.77
Mousepox	R	Virus	pox	99.52
Mumps	R	Virus	mumps	95.74
Pneumonia Virus of Mice (PVM)	R	Virus	pneumonia	unk
Sendai	R	Virus	Sendai disease	98.53

D = Dog
C = Cat
B = Bird
R = Rodent

Table 3: Potentially Airborne Pet Pathogens and Allergens

PATHOGEN or DISEASE	CDB	GROUP	DISEASE	UV D90 J/m^2
Histoplasma capsulatum	DCB	Fungal spore	URD	140
Infectious Bronchitis Virus (IBV)	B	Virus	bronchitis	9
Infectious Laryngotracheitis	B	Virus	respiratory disease	20
Influenza A virus	DCBR	Virus	flu, secondary pneumonia	23
Kyasanur Forest virus	R	Virus	viral disease	unk
Listeria monocytogenes	DCR	Bacteria	Listeriosis	181
Louping Ill (LIV)	DR	Virus	Encephalomyelitis	700
Lymphocytic choriomeningitis (LCMV)	DR	Virus	Armstrong's disease	38
Marek's Disease Virus (Herpesvirus)	B	Virus	Marek's disease	36
Microsporum spp.	DCR	Fungal Spore	Dermatophyopsis	unk
Mycobacterium avium	CBR	Bacteria	Paratuberculosis	52
Mycobacterium bovis	DCR	Bacteria	Tuberculosis	13
Mycobacterium tuberculosis	DC	Bacteria	Tuberculosis	5
Mycoplasma spp.	CBR	Bacteria	infectious anemia, eye disease	8
Newcastle Disease Virus (NDV)	B	Virus	NDV	14
Nipah virus	DCR	Virus	respiratory syndrome	7
Omsk hemorrhagic fever	R	Virus	hemmorrhagic fever	unk
Papilloma virus	B	Virus	wart-like tumors	90
Parainfluenza virus	DR	Virus	flu, colds, croup, pneumonia	21
Pneumocystis carinii	DC	Fungal Spore	pneumocystosis	unk
Polyomavirus	B	Virus	paralysis, diarrhea	564
Pseudomonas aeruginosa	B	Bacteria	infection	18
Pseudomonas diminuta	R	Bacteria	rhinitis	18
Pseudorabies (PRV)	DCR	Virus	Aujeszky's Disease	34
Psittacine Beak and Feather Disease	B	Virus	beak & feather infections	329
Rabies virus	DCR	Virus	rabies	11
Reovirus	BR	Virus	colds, fever, pneumonia	144
Salmonella enteritidis	BR	Bacteria	Salmonellosis	33
Salmonella typhi	BR	Bacteria	Salmonellosis	16
Spirillus minus	DCR	Bacteria	Rat Bite Fever	unk
Sporothrix schenckii	DCR	Fungal Spore	Sporotrichosis	unk
Staphylococcus aureus	DCBR	Bacteria	MRSA, various infections	4
Streptobacillus moniliformis	DCR	Bacteria	Rat Bite Fever	unk
Streptococcus pneumoniae	R	Bacteria	pneumonia	468
Streptococcus pyogenes	DCR	Bacteria	fever	1
Swine Influenza	DC	Virus	H1N1 flu	23
Trichophyton spp.	DCR	Fungal Spore	Dermatophyopsis	unk
Yersinia pestis	DCR	Bacteria	Bubonic & Pneumonic Plague	22
Yersinia pseudotuberculosis	R	Bacteria	pseudotuberculosis	22
Corynebacterium bovis	R	Bacteria	hyperkeratosis	33
Corynebacterium kutscheri	R	Bacteria	pseudotuberculosis	33
Coxsackievirus	R	Virus	colds	81
Echovirus	R	Virus	colds	83
Guineapig adenovirus	R	Virus	colds	886
Junin virus	R	Virus	hemorrhagic fever	37
Klebsiella orthinolytica	R	Bacteria	pneumonia	52
Klebsiella oxytoca	R	Bacteria	pneumonia	52
Klebsiella planticola	R	Bacteria	pneumonia	52
Klebsiella pneumoniae	R	Bacteria	pneumonia	52
Mousepox	R	Virus	pox	18
Mumps	R	Virus	mumps	30
Pneumonia Virus of Mice (PVM)	R	Virus	pneumonia	unk
Sendai	R	Virus	Sendai disease	22

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