Performance of the NQ500 Against Nosocomial Pathogens and the H1N1 Influenza Virus

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Introduction

This report evaluates the performance of the NQ500 air cleaner against hospital-acquired (nosocomial) infectious microbes with special focus on the H1N1 strain of Influenza. The NQ500 uses a combination of filtration and ultraviolet germicidal irradiation (UVGI) to remove or inactivate airborne microbes. Filtration is an effective means of removing particulates from the air, including viruses, and its application is well understood. UVGI is an effective means of inactivating bacteria and viruses, and its use has been the subject of intensive investigation over the past few decades. The effectiveness of UVGI in hospital applications has been well documented in a number of studies and it is evaluated here in terms of its ability to remove a pathogen of great current concern – the H1N1 strain of Influenza. Results indicate that the H1N1 virus is highly susceptible to inactivation with the NQ500 unit producing an inactivation rate of 100% through the UV component, and with a filtration removal rate that is approximately 99.99% the combined removal rate of the NQ500 for H1N1 influenza virus will be 100%.

The NQ500 Air Cleaner

The model NQ500 air cleaner is a unitary air disinfection system that operates at up to 500 cfm (14.16 m^3/min). It contains prefilters and a final HEPA 99.97% filter as well as a UV component capable of producing a UV exposure dose of 328 J/m^2. This UV dose corresponds to a UVGI Rating Value (URV) of 21, which exceeds the recommendations for air disinfection capability as specified by the International Ultraviolet Association (IUVA 2005). Since the removal rates for the NQ500 approach 99.99%, the clean air delivery rate (CADR) is also approximately 500 cfm. In a summary of unitary air cleaner system performance presented in Kowalski (2009), the NQ500 had the highest overall CADR rating and therefore is the highest ranked system of all the 31 systems summarized in Table 1. It should be noted that the CADR is the primary indicator of performance of any recirculating air cleaner and is the product of the removal rate (or inactivation rate) and the total airflow.

Table 1: Modern Unitary UV System Specifications

Manufacturer	Model	Airflow/CADR		Prefilter	Primary Filter	UVP W	Dose J/m^2	URV	Notes
		cfm	m^3/min						
NQ Industries	NQ500	500	14.16	Yes (2)	HEPA	117	328	21	multispeed
Calutech	ADU	400	11.33	Yes	optional	62	74	17	carbon filter
NQ Industries	NQ Clarifier Medical	350	9.91	Yes	HEPA	11.16	16.3	12	carbon filter
Novatron	Bioprotector BP114i	300	8.49	none	MERV13	228	288	20	lab test dose
sterilAir AG	UVR2250-2	265	7.50	optional	none	46	324	21	
sterilAir AG	UVR2250-4	265	7.50	optional	none	92	649	23	
Eco-Rx	RX-400	210	5.95	screen	none	66	41	15	lab test dose
UVC LLC	Airwave	200	5.66	none	MERV13	16	46.7	15	
Sterilite	Arianne 250-N	188	5.33	Yes	none	144	115	19	multispeed
BARO GmbH & Co	AirTube C	177	5.00	optional	none	64	137	19	
Sterilite	Arianne 250-N	177	5.00	Yes	none	144	100	19	multispeed
Holmes Group	BAP920-U	175	4.96	none	MERV15	22	39.5	14	PCO
Sterilite	Arianne 250-N	153	4.33	Yes	none	144	94	18	multispeed
UV Superstore	UV-SC-2AB/10SS	150	4.25	Yes	HEPA	30	86.5	18	tank top unit
Holmes Group	BAP920-U	150	4.25	none	MERV15	22	46.1	15	PCO
Holmes Group	BAP920-U	125	3.54	none	MERV15	22	55.3	16	PCO
BARO GmbH & Co	Air Wetech L	118	3.33	screen	none	128	274	20	
Air Clean Assurance	HDU	110	3.11	Yes	MERV14	12	83.6	18	MERV8 prefilt.
Holmes Group	BAP920-U	100	2.83	none	MERV15	22	69.2	17	PCO
sterilAir AG	UVR2250-1	88	2.50	optional	none	27	190	19	
Virobuster	Steritube	74	2.083	G4	none	57	355	21	multispeed
Amcor	AM-45	60	1.70	none	none	1.96	13.5	11	
Virobuster	Steritube	59	1.67	G4	none	57	443	22	multispeed
Amcor	AM-45C	45	1.27	Yes	none	25	15.9	12	PCO, carbon
Virobuster	Steritube	44	1.25	G4	none	57	592	23	multispeed
Amcor	AM-45C	40	1.13	Yes	none	25	17.8	12	PCO, carbon
Sanuvox	P-900	35	0.99	Yes	none	4.76	48	15	multispeed
Amcor	AM-45C	31	0.88	Yes	none	25	23.2	13	PCO, carbon
Amcor	AM-45	30	0.85	none	none	1.96	26.9	13	
sterilAir AG	LSK2036-U	29.2	0.83	none	none	30	315	21	
sterilAir AG	LSK2018	11.8	0.33	none	none	7	173	19	

Nosocomial Pathogens

Hospital acquired infections have proven to be a rather intractable problem due to their resistance to traditional methods of removal and inactivation, and the emergence of new pathogens, especially those that have acquired drug resistance. The category of nosocomial infections can be considered to also include community-acquired infections that have spread from hospital environments. Nosocomial pathogens includes viruses, bacteria, and pathogenic fungi, the latter often appearing in the form of airborne spores. Some of the most problematic nosocomial pathogens include methicillin resistant *Staphylococcus aureus* (MRSA), multidrug resistant tuberculosis (XTB), *Streptococcus pyogenes*, *Haemophilus influenzae*, and viruses such as SARS virus and H1N1 flu virus. A review of the scientific literature indicates that most of the agents identified as nosocomial pathogens that transmit through direct hand-to-hand or surface contact (i.e. via fomites) also transmit by the airborne route as well. Substantial evidence exists for the airborne transmission of most of these nosocomial infections, including TB, *Staphylococcus aureus, Streptococcus pyogenes, Acinetobacter,* and *Pseudomonas aeruginosa* (Breathnach et al 1998, Allen & Green 1987, Farrington et al 1990, Grieble et al 1970, Kowalski 2006). Table 2 summarizes all the nosocomial pathogens that have been identified as having the capacity to transmit by the airborne route, even if other routes of transmission are predominant (adapted from Kowalski 2009). Not only are all of the microbes in the table capable of airborne transport in indoor environments, but most show evidence of increasing drug resistance. As vaccines, antibiotics, and antifungal agents lose their effectiveness against these pathogens, air cleaning technologies such as filtration and UVGI may be the only effective recourse for protecting patients and workers in hospital environments.

Table 2: Potentially Airborne Nosocomial Microbes

PATHOGEN	GROUP	TYPE	Annual Cases (USA)	Primary Infections	Drug Resistance
Corynebacterium diphtheriae	Bacteria	Contagious	10	diphtheria	Yes
Acinetobacter	Bacteria	Endogenous	147	SSI, meningitis	Yes
Serratia marcescens	Bacteria	Endogenous	479	SSI, pneumonia, bacteremia	Yes
Aspergillus	Fungi	Noncontagious	666	Aspergillosis	Yes
Histoplasma capsulatum	Fungi	Noncontagious	1,000	Histoplasmosis	Yes
Haemophilus influenzae	Bacteria	Contagious	1,162	SSI, pneumonia, meningitis	Yes
Legionella pneumophila	Bacteria	Noncontagious	1,163	pneumonia	?
Klebsiella pneumoniae	Bacteria	Endogenous	1,488	SSI, pneumonia	Yes
Pseudomonas aeruginosa	Bacteria	Noncontagious	2,626	SSI, pneumonia	Yes
Staphylococcus aureus	Bacteria	Endogenous	2,750	SSI, pneumonia	Yes
Rubella virus	Virus	Contagious	3,000	rubella	?
Bordetella pertussis	Bacteria	Contagious	6,564	Whooping cough	Yes
Mycobacterium tuberculosis	Bacteria	Contagious	20,000	TB	Yes
Parainfluenza virus	Virus	Contagious	28,900	flu, pneumonia	?
Varicella-zoster virus	Virus	Contagious	46,016	VZV	Yes
Respiratory Syncytial Virus	Virus	Contagious	75,000	RSV	No
Streptococcus pyogenes	Bacteria	Contagious	213,962	Scarlet fever, SSI	Yes
Streptococcus pneumoniae	Bacteria	Contagious	500,000	pneumonia, meningitis	Yes
Measles virus	Virus	Contagious	500,000	measles	No
Influenza A virus	Virus	Contagious	2,000,000	flu	Yes
SARS virus	Virus	Contagious	10 (China)	SARS	?
Cryptococcus neoformans	Fungi	Noncontagious	high	cryptococcosis	Yes
Alcaligenes	Bacteria	Endogenous	rare	SSI	Yes
Bacteroides fragilis	Bacteria	Endogenous	rare	bacteremia, SSI	Yes
Blastomyces dermatitidis	Fungi	Noncontagious	rare	Blastomycosis	?
Burkholderia pseudomallei	Bacteria	Noncontagious	rare	melioidosis	Yes
Cardiobacterium	Bacteria	Endogenous	rare	endocarditis	Yes
Chlamydia pneumoniae	Bacteria	Contagious	rare	pneumonia	No
Coccidioides immitis	Fungi	Noncontagious	rare	coccidioido-mycosis	?
Haemophilus parainfluenzae	Bacteria	Endogenous	rare	pneumonia, meningitis	Yes
Moraxella	Bacteria	Endogenous	rare	otitis media	Yes
Mucor plumbeus	Fungi	Noncontagious	rare	mucormycosis	No
Nocardia asteroides	Bacteria	Noncontagious	rare	nocardiosis	Yes
Nocardia brasiliensis	Bacteria	Noncontagious	rare	nocardiosis	Yes
Pneumocystis carinii	Fungi	Noncontagious	rare	pneumocystosis	Yes
Rhizopus stolonifer	Fungi	Noncontagious	rare	zygomycosis	No

NOTE: SSI = Surgical Site Infections

UVGI Applications in Hospitals, Military Barracks, and Buildings

Some of the first UV systems ever developed were implemented in hospitals in the 1930s (Wells and Wells 1936, Hart and Sanger 1939, Robertson et al 1939, Kraissl et al 1940, Overholt and Betts 1940). Most of these systems were either Upper Room UVGI systems or Overhead Surgical Site systems for the operating room. In the 1940s, UVGI was demonstrated to reduce infection transmission in an Army barracks and a Navy training center (Schneiter et al 1944, Wheeler et al 1945). Riley demonstrated the effectiveness of UVGI for controlling airborne tuberculosis transmission in 1957 (Riley et al 1957). Hospital air cleaning applications were addressed in detail by Luciano (1977) who presented detailed guidelines for UV system installation in hospital air handling systems. The use of UVGI recirculating systems in hospital isolation rooms has been a mainstay of TB isolation room design for decades, and the Centers for Disease Control (CDC) acknowledged the usefulness of this technology in 1994 (CDC 2005). In 2000, the US Army recommended the use of UVGI for disease isolation (USACE 2000). In 2003, the CDC formally sanctioned the use of UVGI in hospitals (CDC 2003). In 2003, the Federal Emergency Management Administration (FEMA) sanctioned the use of UVGI for protecting building occupants in case of bioweapons attacks (FEMA 2003). In 2003, the Federal government began requiring the use of UVGI for cooling coil irradiation to remove fungal and bacterial growth (GSA 2003).

In regard to hospital applications, there is sufficient evidence from various studies that increasing levels of airborne microbes correlate with increasing infection rates (Lidwell et al 1983, Kowalski 2006). There have not been any published studies as yet to demonstrate a decrease in infection rates resulting from airstream disinfection (either in-duct or room recirculation), but there are ample studies showing that Upper Room systems, which also disinfect air, are capable of producing significant reductions in infection transmission rates, as indicated in Table 3 (adapted from Kowalski 2009). McLean et al (1961) found that UV could reduce influenza transmission by 89%.

Table 3: Results of Hospital Field Trials of Upper Room Systems

System	Location	Infection	Infection Cases		Decrease		Reference
			Before	After	Net	%	
Upper Room UVGI	The Cradle, Evanston	Respiratory infection	14.5%	4.6%	9.9%	68%	Sauer et al 1942
	St. Luke's Hospital, NY	Respiratory infection	10.0%	6.6%	3.4%	33%	Higgons & Hyde 1947
	Home for Hebrew Infants, NY	Varicella epidemic	97%	0%	97%	100%	Wells 1955
	Livermore, CA Veteran's Hospital	Influenza epidemic	19.0%	2.0%	17.0%	89%	McLean 1961
	North Central Bronx Hospital	TB conversions among staff	2.5%	1%	2%	60%	EPRI 1997
	AVERAGE REDUCTION					**70%**	

In addition to hospital field trials of Upper Room systems, there have been a number of successful studies of Overhead Surgical Site UVGI systems in which the surgical site (the operating wound) is disinfected during operations with direct low-level UV exposure. Although these results may not directly relate to air disinfection, it is inevitable that the air in the operating room will be disinfected during the procedure and that airborne microbes may be inactivated prior to actually settling on open wounds. Table 4 summarizes the results of Overhead Surgical Site UVGI systems in hospital operating rooms (adapted from Kowalski 2009).

Table 4: Results of UV Hospital Field Trials in Operating Rooms

System	Location	Infection / Operation	Infection Cases		Decrease		Reference
			Before	After	Net	%	
Overhead	Duke University Hospital	SSI	5%	1%	4%	80%	Kraissl et al 1940
Overhead	NE Deaconess Hospital	SSI	13.8%	2.7%	11.1%	80%	Overholt and Betts 1940
Barrier	Infant & Children's Hospital, Boston	SSI	12.5%	2.7%	9.8%	78%	Del Mundo & McKhann 1941
Overhead	Montreal Neurological Inst	SSI	1.1%	0.36%	0.7%	67%	Woodhall et al 1949
Overhead	MA General Hospital	Craniotomies	5.3%	0.70%	4.6%	87%	Wright & Burke 1969
Overhead	MA General Hospital	Laminectomies	4.1%	0.30%	3.8%	93%	Wright & Burke 1969
Overhead	Duke University Hospital	Hip arthroplasty infection	5%	0.5%	5%	90%	Lowell et al 1980
Overhead	Brigham Hospitals	Hip & Knee	3.5%	0.89%	3%	75%	Young et al 1991
Overhead	Watson Clinic, FL	Mediastinitis	1.4%	0.23%	1.2%	84%	Brown et al 1996
Overhead	St. Francis Hospital	SSI	1.77%	0.57%	1.2%	68%	Ritter et al 2007
Overhead	**AVERAGE REDUCTION**					**80%**	

Removal Rate of the H1N1 Influenza Virus

The H1N1 influenza virus is physiologically identical to influenza A and differs mainly in the antigenic surface properties designated by the 'H1N1' identifier. The virus has a mean diameter of 0.098 microns (Kowalski 2006). The filter removal rate can be directly assessed through the use of filter performance curves extended down to the submicron range (Kowalski and Bahnfleth 2002, Kowalski et al 1999). The removal rate through the prefilter of the NQ500, which is approximately a MERV 6 filter, is 9.2%. The removal rate through the final filter, a HEPA filter, is in excess of 99.99%, as shown in Figure 1. Corroboration of the filter model is provided by a series of test data points for various similar-sized viruses and test aerosols. The test data points in Figure 1 are summarized in Table 5.

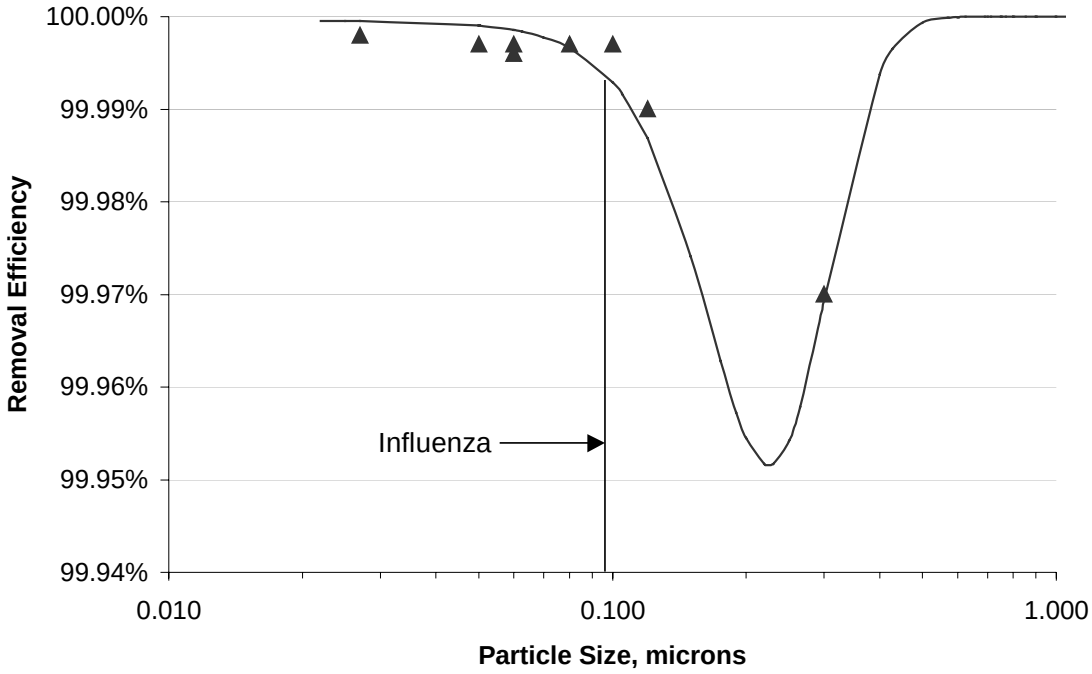

Figure 1: HEPA filter performance curve showing test results and influenza removal efficiency.

Table 5 Summary of HEPA Filter Test Results

Test Agent	Mean Diameter, μm	Removal %	Reference
actinophage S. virginiae S1	0.05	99.997	Roelants et al 1968
T phage E. coli B	0.12	99.915	Washam 1966
T phage E. coli B	0.12	99.99	Jensen 1967
T phage E. coli B	0.1	99.997	Harstad et al 1967
Foot-and-mouth disease virus	0.027	99.998	Thorne & Burrows 1960
Ag aerosol	0.06	99.996	Sinclair 1976
Ag aerosol	0.06	99.997	Sinclair 1976
Ag aerosol	0.08	99.997	Sinclair 1976

Since the most penetrating particle size of about 2 microns has a removal efficiency of about 99.95% (see Figure 1) it can be assumed that all other particulates, including nosocomial pathogens, will be removed by the filter at a rate of at least 99.95%.

The removal rate of influenza due to the UV component is based on the UV exposure dose produced within the unit. The unit produces 117 W of UV output which analysis indicates will produce an exposure dose of 328 J/m^2 (Kowalski 2009). The ultraviolet susceptibility (UV rate constant) of influenza A has been shown to be approximately 0.119 m^2/J in air, or a D90 (90% reduction) of 19 J/m^2 (Jensen 1964). Corroborating evidence for the UV susceptibility comes from studies in water in which the average ultraviolet susceptibility is 0.101 m^2/J, or a D90 of 22.8 J/m^2 (Ross 1971, Hollaender 1944, Abraham 1979). Using the airborne rate constant of 0.119 m^2/J, the calculated inactivation rate for the NQ500 will be as follows:

$$1 - S = 1 - e^{-kD} = 1 - e^{-0.119(328)} = 1 \qquad (1)$$

The inactivation rate of influenza will therefore be 100% through the UV component of the NQ500, to at least ten decimal places of accuracy.

Some question may remain as to whether the H1N1 strain of the influenza virus will have the same UV susceptibility as influenza A. This question may be answered by modeling the H1N1 genome and comparing the predicted UV susceptibilities. Genomic modeling is a new method developed by the author in which the entire genome is sequenced and its UV susceptibility is assessed in terms of the frequency of bases which are most likely to form dimers under UV exposure (Kowalski et al 2009, Kowalski et al 2009a, Kowalski et al 2009b, Kowalski 2009). The genomic model for RNA viruses has an accuracy in excess of 80% in predicting UV susceptibility.

The complete genome of the H1N1 influenza virus has been released by NCBIH and is available in eight segments (NC_002016, NC-002017, NC_002018, NC-002019, NC_002020, NC-002021, NC_002022, NC-002023), which have been compiled by the author (NCBI 2009). Table 5 shows the genomic evaluation results. The parameter Dv is a computed value of the dimerization potential for the various base combinations that are susceptible to photodimerization, whicle the parameters TT, CT, CC, and UY represent the total numbers of such base sequences in the genome. See the previous mentioned references for more details regarding genomic modeling. It is clear that the two genomes, H1N1 and influenza A, are substantially similar. Computation of the UV susceptibility of the H1N1 influenza virus using the genomic model for RNA viruses indicates that the UV D90 value will be approximately 23.5 J/m^2, or slightly more susceptibility than influenza A.

Since the accuracy of the genomic model is estimated to be about +/-17%, the maximum value of the D90 for H1N1 influenza would be about 27.5 J/m^2. This corresponds to a UV rate constant of k = 0.084 m^2/J, from which we can recalculate the inactivation rate from equation (1) as follows:

$$1 - S = 1 - e^{-kD} = 1 - e^{-0.084(328)} = 1 \quad (2)$$

Thus, it can be seen that the removal rate of H1N1 virus through the NQ500 unit will be 100%, even with the most conservative estimated value of the H1N1 UV susceptibility. It should further be noted that this removal rate represents a single pass, and in room recirculation multiple passes are the norm.

Table 6: Summary of Genomic Parameters

Parameter	Influenza A	H1N1 flu
NCBI Genome #	NC_007366-73	NC_002016-23
bases	13498	13588
# T bases	3108	3213
# A bases	4445	4480
# C bases	2644	2596
# G bases	3301	3299
G+C%	44.0436	43.3839
T+A%	55.9564	56.6161
Pyrimidine (Y) %	42.6137	42.751
Purine (U) %	57.3863	57.249
Strand	Template	Template
TT frequency	1380	1445
TT%	10.2237	10.6344
TC frequency	2750	2802
TC %	20.3734	20.6211
CC frequency	1005	996
CC%	7.44555	7.33
YYU frequency	2794	2846
YYU%	20.6994	20.945
Total sites	2087	2122
Total primers	5515	5633
Overlap TT/CT	402	405
Overlap TT/UY	393	395
Ovrlap CC/CT	288	294
Overlap CC/UY	307	308
Overlap CT/UY	697	720
Computed Dv	0.020013	0.01665
Computed D90, J/m^2	24	23.5
Measured D90, J/m^2	23	-

Note: U represents a or G, Y represents T or C

The removal rate of other nosocomial pathogens will depend on the UV susceptibility of each microbe. Not all of these are known at present but a representative summary of four microbes spanning a large range of UV susceptibility is shown in Table 7 alongside the URV rating standard (IUVA 2005). Adenovirus is one of the most UV-resistant microbes while TB is one of the most susceptible. The gray areas in table 7 represent the normal design

range of UV air disinfection systems. The NQ500 rates an URV 21 (at 328 J/m^2 and 500 cfm).

Table 7: UVGI Rating Values (URV) and Typical Removal Rates

URV	Dose J/m^2	Dose μW-s/cm^2	Mean Dose, J/m^2	% Air Disinfection Rates from UV Alone			
				Adenovirus	Influenza	TB	MRSA
1	0.01	1	0.055	0	0	0	1
2	0.10	10	0.15	1	1	5	6
3	0.20	20	0.25	1	2	9	11
4	0.30	30	0.4	2	4	13	16
5	0.50	50	0.63	3	6	21	26
6	0.75	75	0.88	4	9	30	36
7	1.0	100	1.25	5	11	38	45
8	1.5	150	2	8	16	51	59
9	2.5	250	3.75	13	26	69	77
10	5	500	7.5	24	45	91	95
11	10	1000	12.5	42	70	99	100
12	15	1500	17.5	56	83	100	100
13	20	2000	25	66	91	100	100
14	30	3000	35	80	97	100	100
15	40	4000	45	88	99	100	100
16	50	5000	55	93	100	100	100
17	60	6000	70	96	100	100	100
18	80	8000	90	99	100	100	100
19	100	10000	150	100	100	100	100
20	200	20000	250	100	100	100	100
21	300	30000	350	100	100	100	100
22	400	40000	450	100	100	100	100
23	500	50000	750	100	100	100	100
24	1000	100000	1500	100	100	100	100
25	2000	200000	2500	100	100	100	100
UV Rate constants, m^2/J				0.054	0.119	0.4721	0.5957

In-Room Application of the NQ500

The actual effectiveness of any air disinfector or air cleaner will be as much a function of the room volume as of the single pass removal rate. Since the removal rate through the filters and UV component of the NQ500 has been shown to be 100%, the clean air delivery rate (CADR) by which stand-alone recirculation units are rated, will be the same as the total airflow, or a maximum of 500 cfm. A simple relationship has been provided by Kowalski (2009) for estimating the area appropriate for any recirculation unit as follows:

$$Area = \frac{CADR}{1.1} \qquad (3)$$

Applying equation (3) to the NQ500 indicates it is appropriate for areas of about 455 ft^2. Since the unit clearly has excess capacity, especially the UV exposure dose, the actual area it can serve may be much larger. It is important to note that the removal rate for any pathogenic microbe need not be 100%, but need only be that percentage that will result in a reduction of the infection rate to the point that secondary transmissions are inhibited. Kowalski (2006) estimates that a minimum removal rate of about 50-70% will be sufficient to inhibit secondary transmissions, and therefore it can be safely said that this unit will be effective at removing H1N1 in even larger room areas to a degree that will depend on actual room volume and the outside air exchange rate, which may be anywhere form 20-100% depending on the room ventilation characteristics.

Summary

The NQ500 unit demonstrates significant removal capacity for airborne microbes based on the analysis herein, and in particular shows a removal rate for the H1N1 flu virus of 100%. The H1N1 flu virus has been shown analytically and also by comparison with influenza A virus to have a UV susceptibility of about 0.084 m^2/J or a D90 of 23.5 J/m^2 (maximum of 27.5 J/m^2), a value which renders it highly susceptible to the UV dose produced by the NQ500 unit (328 J/m^2). In summary, the NQ500 has the highest possible overall removal rates for H1N1 virus of any of the 31 units listed in Table 1 and should be effective in application to a degree that depends only on proper placement and room ventilation conditions.

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