EFFECTIVENESS OF PORTABLE AIR CLEANERS IN PARTICULATE CONTAMINANT REMOVAL

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ABSTRACT

The primary objective of this study was to evaluate the effectiveness of different commercially available portable indoor air cleaning technologies in removing dust particulates from the indoor air. Suspended respirable particles are of great concern and often identified as important source of indoor air quality problems. The concentrations of particulate and gaseous pollutants encountered in the indoor environment frequently exceed those found outdoors by factor ranging from 2 to 20. Indoor particulates and some contaminants are found to cause or worsen respiratory ailments like asthma and allergies. Commercially available air cleaners with different sets of air filters were tested in a test chamber according to modified ANSI/AHAM AC-1 1988. The number of airborne particles within a set of fixed size ranges was measured with a laser light scattering instrument. The purpose of the study was to test how effectively different sets of filters remove the particulates from the air. The types of filters used were fibrous filters for coarse particles, electrostatic precipitators, electronic filters and HEPA filter. Some devices have incorporated the use of activated charcoal to remove gaseous contaminants from the air but these contaminants were not evaluated in this study. It was seen that different air cleaners perform very different in terms of their efficiency. What determines the overall rate of removal or the space cleaning efficiency is the product of the air flow rate through the air cleaner and filter efficiency.

1. INTRODUCTION

The quality of indoor air is becoming a subject of major concern in a modern air-conditioning. It is gaining a prominent importance for engineers providing the people with healthy and pleasant indoor environments. The concentrations of both particulate and gaseous pollutants encountered in the indoor environment frequently exceed those found outdoors by factors ranging from 2 to 20 [1]. Indoor particulates and some gaseous are found to cause or worsen respiratory ailments like asthma and allergies [2, 3]. Regardless of the fate and distribution of these pollutants, mitigation measures are desired to protect human health [4].

The reduction of airborne particles my be desirable for a number of reasons. Particles my be chemically active or carry pollutants into the lungs. Since particle bound allergens are responsible for triggering allergic reactions, air cleaners are increasingly used as an additional tool in fighting allergies caused by airborne allergens [5].

This study focuses on the use of portable devices designed for cleaning air in a confined space. The usual approach in designing for acceptable indoor air quality has been based on the mass balance technique. A typical model consists of an enclosed space where controlled amount of outside air is supplied through the air handling unit (Figure Infiltration is the uncontrolled amount of the outside air entering the test chamber due untightness.

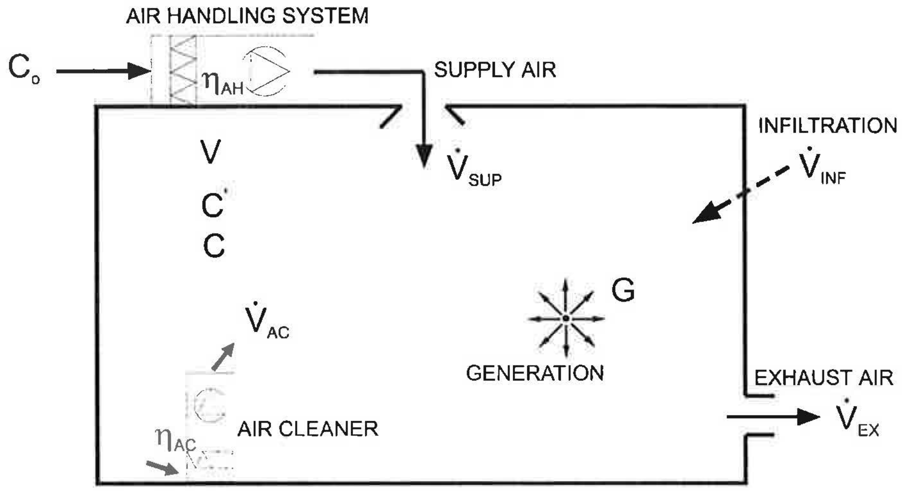

Figure 1: Enclosed space with supplied conditioned air, exhaust air, infiltration, pollutant generation and local air cleaner in a space.

It is assumed that the ventilation air and the air in the conditioned space are complet and instantaneously mixed. A general equation for the concentration of a pollutant can expressed as:

$$V\frac{dC}{dt}=\left[(1-\eta_{AH})\dot{V}_{SUP}+\dot{V}_{INF}\right]C_o+(1-\eta_{AC})C\dot{V}_{AC}+G-C\cdot\dot{V}_{EX} \qquad (1)$$

It is seen from the Eq. 1 that four key parameters determine the concentration of ind air pollutants: source strength, rate of entry, rate of exhaust and rate of removal by the cleaner. It is obvious that four different approaches can be adopted to reduce contaminant concentrations.

Removing the pollutant sources is the simplest way and thus an obvious solution may not always be practical or possible. Pollution sources in buildings are build materials, the furnishings, decorating materials, paintings, adhesives, consumer prod and various processes and activities. It is impossible to achieve an entirely source- environment.

Dilution ventilation refers to ventilation with uncontaminated air to reduce concentration of pollutants in a building. It is widely used method in all kinds of buildi and it provides a comfortable environment. However, two problems are associated with method: first, introducing hundred percent outside air may be energy-consuming despite energy recovery options and second, for most cases the ventilation standards designe dilute the pollutants are often found to be insufficient.

Local exhaust ventilation has an advantage over the dilution ventilation being that the proper placement of the exhaust registers and supply grilles can result in a plug-flow through the space. This provides the maximum air pollutant removal for a given airflow and is effective in energy conservation.

Air cleaners are designed to supplement the above systems. They recirculate the room air in order to reduce the pollutants concentration. Portable filters have the advantage of being relatively inexpensive in comparison to the cost of boosting the HVAC system. Many commercially available units are capable of reducing the concentrations considerably [6, 7]. Unfortunately, despite the claims of different manufacturers, some air cleaners do inevitably fail to perform. It is the primary objective of this study to evaluate the efficiencies of various commercially available air cleaners to remove dust particles from the air.

2. METHODS

The only available standard for testing portable air cleaners or purifiers is ANSI-AHAM Standard AC-1 [8]. The standard method measures the ability of air cleaner to reduce generated particulate matter suspended in the air in a room size test chamber. The efficiency is tested for three different contaminants: dust, smoke and pollen. The natural decay for every contaminant is measured and compared to the decay rate with the air cleaner in operation.

Table 1: Description of tested air cleaners

Air cleaner type	Mounting	Air Flow Rate	Air Changes per Hour	Filter Section	Ionization	Power Consumption	Sound Level
		m^3/h	h^{-1}			W	dBA
A	Table	130	2,5	1. Prefilter 2. Electrostatic filter	YES	24	39
B	Table	118	2,3	1. Prefilter 2. Electrostatic filter 3. Filter impregnated with carbon	YES	23	40
C	Table/ Wall	180	3,4	1. Prefilter 2. Fiberglass filter with granulated carbon	YES	60	36
D	Wall	931	17,8	Electronic Filter	NO	41	37
E	Wall	452	8,6	Electronic Filter	NO	38	34
F	Ceiling	1050	20,0	Electronic Filter	NO	210	47
G	Floor	380	7,3	Electronic Filter	NO	60	40
H	Table	142	2,7	1. Prefilter 2. HEPA filter	YES	not available	not available

Air cleaners used in the tests were received from the manufacturers in a new condition and maintained as such throughout the coarse of the experiments. For all air cleaners air flow rate, power consumption and sound level were measured. Air flow rates measured with anemometer were in most cases lower than those reported by manufacturers. In some cas the manufacturers even reported flow rates without filters being installed in the air clean Table 1 lists the characteristics of tested air cleaners.

Type A: Small portable unit with radial fan and two stage filter; a) open pc polyurethane foam filter and b) electrostatic filter composed of multiple layers of expand non-corrosive aluminum screening which are corrugated for an extended surface area. It h a pre-ionization stage upstream from electrostatic filter to enhance the filter efficiency a post ionization at the air outlet for emission of negative ions to the air stream. Ions generated by carbon filament.

Type B: Small portable unit with cross flow fan and two stage filter; a) electrosta filter consisting of small diameter wires with a positive direct current potential a collecting plate section with a series of parallel plates and b) thin granular charcoal filt The negative ions are generated by steel needles at the air outlet.

Type C: Wall or table mounted unit with axial fan and two stage filter; a) pre-filter a b) electrostatic filter filled with granular charcoal. Negative ions are generated by st needles at the air inlet. The air cleaner features remote control, sensor for detecting peopl movements and sensor for detecting airborne dust and odors.

Type D and E: Same kind of units but different size. They both feature same type electronic filter consisting of two outside frames, two fiberglass collecting pads and hi voltage center screen sandwiched between them. Filter creates an electric field which cau the internal media pads to become fully polarized. This means that each pad becon electrical collecting source for commonly encountered airborne contaminants. Each me pad acts like a highly charged dielectric to attract and hold dust and other lung damagi particles.

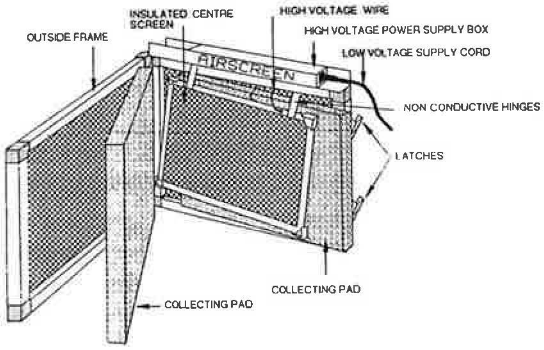

Figure 2: Structure of electronic filter with two fiberglass media pads placed inside th frames.

Type F: Ceiling mounted unit with axial fan and same kind of filter as in type D anc but twice as thick and supplemented by thin fibrous filter impregnated with charcoal.

Type G: Table mounted unit with two cross flow fans and same electronic filter as ty D and E.

Type H: Table mounted unit with radial fan and two stage filter; a) open pore polyurethane foam pre-filter and b) HEPA filter with manufacturer stated efficiency of 99,97% for particles greater than 0,3 μm. Negative ions are generated by carbon filament at the air outlet.

Each cleaner was placed in the airtight chamber with the volume of 52,3 m^3 and tested at the higher air flow rate. All air cleaners which feature negative ion generation were tested with generator switched on. The concentration of dust particles was measured with the Optical Particle Counter, APC-1000, manufactured by Biotest Diagnostics Corp., USA. The instrument contains a class IIIb laser diode with a rated power output of 20 milliwatts at the wavelength of 280 nanometers. Within the particle sensor, light emitted from the laser diode is focused by a series of lenses through a particle sensing zone into a light trap. When a particle enters the zone, it scatters the beam. Scattered light is collected by a second set of lenses and focused on a solid state photo detector. The amplitude of the electrical signal produced by the photo detector is proportional to the size of the particle in the sensing zone. The instrument detects particles relative to four thresholds: greater than 0.3, 0.5, 1.0 and 5.0 microns. The pump draws air through the particle counter at the rate of 2,83 l/min for 15 s for each sample. Concentrations were logged every 30 s.

3. THE EFFICIENCY OF THE AIR CLEANER

It is common to all tests that the known amount of pollutant is injected into the test chamber to reach the initial level of concentration. The first test is conducted without the air cleaner being turned on. This procedure establishes the natural decay rate, which will be subtracted from the rate established during the second test when the air cleaner is turned on. In this way the system is not credited with any performance that is attributable to gravity.

The air cleaners were tested for their efficiency to remove dust particles from the air. The results on their efficiency for cigarette smoke removal has been submitted for publication elsewhere [9].

In a confined chamber where no conditioned air is supplied and no air exhausted out of the chamber and there is no infiltration and contaminant generation, the general equation (Eq. 1) simplifies to a form which shows how concentration *C* changes with time *t*:

$$C = C_i \cdot e^{-\frac{\eta_{AC} \cdot \dot{V}_{AC} \cdot t}{V}} \qquad (2)$$

or

$$C = C_i \cdot e^{-k \cdot t} \qquad (3)$$

where the C_i is the initial contaminant concentration at time t=0 and k is decay constant (min^{-1}). It is clear from the Eq. 2 that in air cleaning, the filter efficiency is not the only important parameter. What determine the overall rate of removal or the space cleaning efficiency is the product of the flow rate through the air cleaner V_{AC} and filter efficiency η_{AC}.

By plotting *lnC* vs *t* for a specific test and calculating the slope of the line obtair through the linear regression analysis, the decay constant *k* is determined. Tests are initia performed to find the natural decay constant k_n for the pollutant of the interest. The cleaner is then introduced into the chamber and the tests repeated to find an experimer decay constant k_e.

The effectiveness of the air cleaner is finally determined by the Clean Air Delivery R (CADR) which is expressed as:

$$\mathrm{CADR} = \left(k_e - k_n\right) V \qquad (4)$$

CADR is a quantitative measure of the air cleaner performance. If an air cleaner ha CADR of 100 for dust particles, it corresponds to a reduction of dust particles to equivalent concentration as would be achieved by adding 100 m^3 of clean air per hour.

4. RESULTS AND DISCUSSION

It is almost impossible to assure that the initial concentrations of particles in differ size classes would be the same for all the tests. For the efficiency evaluation, a n dimensional number (C/C_o), obtained by dividing the airborne particle concentration (C) the initial airborne particle concentration (C_o), was used. Figure 3 shows the time change particle concentration in a test chamber when different air cleaners were operated fo hours.

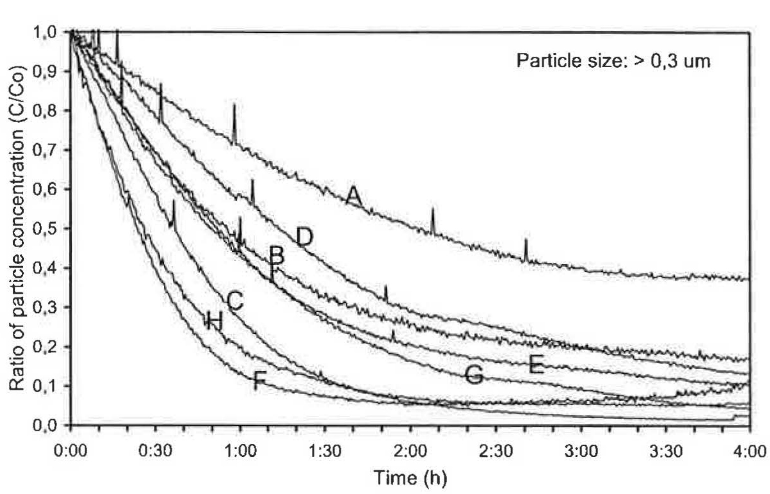

Figure 3: The time change of particle concentration in a test chamber with different air cleaners in operation for 4 hours.

Values for Clean Air Delivery Rate (CADR) were calculated for different particle s classes in order to examine the efficiency of air cleaners in every size class. Values particles greater than 0,3 μm and greater than 1,0 μm presented in Figure 4 are based decay rates calculated for the first hour of each test.

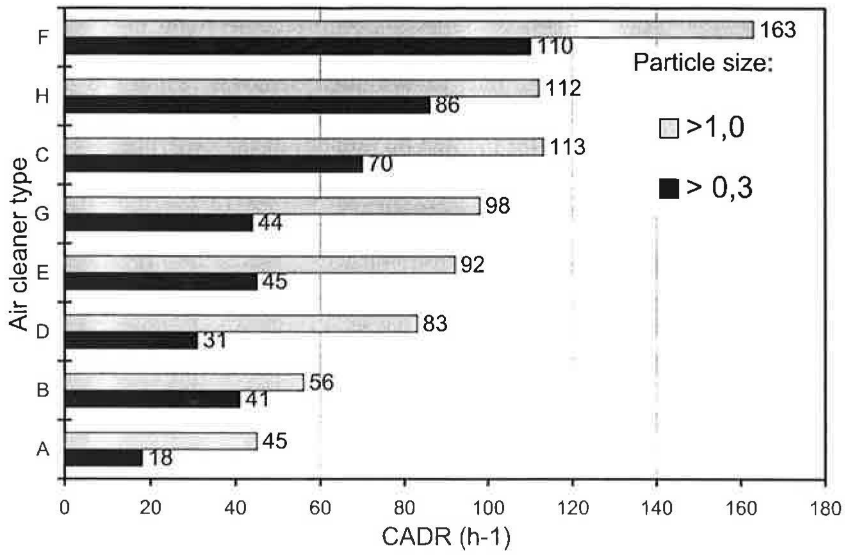

Figure 4: Clean Air Delivery Rate (CADR) for different air cleaners

Different air cleaners performed very different in terms of steady state particle concentration that was reached in a chamber after four hours of operation (Figure 5).

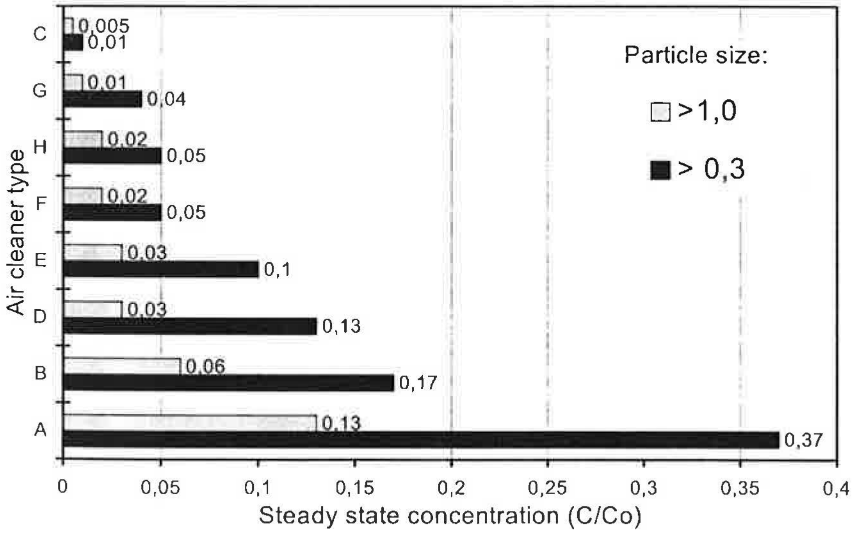

Figure 5: Steady state particle concentration in a test chamber after four hours of operation

CADR value enables the customer to compare different air cleaners on the same scale. It takes into consideration the performance of the entire machine and it shows how the air cleaner will perform in a room of given size. But for the future research on air cleaning technologies, it is important to evaluate the efficiency of filters inside the air cleaners. A was shown in Eq. 2, the product of flow rate through the air cleaner V_{AC} and fi efficiency η_{AC} determine the overall rate of pollutant removal. Figure 6 shows efficiency of filter sections for different air cleaners. The efficiency is calculated from E and Eq. 3, with the decay rate *k* taken for the first 60 minutes of the experiment.

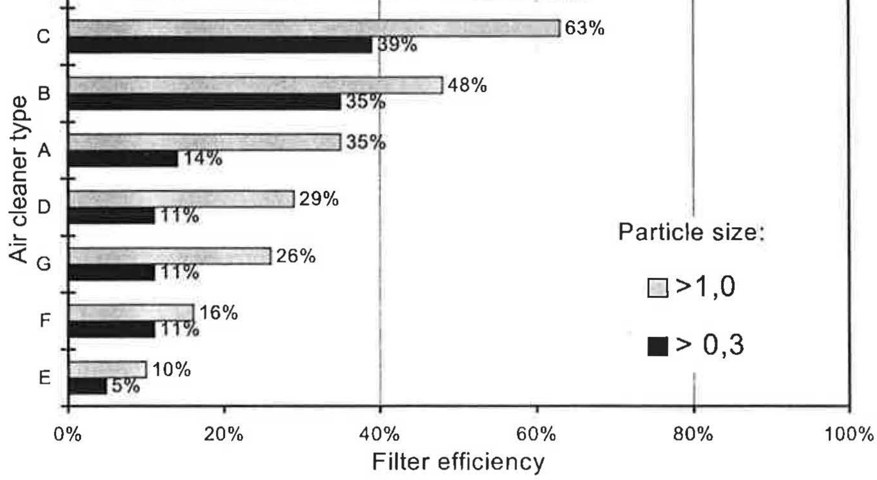

Figure 6: Filter efficiency for different air cleaners calculated from the decay rate fo the first hour of the experiment

Values of Clean Air Delivery Rate presented in Figure 4 give the best judgment o cleaner overall performance. CADR value reflects the combination of all parameters are relevant to the air cleaning; namely air flow volume through the air cleaner, f efficiency and room air distribution. The highest CADR value has ceiling mounted cleaner F, which has a very high air flow rate but very poor filter efficiency. It is a ra noisy device with 47 dB(A) and it has the highest power consumption. Not surprisingly best overall performance goes to the air cleaner H which has a HEPA filter manufacturer rated efficiency of 99,97 % for particles greater than 0,3 μm. Regardles low air flow rate it has a very high CADR value and it is one of the best in terms of particle decay in a 4 hour experiment. The air cleaner C is interesting for its abilit reduce the particle concentration after 4 hours to the lowest level.

Consumers are usually concerned about the price that they have to pay, to get solution that they require. Table 2 summarizes the values showing how much the consu will pay to get a cubic meter of clean air per hour. Values are calculated by dividing price for the air cleaner by CADR, taking into account the measurements of particles gr than 0,3 μm.

Table 2: Prices for m^3 of clean air (particles grater than 0,3 μm) per hour, for different air cleaners. All values are based on current market prices.

Price for a liter of delivered clean air per hour (DEM)							
Air Cleaner Type							
H	B	C	F	A	G	E	D
5,98	6,71	9,57	15,27	21,22	23,75	30,93	37,45

5. CONCLUSIONS

The quality of indoor air is becoming a subject of major concern in a modern air-conditioning. Suspended respirable particles are of great concern and often identified as important source of indoor air quality problems. The primary objective of this study was to evaluate the effectiveness of different commercially available portable indoor air cleaning technologies in removing dust particulates from the indoor air. Commercially available air cleaners with different sets of filters were tested according to modified ANSI/AHAM Standard AC-1, 1988 for dust particles. The use of ionizers that electrically charge the particles have an influence to overall filtration efficiency and all the measurements were done with ionizers on. Clean Air Delivery Rates which enable the consumer to compare different air cleaners on the same scale were calculated for different air cleaners. Consumer have an objective, easy way to determine which room air cleaner is best for their use. CADR eliminates their questions about type of filter, fan size and other mechanical considerations. By knowing the size of the room, consumers can choose an effective air cleaner. As it may be expected, air cleaner with HEPA filter has the best overall performance despite its low air flow volume. The measurements show that the air flow volume, often reported by the sales people as most important parameter, is just one parameter that influences the CADR value. The other parameter is the efficiency of the filter inside the air cleaner which can only be determined by measurements of particle concentration decay. The research shows a great diversity of commercially available air cleaners for indoor particle control on the market. CADR value is a helpful tool to chose the right air cleaner for a given conditions.

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SIMBOLS

C	pollutant concentration in a test chamber ($\mu g/m^3$)		
C_o	pollutant concentration of the outside air ($\mu g/m^3$)		
CADR	Clean Air Delivery Rate (h^{-1})		
G	generation rate of the pollutant ($\mu g/s$)		
k	decay rate (min^{-1})	t	time (s)
V	test chamber volume		
$\dot{V}_{SUP}$	air flow rate of air handling system (m^3/h)		
$\dot{V}_{EX}$	air flow rate leaving room (m^3/h)		
$\dot{V}_{AC}$	air flow rate through the air cleaner (m^3/h)		
$\dot{V}_{INF}$	infiltration flow rate (m^3/h)		
η_{AH}	efficiency of the air handling system filtration		
η_{AC}	efficiency of the air cleaner filtration		