## *Those Other Filtration Devices: Hype or Help?*

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## Misleading Ads

- "Removes virtually any contaminant including gases and VOCs"
- "Relieves asthma and allergies"
- "Eliminates allergies and other maladies caused by molds"
- Eliminates almost 100% of such harmful airborne particulates as dust, bacteria, viruses, pollen, mold, spores, tobacco, and general room odors"

| Particle Size | Deposition Factors |
|---|---|
| LARGER THAN FEW MICRONS | GRAVITATIONAL SETTLING |
| LESS THAN 0.3 MICRONS | INDOOR AIR MOTION/ ELECTROSTATIC FORCES |

## Particle Characteristics of Allergens

| TYPE | SIZE RANGE (micron) | SETTLING RATE |
|---|---|---|
| Dust Mite | 10-35 | Rapid (e g, 20 micron particle falls 1 meter in about 80 seconds) |
| Cat/Pet Dander | <2 to >10 | Fines settle slowly (e g, 0.2 micron particle falls 1 meter in about 5 days) |
| Cockroach | 80% >10 | Rapid |
| Common Fungal Spores | 2-10 | Varies |
| Plant Pollen | 15-25 | Rapid |
| ETS | Mean ~ 0.2 | Negligible |

*Particle must be airborne long enough for air cleaner to have any effect*

## Types of Air Cleaners

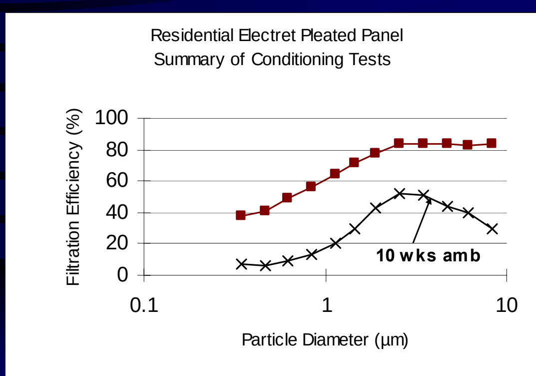
- Particle Removal
  - Filters
  - Electrostatic Precipitators (ESP)
  - Ionizers
- Gas Removal by Adsorbents
- Portable vs. Central

## Filter types

- ►Viscous-media panel filters
- ►Renewable-media filters
- ►Electrostatic filters
- ►Electret filters

## *Electrets*

- Polymeric extruded fibers with built-in charge
- Advantages
  - **Low pressure drop**
  - **Higher initial efficiencies due to inherent charge**
- Disadvatages
  - **drop in efficiency during the loading life cycle once installed in an ambient airstream**
    - ***VOCs or super-fine nanoparticles, can neutralize the fiber charge reverting the media to the lower efficiency levels of non-electret media***




Hanley, J., et al., IA '99

## HEPA filters (99.97% efficient @ 0.3 µm)

- pressure drop substantial (energy cost↑)
- newer HEPAs available w/ lower ▲P

## Electrostatic air cleaners (electronic, or electrostatic precipitators)

- Basic design
  - Ionizing plate

## Electrostatic air cleaners

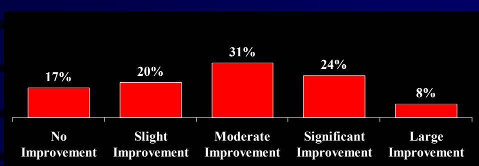
- Advantages
  - High initial efficiencies; No pressure drop
- Disadvantages
  - Produces ozone unintentionally
  - Requires frequent cleaning to maintain efficiency
  - **EAC slowly loses its ability to charge particles due to build-up of silicone deposits on the electrical ionizing grid wires (Hanley, et al, 2003)**

## ***Portable Air Cleaners***

# Portable Air Cleaners

- 3 out of every 10 households now own P.A.C.
- Effectiveness limited by flow rate and efficiency of collection
- Primarily for cleaning air in a single room
- Components must be replaced or cleaned periodically
- Noise factors
- Advertisements are inundated with hype
- AHAM ratings for particle removal

# Air Cleaner Led to Improvement in Health




- One-third report that their use of an air cleaner has led to an improvement in their health / health of other household members.
- Associated factors include the following:
  - Extremely/very concerned about IAQ; Own 2+ air cleaners; Use all year round; Have child or adult respiratory sufferer.

*Base: Total returns (n=936). Source: Q50. Has use of an air cleaner led to an improvement in your health or the health of other household members?*

# *Health benefits from Portable Air Cleaning*

- Studies far from definitive
- Studies to date failed to separate effects of air clng from the effects of applied source control measures (i.e. allergen-proof bed encasings, washing pets, excl. pets from home, etc)
- Well-designed studies needed; must include:
  - **proper controls**
  - **clinical evaluation**
  - **rigorous control/reporting of relevant environmental variables**

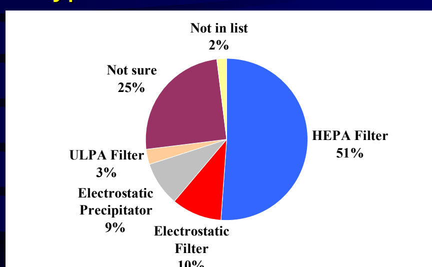
(National Academy of Sciences, 2000, Eggleston, et al. 2001)

# Portable Air Cleaners

- Not sufficient alone, for effective reduction of exposure to indoor allergens; total approach req'd for optimal improvement of clinical symptoms
- Limited number of studies reveal inconsistent results on environmental & clinical effects
- Some benefits observed w/young asthma patients sensitized to pets (may be more responsive to intervention as opposed to adults)

J. Allergy Clinic; Immunology 1999; 104:447-51

## Type of Air Cleaner




- Half own a HEPA filter air cleaner, while one fifth own a machine with an electrostatic filter or electrostatic precipitator.
- One-quarter are not sure about the type of air cleaner they own.

*Base: Total returns (n=936). Source: Q20. What type of air cleaner do you own?*

## Summary:

- HEPA and EACs demonstrated highest η's on dust & ETS particles
- Units demonstrated similar η's on removal of total and viable spores (70-90% eff.)
- No apparent effect on viability
- Ionizers & ozone devices ineffective
- To be effective, clean air delivery rates must compete w/ source emission rate and other removal processes

Shaughnessy, et al.,
Indoor Air Journal '94

## Particle Dynamics affecting Indoor Airborne Levels

- **Penetration**
- **Deposition**
- **Resuspension**
- **Removal by ventilation**
- **Chemical reactions involving vapors/gases leading to particle generation (condensation nuclei)**

## AHAM Standard AC-1, 2002

- AHAM testing of air cleaners in the U.S. presented to the American National Standards Institute (ANSI) for recognition as American National Standards
- Testing for removal of particulate (smoke, dust, pollen)
- Uses CADR model to evaluate performance

***Clean Air Delivery Rate (CADR) is the amount of "equivalent cleaned air" provided by an air cleaner***

## Modeling the Indoor Environment

***Assumptions:***

✓ ***air concentrations of contaminants well-mixed***

✓ ***change in contaminant conc'n described by 1st order differential equation***

## *Mass Balance Equation:*

$$\frac{dC}{dt} = S/V + P\lambda_v C_o - \Lambda C_i \qquad (1)$$

*Where:*

- S is the emission rate in mass per unit time
- V is the volume of the indoor space
- $\lambda_v$ is the air infiltration rate (in units of inverse time)
- P is the penetration factor
- Co is the outdoor contaminant concentration
- $C_i$ is the indoor contaminant concentration
- $\Lambda$ represents all first order removal processes (in units of inverse time)

## Indoor removal processes

$$\Lambda = \lambda_v + \lambda_d + \lambda_{ac} \qquad (2)$$

Where:

- $\lambda_v$ is removal rate based on ventilation (in units of inverse time)
- $\lambda_d$ is removal rate based on deposition on surfaces
- $\lambda_{ac}$ is removal rate based on air cleaner

## *For testing in a room-sized chamber (static conditions):*

- *–Testing begins after contaminant source turned off; S=0*
- *–Infiltrating contaminant, $C_0$, negligible*

## *Equation reduces to:*

$$\frac{dC}{dt} = -\Lambda C_i = -(\lambda_v + \lambda_d + \lambda_{ac})C_i \qquad (3)$$

## Solving for eqn 3:

$$C(t) = C(0)\exp(-\Lambda t) = C(0)\exp[-(\lambda_v + \lambda_d + \lambda_{ac})t] \quad (4)$$

**Where:**
**C(0) is the contaminant concentration at the start of the test**
**C(t) is the concentration at time, t**

## Rearranging the terms in equation (4) and take the natural log of both sides:

$$\Lambda = \lambda_v + \lambda_d + \lambda_{ac} = \frac{\ln(C(0)/C(t))}{t} \quad (5)$$

***Composite removal constant, Λ , determined as slope of plot of ln C vs. t (linear regression)***

## *In order to explicitly account for room size, the ANSI/AHAM standard defines CADR as:*

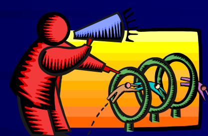
$$CADR = V(\Lambda_{AC} - \Lambda_{noAC}) = V(\lambda_v + \lambda_d + \lambda_{ac} - \lambda_v - \lambda_d) = V\lambda_{ac} \quad (6)$$

***In the U.S. the CADRs are expressed as $ft^3$/min; permits both an intercomparison of performance among various air cleaners and a comparison of air cleaner operation to other contaminant removal processes***

## What is the minimum Effective Cleaning Rate, CADR, required to impact an indoor environment?


www.aham.org

## To be effective on contaminant removal, the air cleaner must compete with:



- Surface deposition
- Ventilation (outdoor air exchange)
- With vapor-phase contaminants, rate of indoor rxns must be considered

*Effectiveness, ε, has been defined by Nazaroff (2000) as the difference in indoor concentration due to air cleaning compared to the "no-cleaning" case; rearranging above equations ε can be expressed as:*

$$\varepsilon = \frac{CADR}{V(\lambda_v + \lambda_d) + CADR} \quad (7)$$

The closer the effectiveness is to 1, the more ideal the performance of the air cleaner is in removal of the contaminant

## *Recommended minimum ε for Air Cleaners*

*(reduction in steady state concentration)*

- 0.50 Whitby, 1983
- 0.80 AHAM, 2002, and Swedish Asthma and Allergy Association Guidelines, 1999

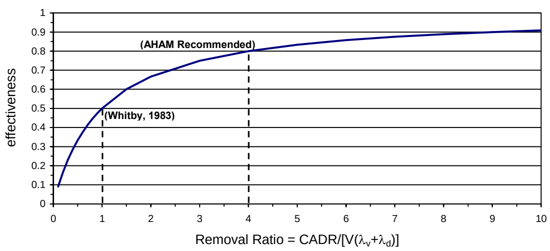



**Figure 1.** Effectiveness of airborne contaminant removal as a function of the ratio between air cleaner performance and the other removal processes, ventilation and deposition (for particles) (adapted from Nazaroff, et al., Healthy Buildings 2000)

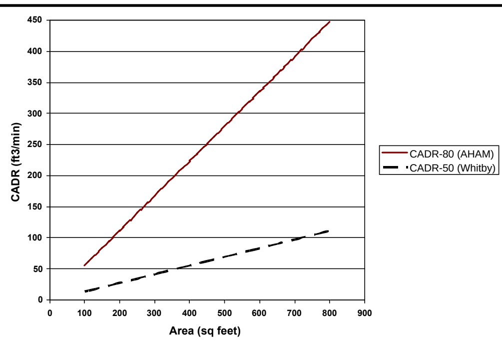



**Figure 2.** Clean Air Delivery Rate as a function of indoor area for two effectiveness values, 80% as recommended by AHAM and 50%, based on Whitby, et. al. (1983); graph applies to removal of smaller particles, less than ~1 micron in size (Shaughnessy & Sextro, submitted, 2005).

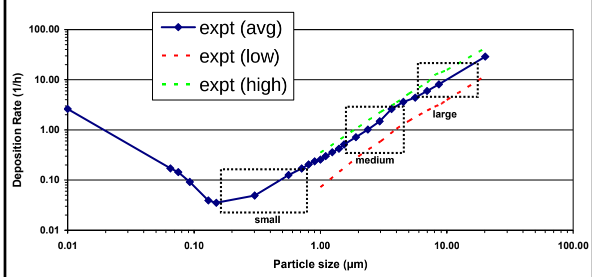



**Figure 5.** Particle removal by deposition as a function of particle size."Small" refers to the particle size region associated with the peak in the ETS mass distribution; "medium" refers to the size region associated with some allergens and with larger ambient aerosols; and "large" refers to the size region associated with pollens & sources of asthma-related allergens such as dust mites.

Thatcher, et.al. (2002) and Xu, et.al. (1994), as reported by Fisk, et.al. (2002)

## When compared with typical residential ventilation rates (~ 1 per h):

- deposition losses for ***small particles***, (<0.8 um), have little impact on the particle removal ratio; $\lambda_d = 0.05\ h^{-1}$
- deposition losses for ***medium size particles*** (1-4 um) are about the same as those due to ventilation; $\lambda_d = 1\ h^{-1}$
- deposition losses ***large particles*** (6-20 um) deposit at rates >> removal rate due to ventilation; $\lambda_d = 10\ h^{-1}$

***Effectiveness, ε, of air cleaner***

$$\varepsilon = \frac{CADR}{V(\lambda_v + \lambda_d) + CADR} \quad (7)$$

The closer the effectiveness is to 1, the more ideal the performance of the air cleaner is in removal of the contaminant

$$\varepsilon = \frac{CADR}{V(\lambda_v + \lambda_d) + CADR}$$

**Recall that:** $CADR = V\lambda_{ac}$

$$\varepsilon = \frac{\lambda_{ac}}{(\lambda_v + \lambda_d + \lambda_{ac})}$$

***As $\lambda_d$ increases, the effectiveness ($\varepsilon$) afforded by the air cleaner decreases***

## Relationship between CADR, room size (assuming 8 ft (~2.5 m) ceiling), and particle size category

$$\mathrm{CADR} = A\frac{8\varepsilon(\lambda_v + \lambda_d)}{1-\varepsilon} \qquad (8)$$

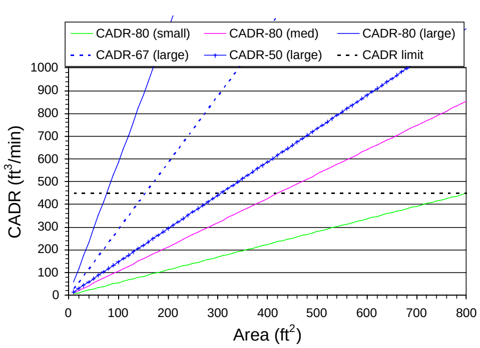


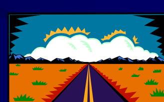

**Figure 6.** Clean Air Delivery Rate as a function of indoor space area and particle size. Volume is based on a ceiling height of 8 ft. CADR-80, -67, and -50 are, respectively, the CADR values based on 80 %, 67% and 50% reduction in particle concentrations due to air cleaner operation. (Shaughnessy & Sextro, submitted, 2005).

**NAS, Clearing the Air Report (2001):**

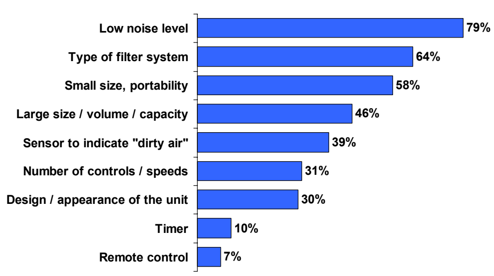
*Limited evidence indicating that particle air cleaning is associated with a reduction in the exacerbation of asthma symptoms….“theoretical and empirical data suggest that air cleaners are most likely to be effective in reducing indoor concentrations of particles smaller than approximately 2 microns. However, much of the airborne allergen appears to be within larger particles”*

## Advantages of Using CADR (clean air equivalent) model

- Performance based approach simulates real world conditions (not single-pass eff’cy)
- Allows side-by-side comparison
- Can be used to size air cleaner for a given space



## Important Design and Functional Features




- *Low noise level* has the highest “extremely/very important” rating among this set of features. Eight out of 10 of those who purchased an air cleaner rate this feature extremely/very important.

*Base: Those who purchased an air cleaner new (n=785). Source: Q33. How important were each of the following features in your decision to purchase an air cleaner?*

## Selecting a Portable Air Cleaner

- ✓ based on room size
- ✓ noise factors
- ✓ typically good for particulates only
- ✓ not whole house
- ✓ look for CADR of between 150-300 (AHAM rating)

## Summary

- **Mathematical mass balance model (utilized for CADRs), appropriate for solid and gas-phase analytes**
- **Air clnr removal rate must be >> the rates afforded afforded by ventilation & deposition on surfaces**
- **Many air purifier products, small odor removing devices, and so-called wonder products, may have little impact on contaminant removal**

## Questions to be Addressed

- **What contaminants should we be evaluating for removal?**
- **Are new technologies/features effective?**
- **Claims oversight…. Is there any oversight on claims related to air cleaner performance?**
- **What standards/methods other than AHAM AC-1 are used in other countries?**
- **How to practically improve on methods of evaluation?**
- **Should a minimum level of performance be required for an air cleaner?**

## Emerging Technologies

- **P.C.O.**
- **UV-C**
- **Sorbent technology**
- **Ionization/electrostatic devices**
- **Media filtration**

## UVGI Irradiation

- **used in TB isolation rooms, waiting rooms, radiology areas**
- **duct or upper room irradiation mounts**
- **CDC (1994) considers only as supplemental to engineering controls (i.e. ventilation, HEPA, negative P)**
- **not demonstrated to be highly effective against fungal spores**

## Application of UV

- upper room air irradiation
- ductwork/plenum
- portable air cleaners

## Lamp Output Factors

- Air velocity (cooling effect reduces intensity)
- Temperature ambient air
- Age of lamp (depreciates quickly in first 100 hours)
- Cleanliness (dust buildup)
- Wattage
- Reflectance
- Inverse square law (intensity ↓ in proportion to square of d from lamp)

## UV Microbial Factors

- Dose = (field intensity) x (time)
  - what is the lethal dose?
    - size of field
    - residence time in field
    - specific microorganism
- Humidity (R.H. > 65%, germicidal effect ↓)
- Spores may be damaged, but not rendered inviable

**"Effectiveness of Germicidal Ultraviolet Irradiation for Reducing Fungal Contaminants within Air Handling Units"**

Applied and Environmental Microbiology, Vol 67 #8, 3712-3715, August, 2001.

Levetin, E., Shaughnessy, R.J., Rogers,C.

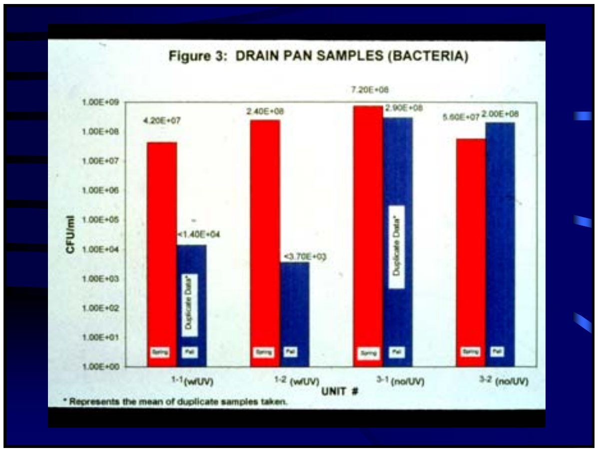
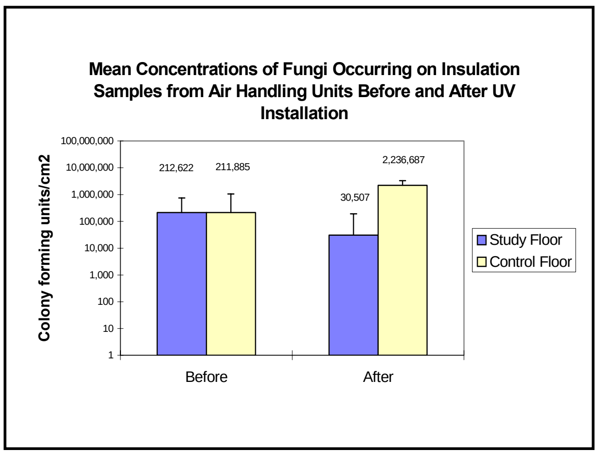
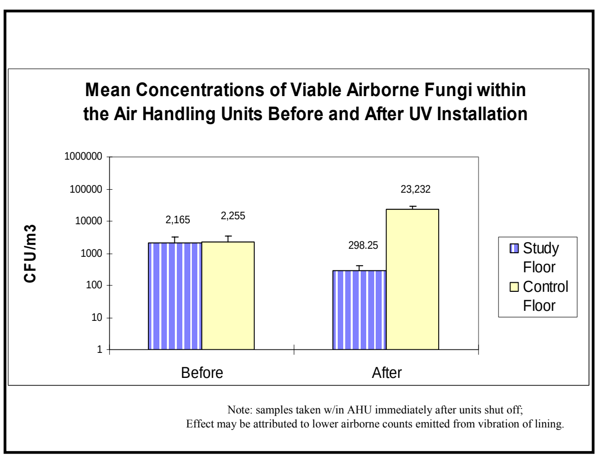


Figure 3: DRAIN PAN SAMPLES (BACTERIA)
CFU/ml
1.00E+09
1.00E+08
1.00E+07
1.00E+06
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
4.20E+07
<1.40E+04
2.40E+08
<3.70E+03
7.20E+08
2.90E+08
5.60E+07
2.00E+08
Duplicate Data*
Duplicate Data*
1-1 (w/UV)
1-2 (w/UV)
3-1 (no/UV)
3-2 (no/UV)
UNIT #
* Represents the mean of duplicate samples taken.

Mean Concentrations of Fungi Occurring on Insulation Samples from Air Handling Units Before and After UV Installation
Colony forming units/cm2
100,000,000
10,000,000
1,000,000
100,000
10,000
1,000
100
10
1
212,622
211,885
30,507
2,236,687
Before
After
Study Floor
Control Floor

Mean Concentrations of Viable Airborne Fungi within the Air Handling Units Before and After UV Installation
CFU/m3
1000000
100000
10000
1000
100
10
1
2,165
2,255
298.25
23,232
Before
After
Study Floor
Control Floor
Note: samples taken w/in AHU immediately after units shut off;
Effect may be attributed to lower airborne counts emitted from vibration of lining.

## Summary

- Positive correlation between operation of UV-C lamps and reduction of microbial growth in duct lining and drain pan samples from ahu s
- Effect on bacteria in water more pronounced than on fungi
- No ozone buildup noted

Levetin, Shaughnessy, Rogers, 2001

## Summary (cont'd)

- UV-C is direct line-of-sight mechanism; areas not irradiated showed no visible improvement
- Further studies needed as to overall effectiveness of UV-C in ahu s, and the effect on the passing air stream

Levetin, et al., 2001

## "Effect of UVGI in HVAC on Workers' Health" Menzies, et al, Lancet, Nov, 2003

- Results:
  - Reduction of microbial/endotoxins on irradiated surfaces
  - Reduction in worker-related symptoms
- Limitations:
  - Only 3 bldgs; nonrandomized intervention
  - Very low initial microbial concentrations
  - No effect on thermal/chemical indices
  - Only slight effect on worksite air microbes
  - No explanation for apparent health effects

## "Effectiveness of UV in Ductwork",
**A.R.T.I.,Van Osdell & Foarde, Nov 2003**

- UV inactivated vegetative bacteria, bacteria and fungal spores in ductwork
- Veg bacteria more susceptible while spore forming bacteria and fungi more resistant
- Reliance on design eqns to predict kill may be prone to error; actual testing under environmental conditions recommended

Moisture control, properly designed dehumidifying/cooling HVAC processes, drain pans designed to drain, and installing nonporous surfaces downstream of coils should collectively continue to be primary approaches to controlling microbial growth in AHUs.