Steve Froelicher, PhD, Senior Scientist
Prism Analytical Technologies
s.froelicher@pati-air.com
Office Number (989)-772-5088

Air Cleaners, Air Purifiers, and Air Cleansing Processes For Reduction of Formaldehyde and Volatile Organic Compounds For Indoor Air Quality Improvement

Acknowledgements

- Alice Delia, Prism Analytical Technologies
- Greg Joutras, Carrier Enterprise

Outline

- Indoor air quality basics
  - Different aspects of IAQ (chemicals, particulate, allergens, comfort factors, etc.)
  - Typical VOC Sources
- Methods of indoor air remediation
  - Source Identification/Reduction/Removal or Remediation
  - Air Filtration – MERV ratings; particle sizes; filtration mechanisms
  - Air Filtration with enhanced air cleansing technology
    - Photocatalytic Oxidation (PCO); ionization methods; cold plasma; others
  - Zone treatment – ozonation, ClO_2, etc.
    - Shock treatment;

What Encompasses Indoor Air Quality?

Occupant Comfort
(Temperature, Humidity)

Particulate-Lifestyle
(Skin Cells, Dander, Textile & Paper Fibers, Smoke)

Radon

Allergens
(Pet Dander, Dust Mites)

CO, CO_2

Indoor Air Quality

Particulate-Building
(Fiberglass, Corrosion, Rust)

Mold
(Spores, Mycotoxins, MVOCs, Debris)

Volatile Organic Compounds (VOCs)

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Indoor Air Quality Basics

- Indoor air is contaminated with particulates, allergens, molds, and volatile organic compounds (indoor air pollution is among the top five environmental health risks; EPA (2009))
- Particulate matter, allergens, tobacco smoke, VOCs can all affect occupant health
- Comfort levels for occupants are desired to be maintained
  - Source removal/reduction is preferred if possible to reduce indoor VOCs
  - Indoor air remediation by filtration
  - Indoor air remediation by air cleansing processes

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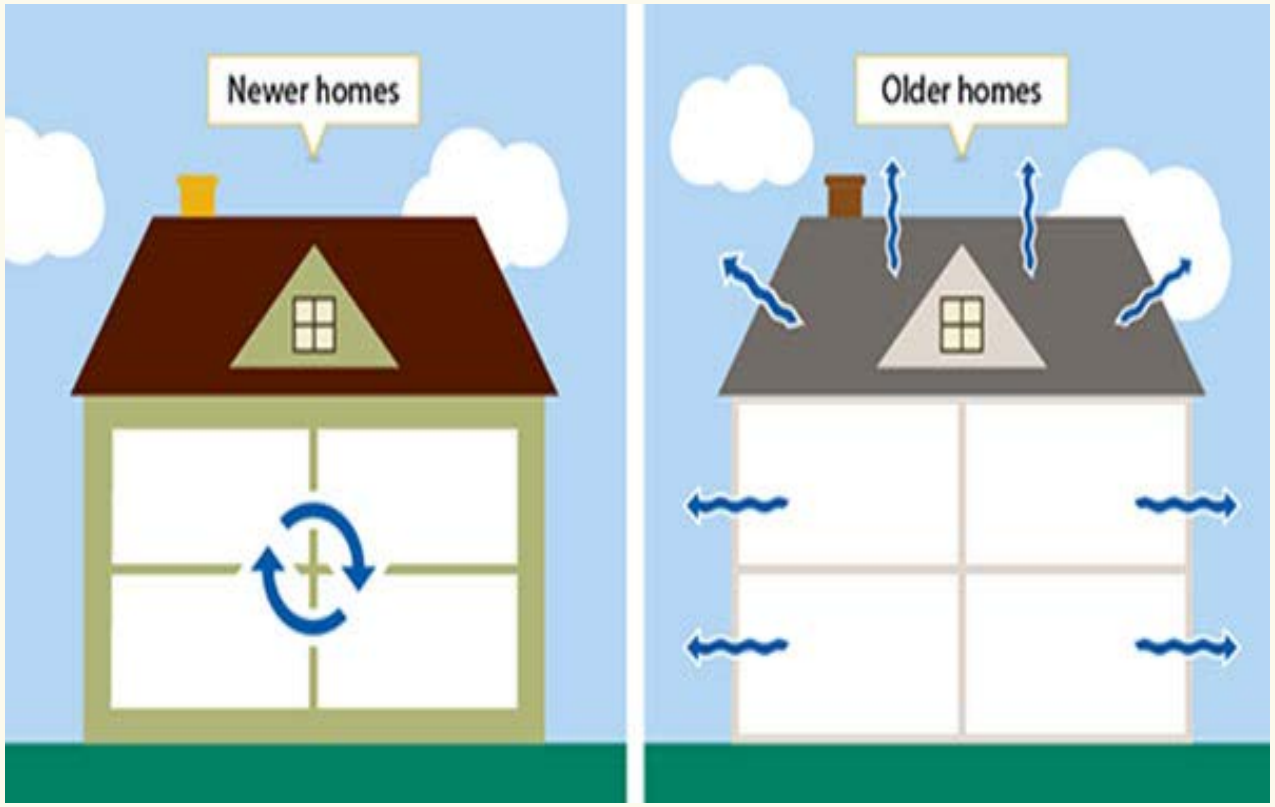
Indoor Air Quality Basics

- Buildings (homes/businesses, etc.) have a **"baseline"** VOC and formaldehyde level
  - **"Baseline"** established from local ambient outdoor levels + building infrastructure (i.e., Materials of Construction (MOC)) + carpeting + furnishings + other
    - Local ambient outdoor levels usually low for VOCs and formaldehyde
    - LEED, et.al. – efforts to keep "baseline" low through proper selection of MOC
  - Indoor air quality can be instantly impacted through use of personal care products, cleaning products, new construction, repairs, new furnishings, new carpeting, remediation and restoration efforts, etc.
- IAQ testing yields a "snap-shot in time" assessment of occupant exposure to VOCs.

Newer Homes are more energy efficient



…but VOCs are also more efficiently "trapped" within a newer home.

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Occupant lifestyle: VOCs from Home Contamination

- Some materials remain in home for long periods, even if located and removed **(Note: Use of these materials elevate the TVOC above "baseline")**
- Moth Balls or Moth Crystals
  - Naphthalene based
  - para-Dichlorobenzene based
- Coatings and Paints
- Kerosene / Diesel / Fuel Oil
- Heavier Solvents / Turpentine
- Chlorinated Solvents
  - Cleaning solvents
  - Dry cleaning solvents
- Toluene and Xylenes
  - Used in many adhesives and caulks

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VOCs from Building Materials

- Flooring
  - Formaldehyde, solvents
- Vinyl Flooring
  - Tetradecane
- Cabinetry
  - Formaldehyde, toluene, xylenes
- Drywall
  - Sulfur species
- Paint
  - Texanols, butyl cellusolve, HCs
- Carpeting
  - Caprolactam
- PVC Cement
  - Tetrahydrofuran, methylethylketone
- Plastic Materials
- HVAC
  - Freons™
- Fiberglass
  - Phenol/formaldehyde
- Spray Foam Insulation
  - Freons™, isobutane, butane, HCs
  - Pentafluoropropane
  - Trans 1,2-dichloroethene
- Rigid Insulation Polystyrene
  - Styrene
- Adhesives
  - Toluene, Xylenes
  - Phthalate esters

Occupant lifestyle: VOCs from Home Contents

Occupant chemicals are significantly reduced when current owner or tenant vacates **(Note: empty homes/businesses eventually return to "baseline" VOC levels)**

- Alcohol Products
  - Ethanol, Isopropyl Alcohol
  - Very common
- Personal Care Products
  - Acetone, alcohols, esters
  - Very common
- Gasoline
  - Benzene, toluene, xylenes, C5-C8 HCs
  - Very common
- Odorants or Fragrance Products
  - Limonene, a-Pinene

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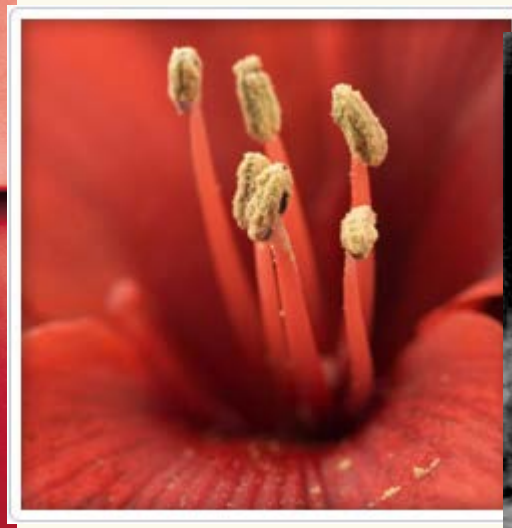
Challenge: Everyone is Different

- Depend on:
  - Specific VOC or type of VOC
  - Level of exposure
  - Length of exposure
  - Individual's sensitivity
- Health Effects
  - Eye and respiratory irritation, dizziness, headache, nausea, etc.

- **No Effect** → **Irritating** → **Highly Toxic**

www.epa.gov/iaq/voc.html
toxtown.nlm.nih.gov/text_version/chemicals.php?id=31

Particulate



Dust - Dander – Pollen

Slide Courtesy of Greg Jouras (HVAC Solutions)

Particulate Matter (PM) – What is the Concern?

- Microscopic solid or liquid matter
  - Fine < 2.5 um **(these particles can embed deep in the lungs)**
  - Respirable Coarse 2.5 – 10 um **(embed in upper respiratory tract)**
  - Coarse (Dust) > 10 um **(embed in nose/throat)**
- Health symptoms
  - Allergies, asthma, respiratory conditions, cardiovascular conditions, cancer
- Indicate home conditions and activities

Microbial

Single cell Living Organisms

Virus

Bacteria

Mold

Slide Courtesy of Greg Joutras (HVAC Solutions)

How Can IAQ Be Improved? SOURCE REMOVAL/REDUCTION

- If possible, the best way to improve indoor air quality is to remove or reduce the source of contamination.

…when this isn't possible then…

Ventilation

- The next best approach is to improve ventilation and add fresh outdoor air (where practical)

  …when this isn't possible then…

…Filtration/Air Cleansing is necessary

- Filtration Types
- What type of filter is appropriate for different particle sizes
- How can you filter VOCs?
- What other air cleansing technology is available?

IAQ Improvement

- Improving indoor air quality usually involves a combination of:
  - Source removal/reduction
  - Ventilation improvements
  - Utilization of air cleaners/cleansing
    - Air cleaners can be installed in HVAC for whole house
    - Air cleaners can be portable room air cleaners

Regarding Air Cleaners…

- Air Cleaners have primary and secondary impact on indoor air quality
  - Primary:
    - Contaminant concentration reduction
  - Secondary:
    - Energy use
    - Possible by-product production

- J.A. Siegel “Primary and Secondary Consequences of Indoor Air Cleaners” Indoor Air, Vol 26, 88-96 (2016)

Regarding Air Cleaners…

- Common misconception: Air Cleaners will always improve indoor air quality
  - If part of central (i.e., whole-house system), filters can quickly clog and reduce ventilation rate/air movement)
  - Depending on air cleaner, VOCs may not be removed
  - Secondary by-products from cleansing technology may be part of air returned from unit (i.e., effluent) (ozone; PCO; UV light)

Filtration Types
- most commonly used

Standard MERV Rating	Dust Spot Efficiency	Arrestance	Typical Controlled Contaminant	Typical Applications and Limitations	Typical Air Filter/Cleaner Type
13	70-75%	>95%	1.0-3.0 pm Particle Size Legionella	**Superior** Residential homes	**Pleated Filters** - Disposable, extended surface area, thick with cotton-polyester blend media, cardboard frame. **Box Filter** - Rigid Style Cartridge Filters 6 to 12" deep may use lofted or paper media.
11	60-65%	>95%	1.0-3.0 pm Particle Size Humidifier Dust Lead Dust	**Better** Commercial Bldg. Residential Homes	
8	30-35%	>90%	3.0-10.0 pm Particle Size Mold Spores	**Good** Commercial Bldg.	**Pleated Filters** - Disposable, extended surface area, thick with cotton-polyester blend media, cardboard frame. **Cartridge Filters** - Graded density viscous coated cube or pocket filters, synthetic media.
6	<20%	85-90%	3.0-10.0 pm Particle Size Fabric Protector Dusting Aids	Industrial Workplace	

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Filtration Types
- most commonly used

Comparative cost: (from nationwide building products store)

Allergen reduction furnace filters (MERV rating of 12) (electrostatic pleated) 3 month lifetime	$25-40
Basic pleated (MERV rating of 5) 3 month lifetime	$4 and up

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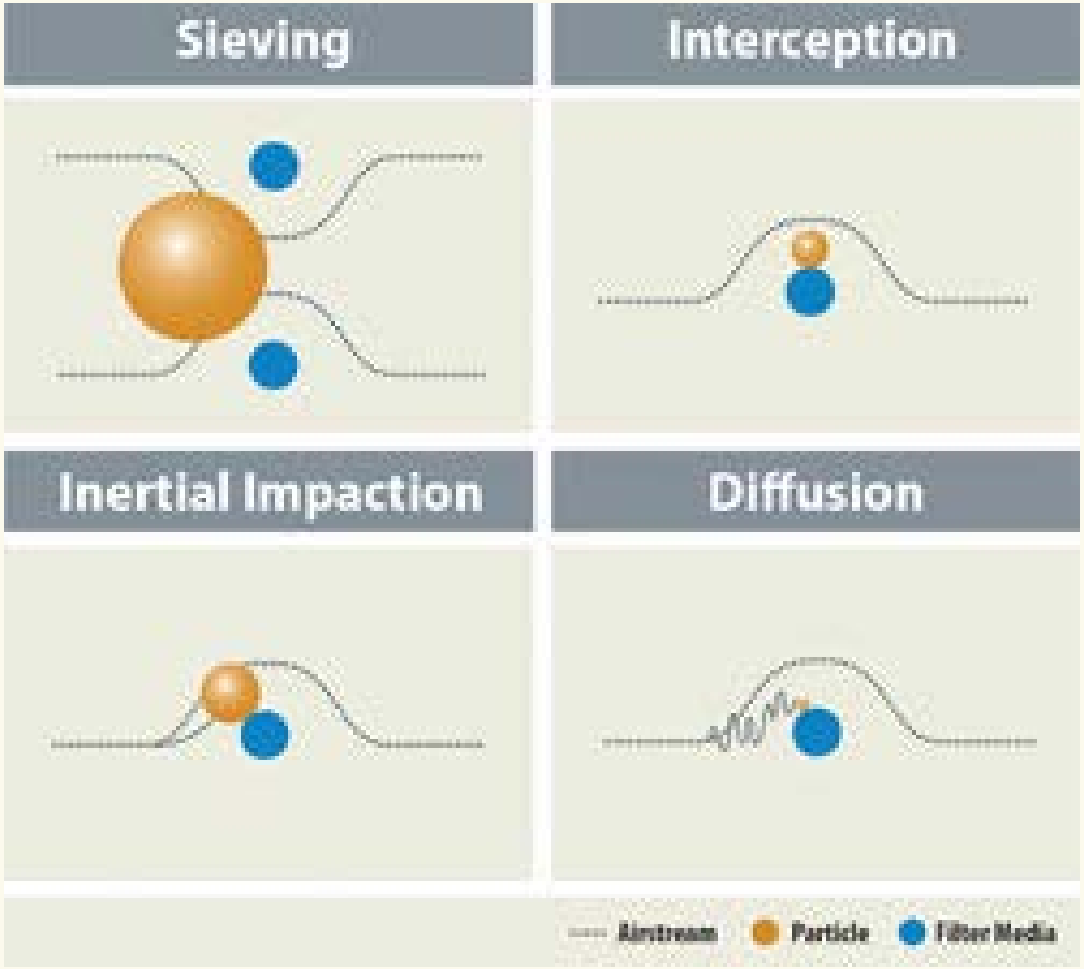
Summary of Mechanisms



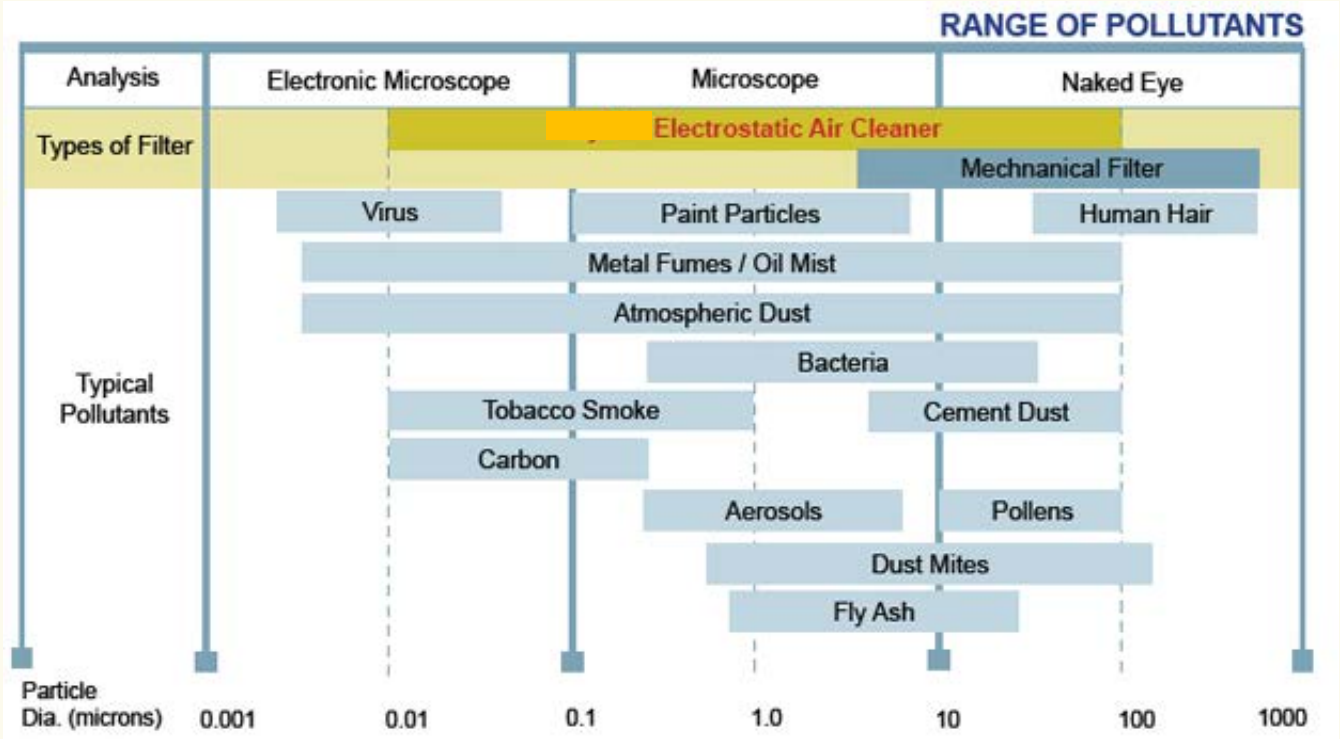
Considerations

- Impaction and interception are dominant for particle sizes > 0.2 microns

- Diffusion is dominant for particle sizes < 0.2 microns
  - Many of these particles pass through

Filtration:

Range of particle sizes for pollutants



- **Formaldehyde diameter ~ 0.0001 um**
- **VOCs typically too small in diameter to be trapped by traditional filtration devices**

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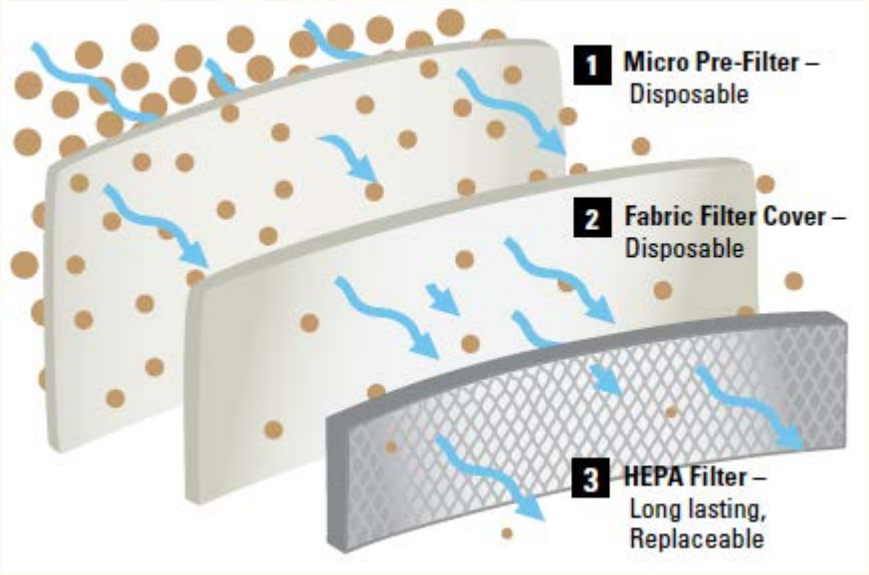
Single Stage: ex: HEPA Filters

- HEPA – High Efficiency Particulate Arrestance
- Useful for filtering out particulate matter, allergens that are 0.3 microns or larger



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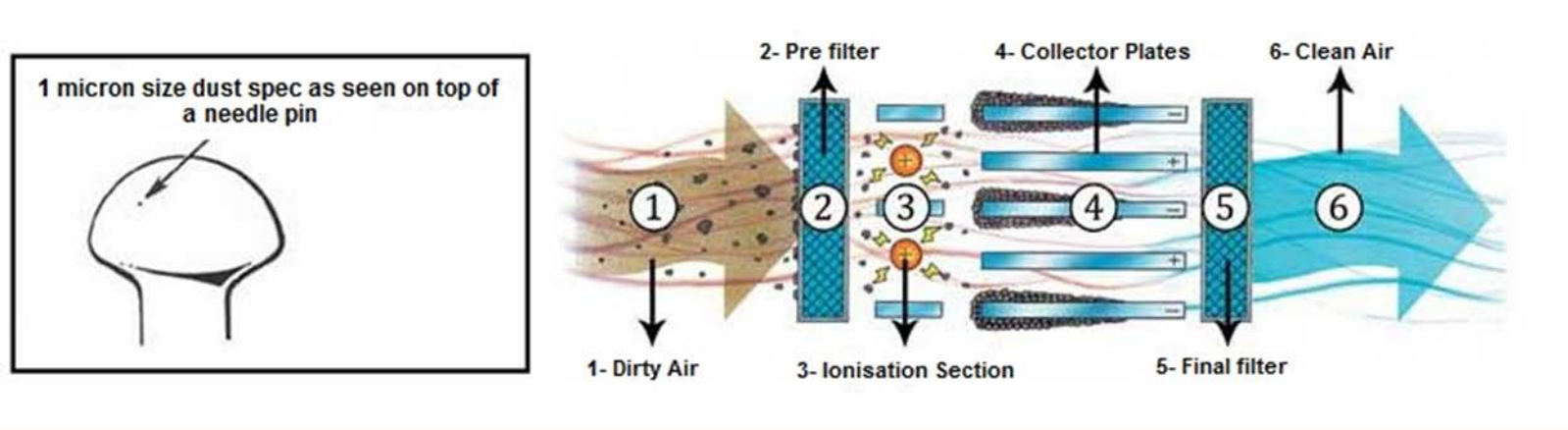
Single Stage Filters

- Straining, Inertial impaction and Interception are the primary mechanisms for Media type
- Useful for particulate matter remediation (generally > 0.2 microns)
- VOCs/formaldehyde are not captured with single stage filters.

Air Filter with Electrostatic filter

- Unfiltered air is passed through a pre-filter and electrostatically charged in the ionization section
- Positively charged particles are collected on the negative collector plate; this plate needs to be frequently cleaned



What about VOC/formaldehyde Removal?

- Gaseous pollutants require that sorbent materials be present
- Difficult to compare sorbents because guidelines don’t exist yet for portable units
- ASHRAE developing guidelines for HVAC installed systems (Committee 145)

VOC removal effectiveness

- Depends on:
  - Airflow rate and velocity through sorbent
  - Concentration of contaminants
  - Total available surface area of the sorbent
  - Temperature and relative humidity of the gas stream

  - Usually an activated carbon sorbent
  - Effective at removing formaldehyde
  - Case study: 3 month use in home; reduced formaldehyde from 120 ng/L to 43 ng/L

VOC removal Mechanisms

- Adsorption
  - Physical attraction of gas or vapor molecules to a surface
  - Limited capacity
  - Require frequent maintenance
  - Work better at lower temperature and humidity

Activated carbon, silica gel, activated alumina, zeolites, synthetic polymers, porous clay minerals

VOC removal Mechanisms

Chemisorption

The VOC reacts with the sorbent material

Bind to the sorbent as organic or inorganic salts

Sometimes, the final product is broken down further and released back to the atmosphere as CO_2 and H_2O.

Potassium permanganate impregnated into aluminum oxide effective at removing formaldehyde and sulfur and nitrogen oxides

What about airborne virus/bacteria/mold?

- Methods of Filtration:
  - One Stage: Media or HEPA – particulate matter remediation
  - Two Stage: HEPA + activated carbon filter – particulate matter + VOC remediation
  - Enhanced Two Stage: HEPA + activated carbon filter + cleansing technology (electrostatic, UV, ionization, photocatalytic oxidation, ozone, cold plasma, etc.)

Air Cleaner Types…

Technology	Description	Contaminant	Review article[a]
Media filtration	Porous media	Particles	Fisk (2013)[b]
Sorbents	Physio- or chemosorbents	Organic and inorganic gas-phase	Harper (2000)
UVC/UVGI	Ultraviolet (UV) lamp	Bioaerosols (airborne or on surfaces)	Miller et al. (2013)
Photocatalytic oxidation (PCO)	UV lamp and photocatalyst	Organic and inorganic gas-phase (occasionally bioaerosols)	Mo et al. (2009)
Electronic air cleaners (EACs)	Corona or pin ionizer, enhanced deposition in or out of device	Particles	Mizuno (2000)[c]
Plasma	Electrical discharge	Organic gas-phase	Chen et al. (2009)
Catalyst	Excludes PCO photocatalysts	Organic and inorganic gas-phase	
Plants	Various botanical systems	Particulate and gas-phase	Soreanu et al. (2013)
Ozone	UV or corona generation of ozone	Organic gas-phase (occasionally bioaerosols)	

a If available.

b Review of health benefits of particle media filtration, not all aspects of media filters.

c Includes other applications besides just indoor air.

Pollutant destruction filters

- Deactivation or destruction of pollutants (active filters)
  - UV Germicidal Irradiation Cleaners
  - Photocatalytic Oxidation (PCI) Cleaners
  - Ozone Generators

UV Light Benefits

- Limits Mold and Bacteria Growth on HVAC Coils (if part of whole house system)
- Reduces Maintenance Costs
- Reduces Airborne Contaminants

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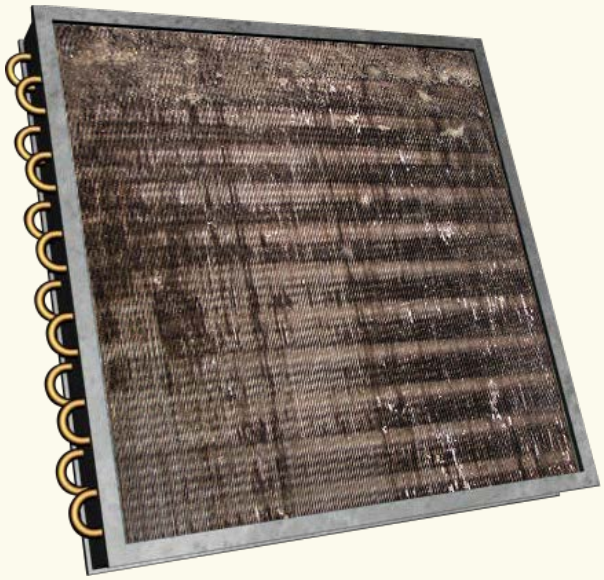
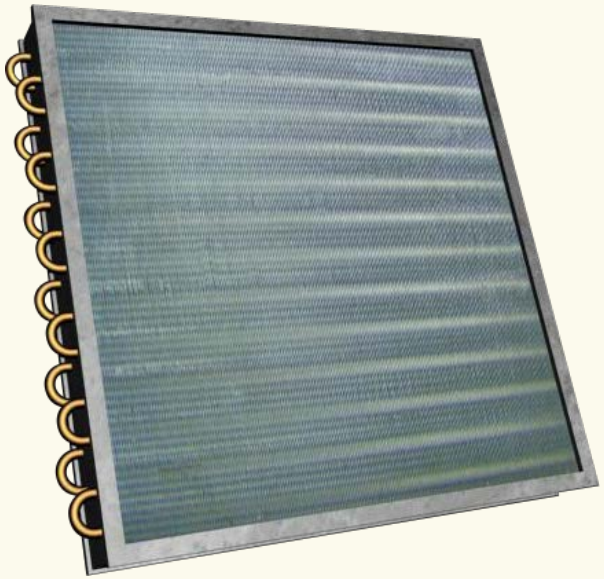
Dirty Coil





Without UV

With UV

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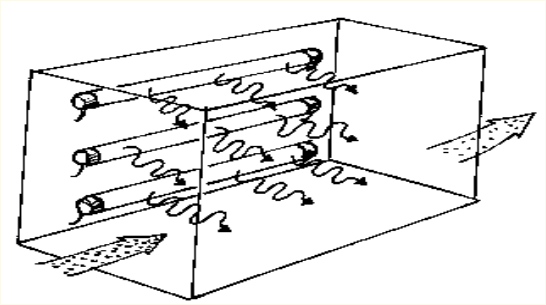
UV Light

- 254 nm light first used in 1950's
- Efficient and effective
- Disrupts RNA/DNA to sterilize
- UV is a proven "object specific" treatment
- Problem: UV does not travel well
- Inverse Square Law
- To achieve the proper CT value (or "Kill dose") you need:
- UV energy x Time = Kill Dosage (CT Value)



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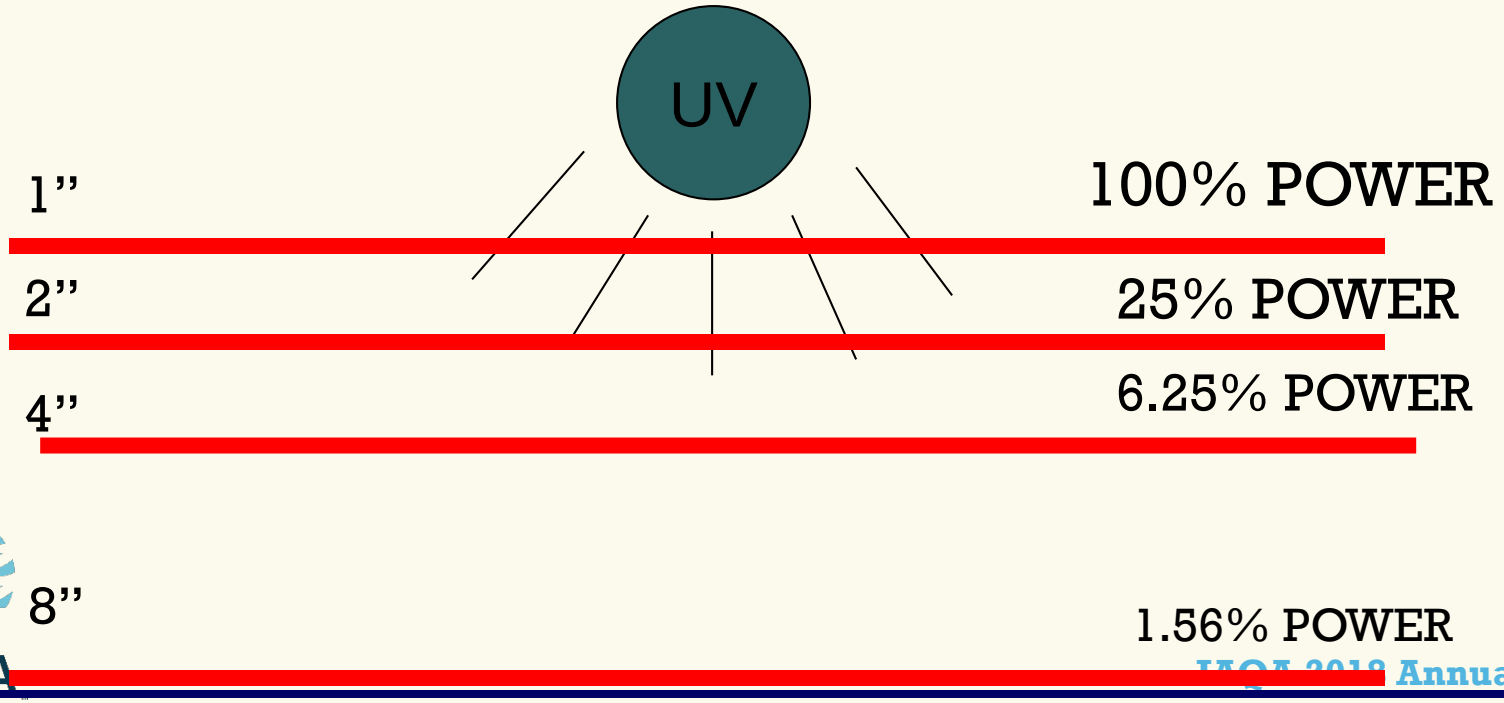
Germicidal Ultra Violet Light

Inverse Square Law



Multi-stage Air Filter

HEPA filter removes particulate matter

Charcoal layer reduces odors and VOCs

UV light reduces air-borne germ; TiO_2 is activated and helps to decompose remaining molecules

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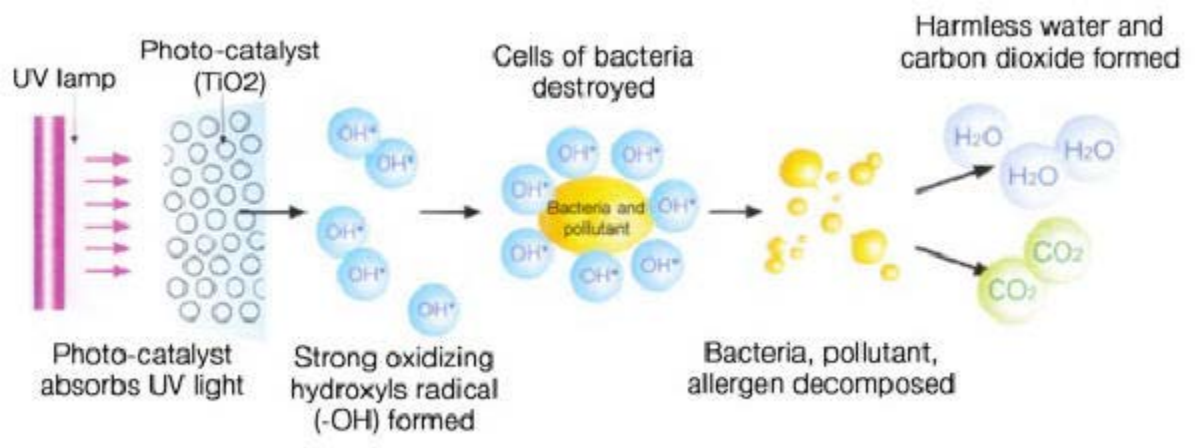
Limitations

- Limited effectiveness in destroying airborne viruses, bacteria, and molds mainly due to amount of time of exposure to the UV light
- Should be used with, but not in replacement, of other filtration devices
- Some mold and bacterial spores require higher UV exposures

Photocatalytic oxidation



Photocatalytic Filter – Combine UV light with a TiO_2-coated filter

Hydroxyl radicals and Superoxide ions are generated – highly reactive

PCO

- These units are designed to destroy gaseous pollutants by changing them into harmless products
- The hydroxyl radicals oxidize gaseous pollutants adsorbed on the catalyst surface.
- They are also designed to remove particulates
- Limitation: most available catalysts are ineffective at destroying gaseous pollutants in indoor air

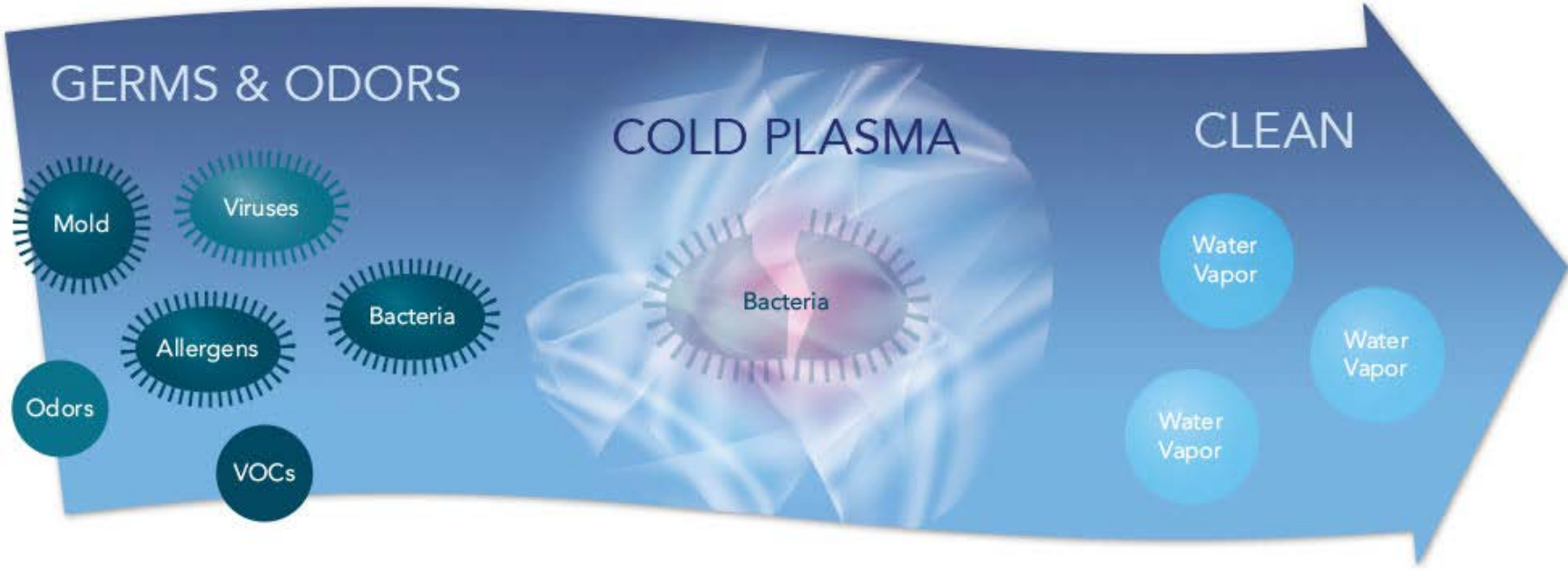
PCO

- Some PCO units fail to destroy pollutants completely and produce new indoor pollutants that may cause irritation of the eyes, throat, and nose
- Ex: formaldehyde
- Ex: HCl from chlorides

Air cleaners with ozone generation

- Use UV light or corona discharge to produce low level ozone
- Ozone dispersed by fan into living space
- FDA requires these type of units to be limited to less than 50 ppb of ozone
- At these levels, ozone destruction of bacteria, allergens, etc. not highly effective

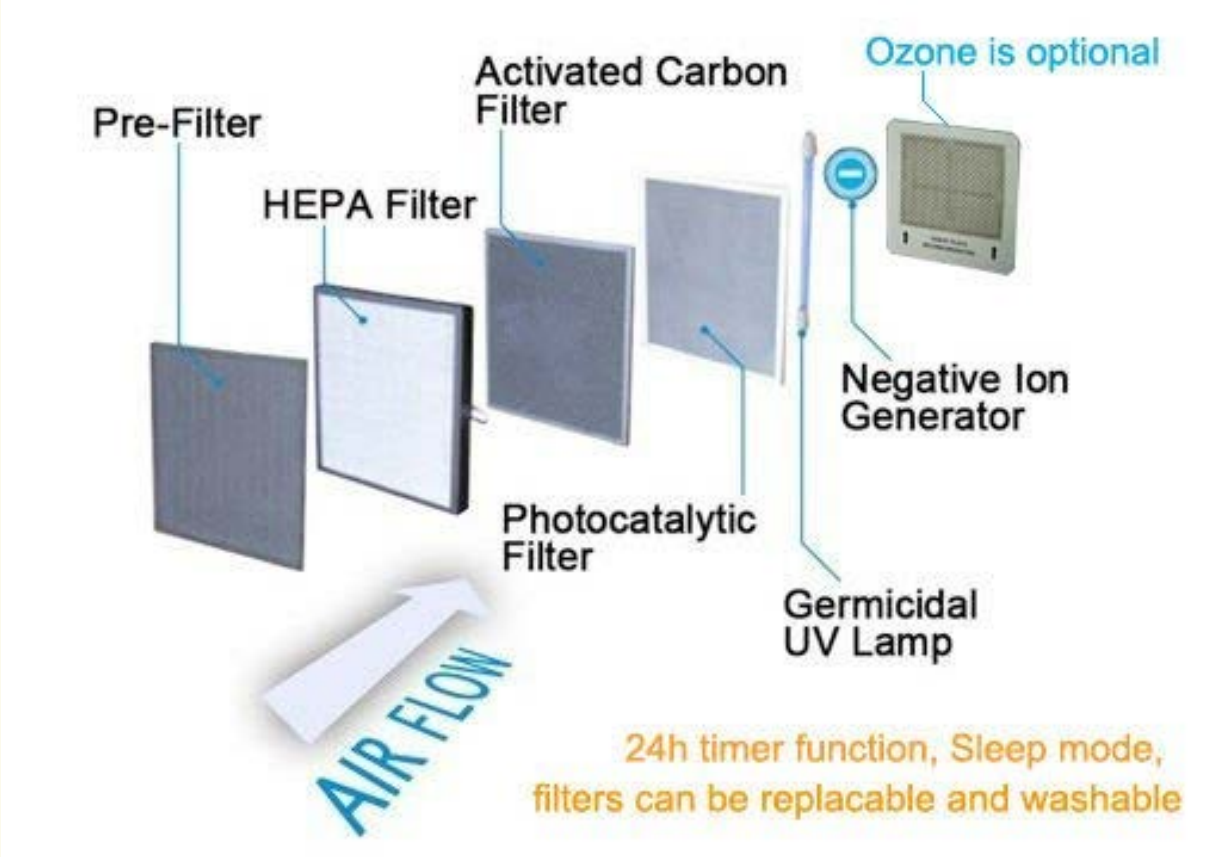
Air filter using Cold Plasma



Needle-point ionization breaks down gases in the air stream with electron-volt potential numbers below 12 to harmless gases

Positive and negative ions are attracted to airborne particles, improving the effectiveness of particulate filtration

Different stages of multi-stage air filter



Multi-stage air filter

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Comparison

- Price ranges:
- Small room units: $90 and up
- Pricing up to $500 for room units
- Most are available at Building Supply stores

Conclusions regarding Air destruction filters

- Buyer beware regarding potential hazards of use
- Scientific evidence suggests that secondary products exist that can re-pollute indoor air
- Know what you are buying
- Ask questions

Ozonation – Whole house or zone shock treatment

- 3500 mg/hr ozone generator
- Ozone reacts with pollutants/allergens/etc.
- Can cause damage to materials of construction in local environment
- Can cause the creation of new VOCs due to decomposition of materials of construction

Ozonation – Impact on MOC

Ozone is a powerful oxidizing agent

Causes substantial damage to rubber products, surface coatings, polymers

Rubber seals, sealing compounds, weatherproofing glazed windows

PVC very vulnerable to damage

Common by-products: Formaldehyde; aldehydes in C_2 – C_{12} range

Chlorine dioxide (ClO_2) – Whole house or Zone shock treatment

- ClO_2 is an oxidizer
- Less reactive than O_3 or Cl_2
- Helps eliminate odors/microbials
- Usually does not form secondary reaction products as ozone does.

Conclusions

- Source reduction is best option for pollutant removal
- Improved ventilation and added fresh air intake can be effective at improving IAQ
- Particulates, bacteria, large molecules can be removed by mechanical filters (HEPA, etc.); MERV ratings are useful
- VOCs, formaldehyde can be removed using carbon bed adsorbents
- Advanced technologies (UV, PCO, Cold Plasma, needlepoint ionization, etc.) can be used to break down bacteria, viruses, allergens
- Understand potential secondary by-products

Questions?

Steve Froelicher
s.froelicher@pati-air.com