Biological and chemical air treatment devices
Principles and challenges

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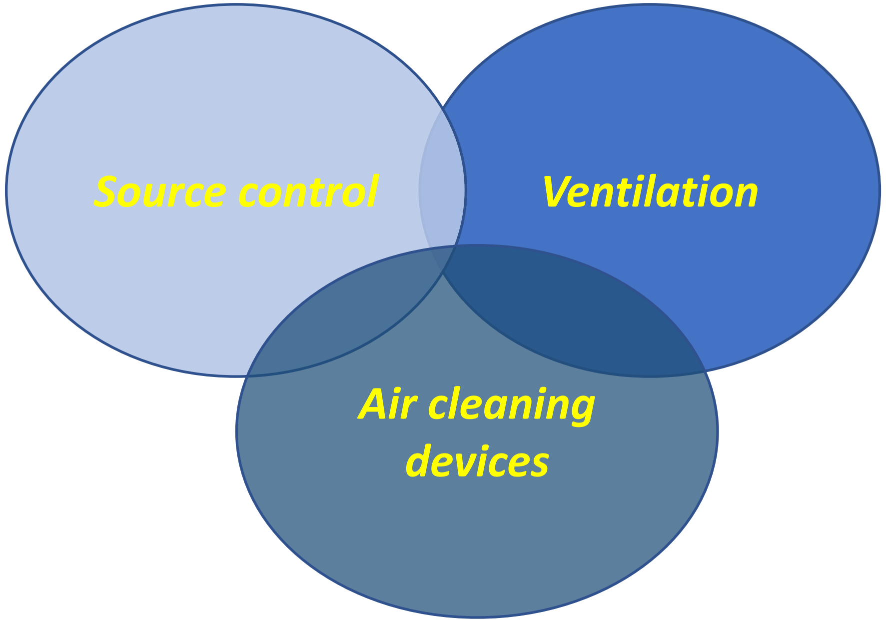
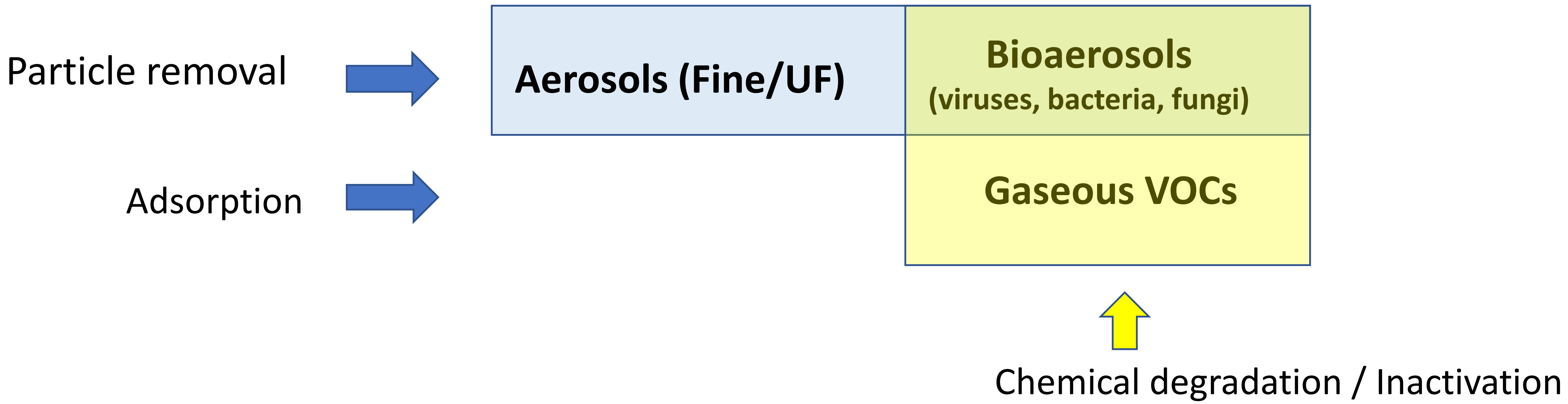


Air cleaning devices (ACD) <u>are not a substitute</u> for ventilation, and should not be used as a reason to reduce ventilation, but can be a useful strategy to reduce airborne contamination risks in poorly ventilated spaces.

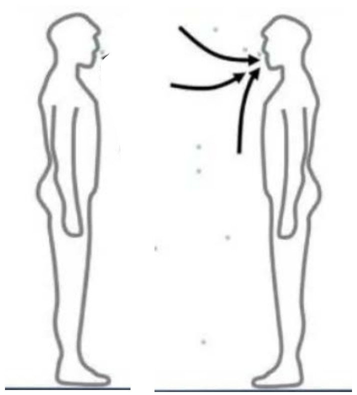
Target indoor pollutants:

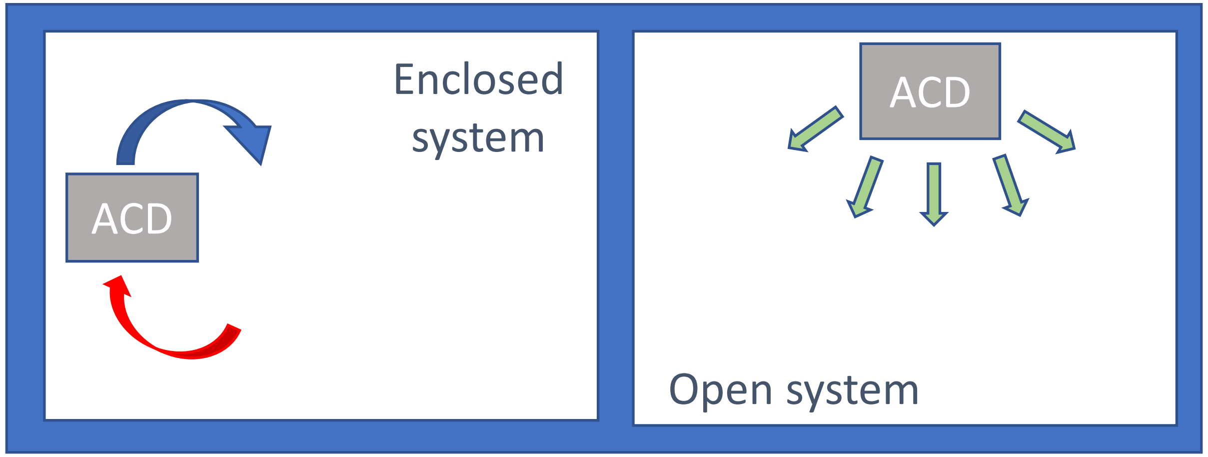


The coexistence of pathogens with other pollutants (PM and VOCs, etc.) in natural air environment makes decontamination complicated and challenging.

Treatment approaches:

Both approaches are unlikely to be effective at mitigating short range person-to-person transmission.





Enclosed devices: stand-alone unit that draw air into the device using a fan and treat the air while it is inside the device before returning treated air to the room.

Open devices: use the room itself as the zone where the technology interacts with the virus/pollutants (i.e., emission to the room of radiation or treatment agent).

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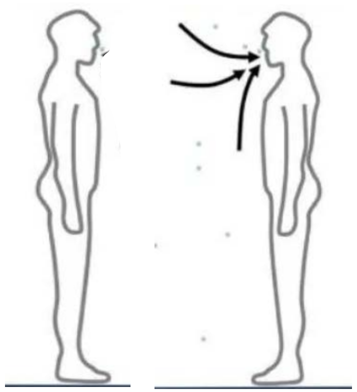

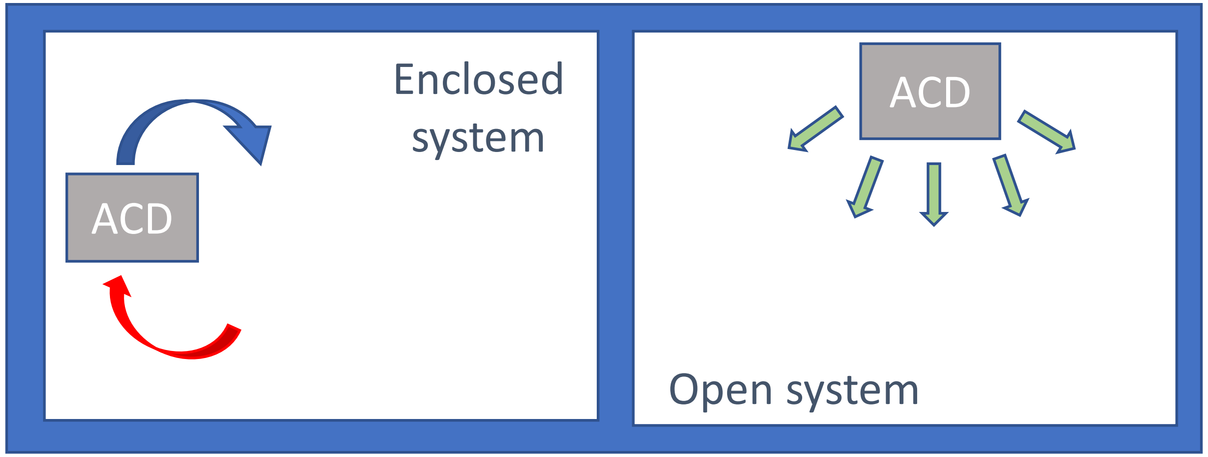

Treatment technologies of common ACDs:

<table>
<tr><th>Particulate Matter</th><th>Bioaerosols</th><th>Gaseous pollutants (VOCs)</th></tr>
<tr><td colspan="2">Fibrous filtration</td><td>AC filters</td></tr>
<tr><td colspan="2">Ionisers</td><td></td></tr>
<tr><td colspan="2">electrostatic precipitation</td><td></td></tr>
<tr><td></td><td colspan="2">Irradiation (mainly germicidal UV – UVC)</td></tr>
<tr><td></td><td colspan="2">Chemical oxidation</td></tr>
<tr><td></td><td colspan="2">Photocatalytic oxidation (e.g., TiO_2)</td></tr>
<tr><td></td><td colspan="2">Plasma cleaning</td></tr>
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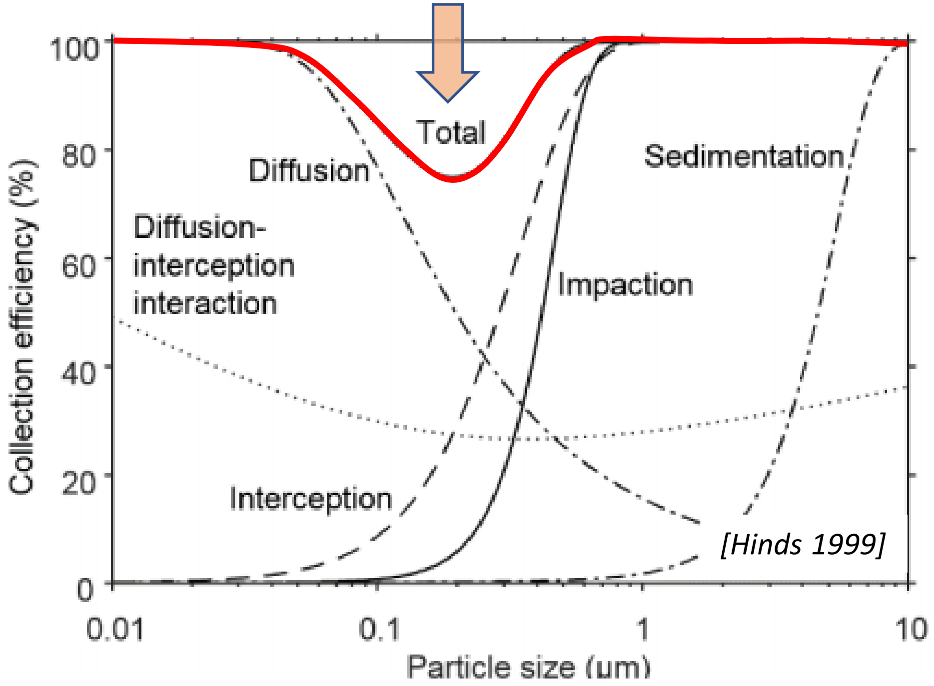
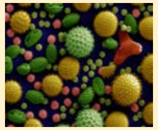
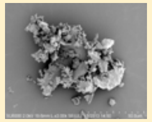
Filtration

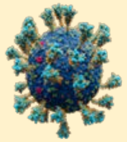
Filter material

- *Glass fibers*
- *Activated Carbon Fibers*
- *non-woven nanofibers*
- *Electret filter material*
- *Biocide addition (Ag…)*




- Pollen, dust, bacteria (0.2-2.0 µm),
- virus (0.02-0.3 µm)



Viruses are often contained within exhaled droplets and aerosols, with those in the 1-100 µm range likely to pose the highest risks.

Type	Pre filter	Medium filter	HEPA filter	ULPA
PM removal efficiency	<60%	60-90%	99.97% (0.3 µm)	99.999% (0.12-0.17 µm)

✓ Relatively simple devices.
✓ High grade filter are likely to be effective at removing fine/UF aerosols, including airborne virus and bacteria.

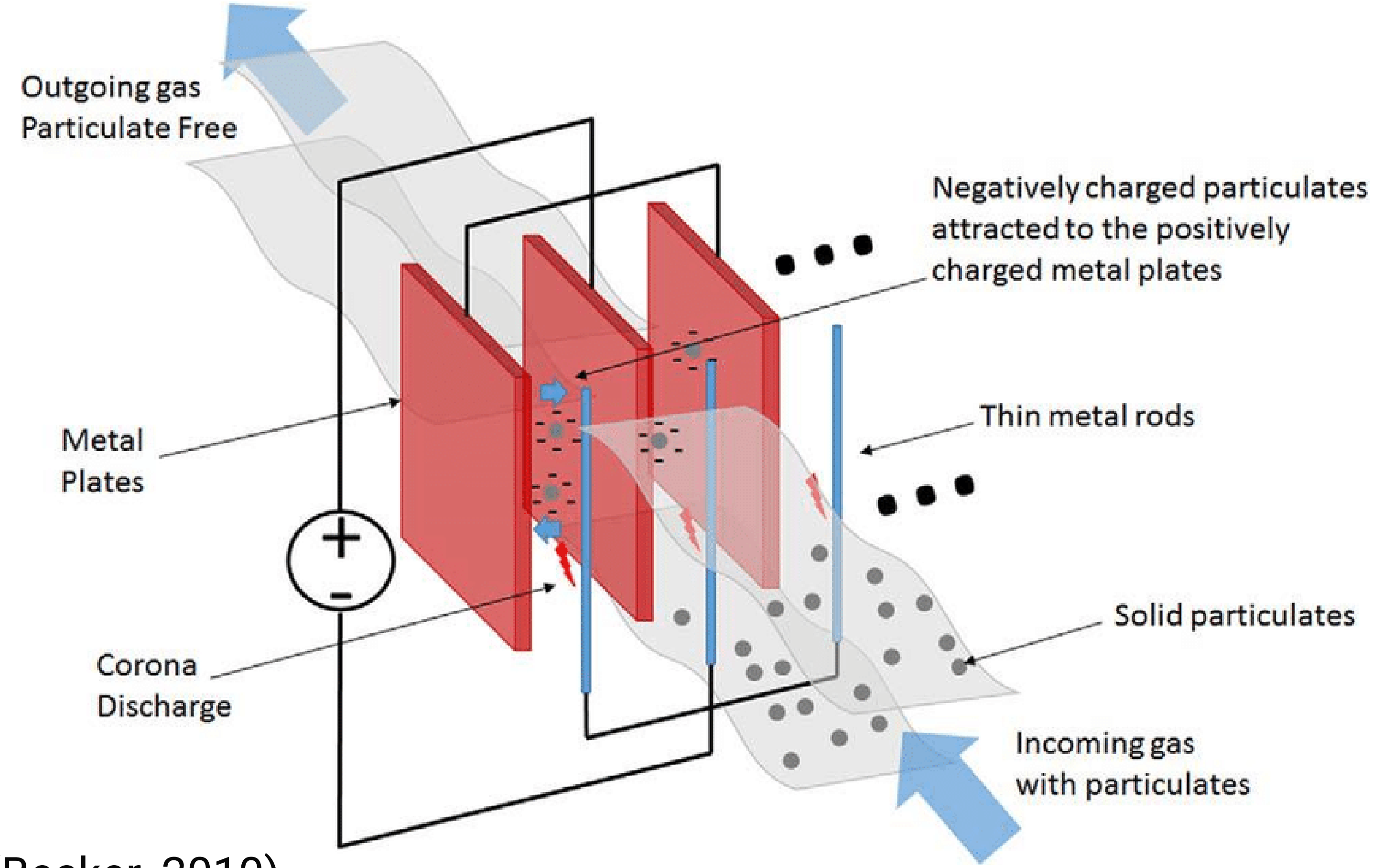
❖ Usually **provide only PM removal** with limited inhibition ability against airborne microorganisms
❖ **High air resistance + filter clogging ➔** Increase energy and maintenance requirements.
❖ Improper maintenance may result in new hazards (filter colonization / chemical by-products)

Electrostatic participators (ESPs):

Performance is very sensitive to:

1) Electrical resistivity
2) Particle size distribution

- Overall PM removal efficiency by ESPs << by Fiber mats and HEPA filters (Brincat et al., 2016).
- ESPs are effective in destroying bacteria and fungal spores but not viruses (Zheng et al 2013).
- **May lead to ozone and NOx formation!**

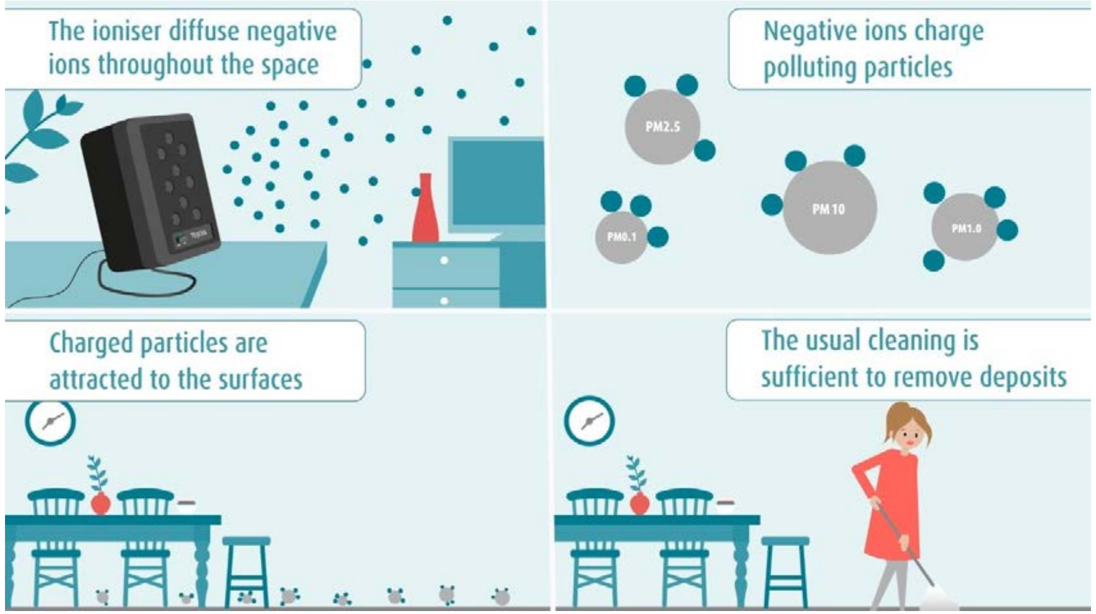


(Becker, 2010)

Ionizers

- **Ion-induced enhancement of non-biological and biological aerosols removal** (e.g., Huang et al., 2009, 2015, Alonso et al., 2016).
- **Removal efficiency is affected by distance to the source of ions, type and size of particle** (e.g., Alonso et al 2016).
- **Limited evidence for inactivation of viruses and bacteria by negative ions** (e.g., Hyun et al., 2017, Hagbom et al 2015, Escombe 2009,)
- **Biocidal mechanisms of air ions still needs further investigation.**

https://www.youtube.com/watch?v=Q917P1gBZcU



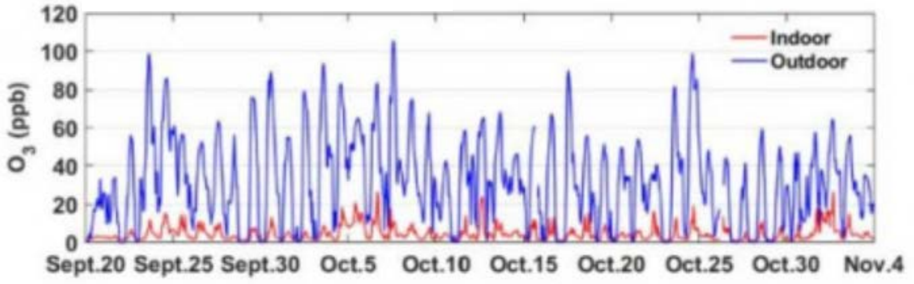
Electrically charge air molecules are released to room air ➔ charge aerosols ➔ preferential deposition on available surfaces/collector plate.

Advantage:
- Low power
- Low maintenance
- Quiet

Disadvantages:
- Charged aerosols may deposit on room surfaces rather than been removed ➔ surface contamination.
- Potential ozone production.

What's the big deal of Indoor O_3 emissions?

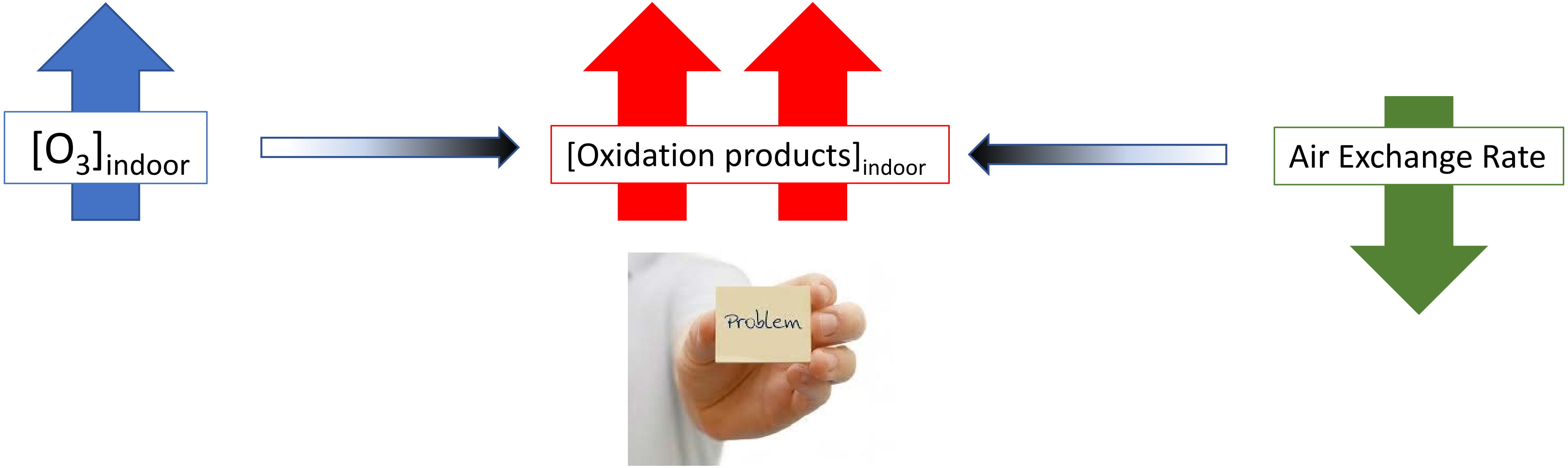
(Xu et al., 2020)



$[O_3]_{indoor} << [O_3]_{outdoor}$ (usually 20-70%)

(e.g., Romieu et al. , 1998; Bernard et al. , 1999; Weschler, 2001)

- **Ozone is the main initiator of indoor chemistry!**
- **Leads to formation of gaseous oxidation products and ultra-fine aerosols.**



Inactivation and decontamination….

Irradiation and photo-oxidation

Germicidal UV light (λ=254 nm) is often used to inactivate fungi, bacteria and viruses by **damaging** their **DNA/RNA**.
Can also yield **photodegradation of chemical pollutants**.

- ✓ Efficient inactivation has been shown for various microorganisms
- ✓ Enclosed systems eliminate UV exposure risk
- ✓ Potentially quitter than filter-based devises

UV-B (280-320nm) and UV-A (320-400) light can damage and kill cells by causing protein and lipid oxidation.

Current challenges regarding UV-based treatment systems:

1. **Dose depends on distance and exposure time**…
   - Most demonstrated with short *irradiation distance* to target microorganisms (e.g., Darnell *et al*, 2004; Heilingloh *et al*, 2020, Heßling *et al.,*2020).
   - Most studies used exposed liquid viral samples, not ***airborne bioaerosols***.
2. Photolysis of other substances (gaseous or particulate) may lead to ***formation secondary pollutants*** (e.g., formaldehyde) that can be released to room air!
3. Emissions at 185 nm (LP-Hg lamps) will lead to **O_3 formation**.

Photocatalyst (e.g., TiO_2 ZnO and H_2O_2)

- Enable to utilize **wider range of UV-vis spectrum and at lower doses**.
- Some catalysts can yield **oxidation and reduction chemistry** to treat different pollutants simultaneously.

Photo- and chemical oxidation are common technologies applied also for VOCs degradation.

- *O_3 can act as chemical decontaminant for unsaturated pollutants and disinfectant (at doses >> AQS).*
- *$^{\cdot}OH$ radicals quickly react with wide range of organic compounds.*

H_2O_2 + UV-C → $2^{\cdot}OH$

TiO_2 + UV/A-C → $e^- + h^+$.... $^{\cdot}OH$

O_2 + V-UV → O + O

O + O_2 → O_3

O_3+ UV ⟷ O + O_2

O^* + H_2O → $2^{\cdot}OH$

H_2O + V-UV → $^{\cdot}OH$ + H

Biological oxidation can also be applied for degradation of certain VOCs – biofilters, Dynamic Botanical Air Filtration system (DBAF)

Degradation of parent pollutant is NOT necessarily enough! What are the oxidation products?

To purify indoor air, necessary to combine various treatment methods corresponding to the types of pollutants present in the air (Liu et al. 2017).

Ionization / electrostatic charging with filtration - *to enhance filter efficiency* (e.g., Huang et al 2009)

Filtration + UV or photocatalysts *(concentrating effect on filter enhances photocatalysis while chemical degradation regenerates the filter)*

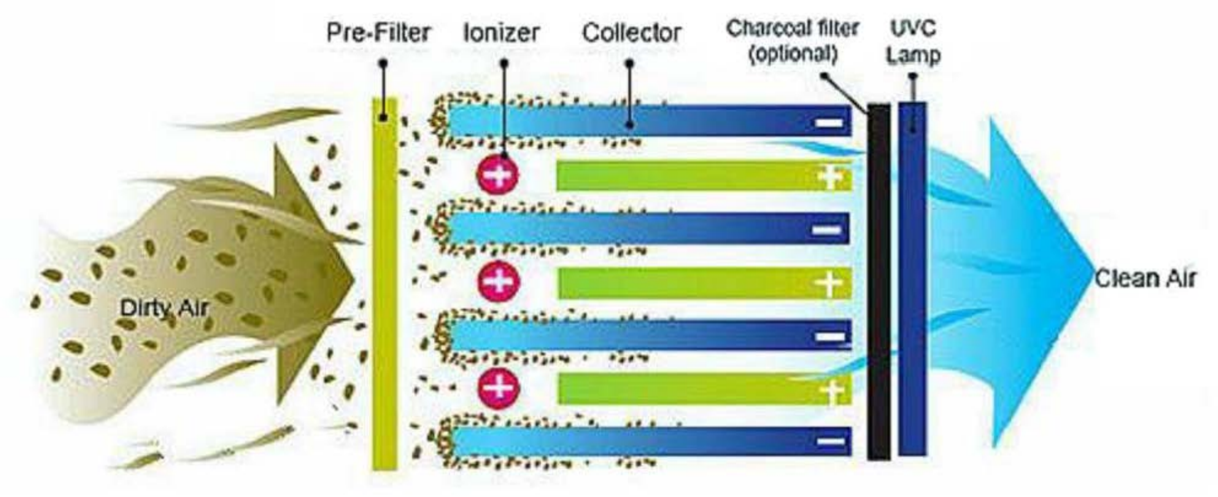
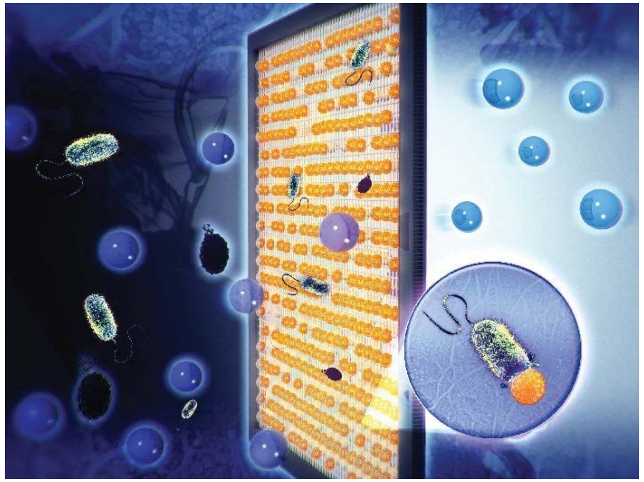


Fig. 7. Schematic of Electrostatic air filter.

Biocide-doped filters (e.g., silver nanoparticles)



https://www.korea.net/NewsFocus/Sci-Tech/view?articleId=121935

General challenges for ACDs:

Effectiveness of air cleaning devices depends on multiple parameters: underlying **technology**, **design** of the device, the **in-room location** of the device, the **environment** it is used in and the **maintenance** of the device.

- **Performance of most devices is based on data measured in idealised controlled environments**, and is likely to be different and often lower in a real-world setting.

- **No international test standards for microbial inactivation and removal** (manufacturers tend to rely on university laboratories).

- **Regulatory processes that may apply to air cleaning devices are complex** (→ for same class of devices large variability in quality and effectiveness).

Conclusions

- ACD are not substituting proper ventilation! ***(source control, ventilation, air cleaning devices)***
- Proper air cleaning will most likely require combination of various technologies.

Purification Technique	Pollutants			
	Suspended particles	Volatility organic contaminants	Microorganism	
	Dust, pollen, secondary pollutants, lampblack, etc. Diameter 0.01–100 μm	Formaldehyde, benzene, ammonia, etc. Diameter 0.0001–0. 001 μm	Bacteria Diameter 0.2–10 μm	Virus Diameter 0.01–0.3 μm
Filtration	Effective	Noneffective	Effective	Noneffective
Adsorption	Partially effective	High-efficiency	Partially effective	Noneffective
Water washing purification	Effective	Partially effective	Noneffective	Noneffective
Electrostatic precipitation	Effective	Not obvious	Partially effective	Noneffective
Anion technology	Effective	Not obvious	Partially effective	Noneffective
Photocatalysis purifying technology	Not obvious	Effective	Effective	Effective
Plasma cleaning technology	Not obvious	Effective	Effective	Effective
Ultraviolet radiation	Noneffective	Noneffective	High-efficiency	High-efficiency

(Liu et al 2017)

- Need to ensure we do not replace biological health-risk with a chemical one
- Need to improve regulation regarding indoor air standards and air cleaning devices.
- Usage of air cleaning devices is increasing→ need to support industry and consumers in ensuring they are selecting and using devices safely and effectively.

Thank you for your attention!