



**MITIGATING DISEASE TRANSMISSION
WITH GERMICIDAL UV-C**

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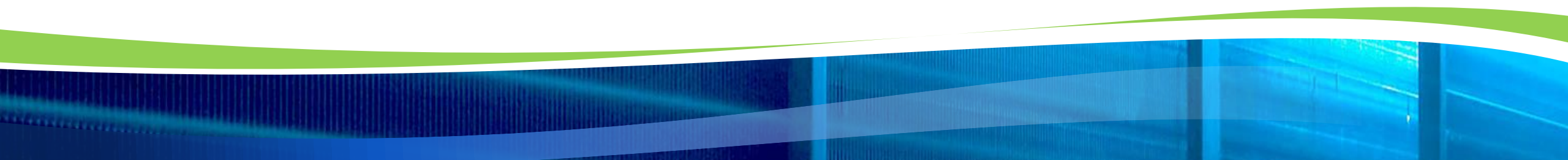
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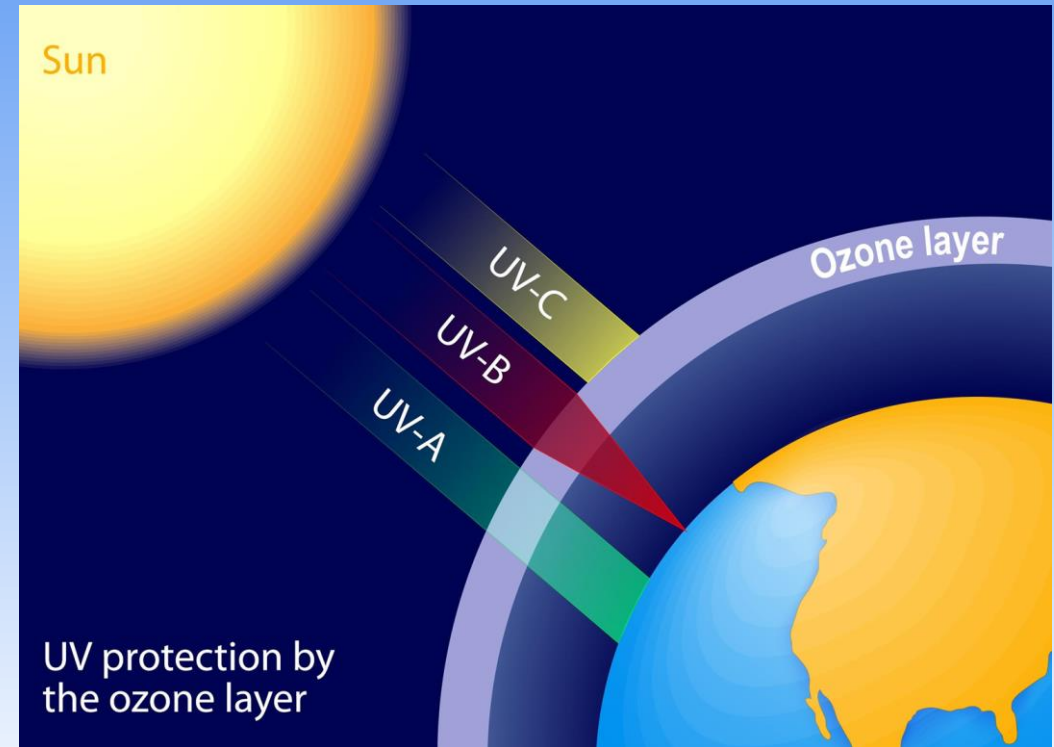
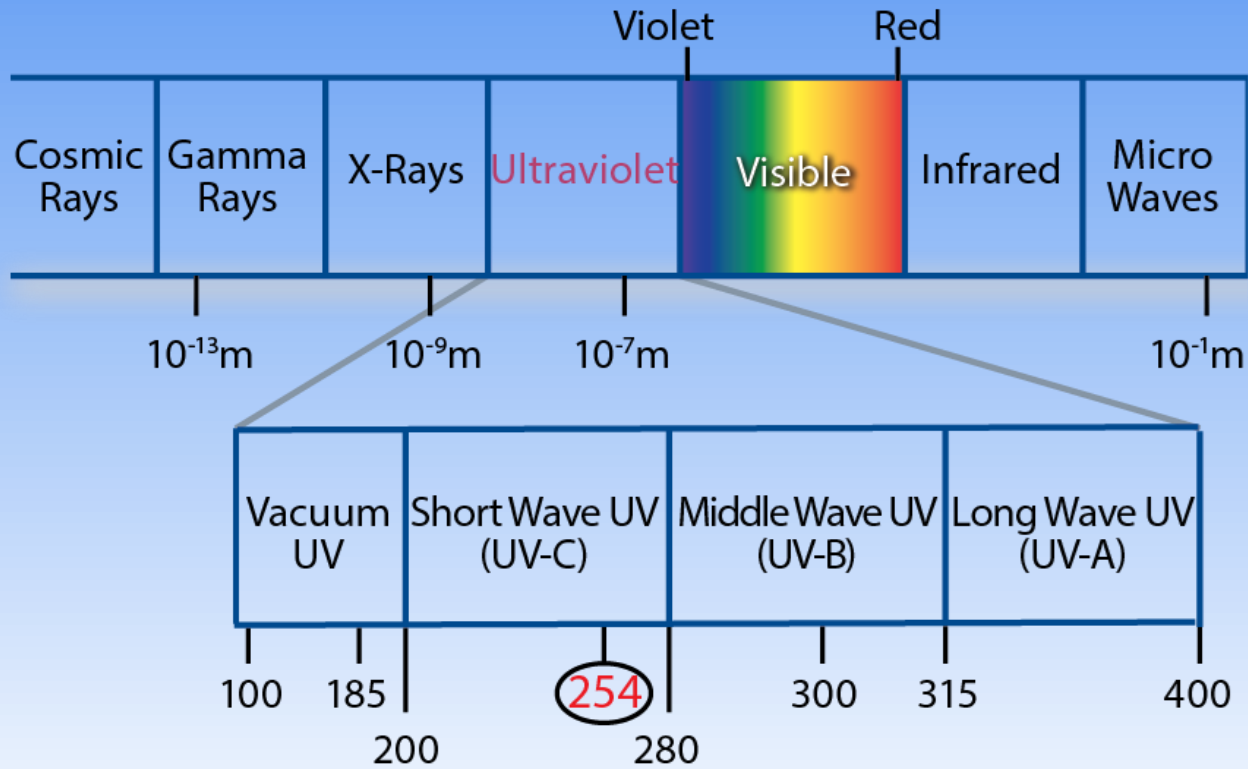
WHAT WE'LL REVIEW:

- ▶ Basics of Germicidal UV-C
- ▶ Infectious Diseases
 - Inactivating Airborne Pathogens
- ▶ Applications
 - Airstream Disinfection / In-duct “On the Fly”
 - Upper-Air / Room Disinfection
 - HVAC Coil / Surface Cleaning
 - American Society of Heating & Air-Conditioning Engineers (ASHRAE) Position
- ▶ Review / Questions

BASICS OF GERMICIDAL UV-C



ELECTROMAGNETIC SPECTRUM



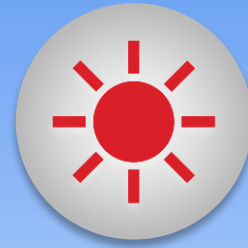
ELECTROMAGNETIC SPECTRUM



400-315 nm

UV-A long-wave

Responsible for skin tanning & wrinkles



315-280 nm

UV-B medium-wave;

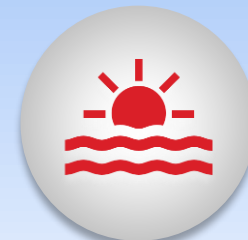
Primarily responsible for skin reddening and skin cancer



280-200 nm

UV-C short-wave;

Most effective Germicidal control



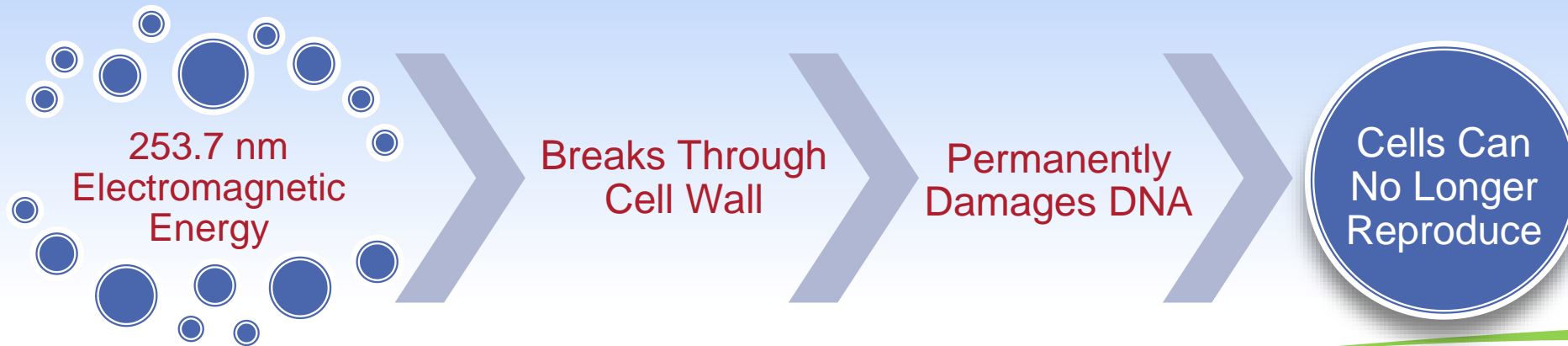
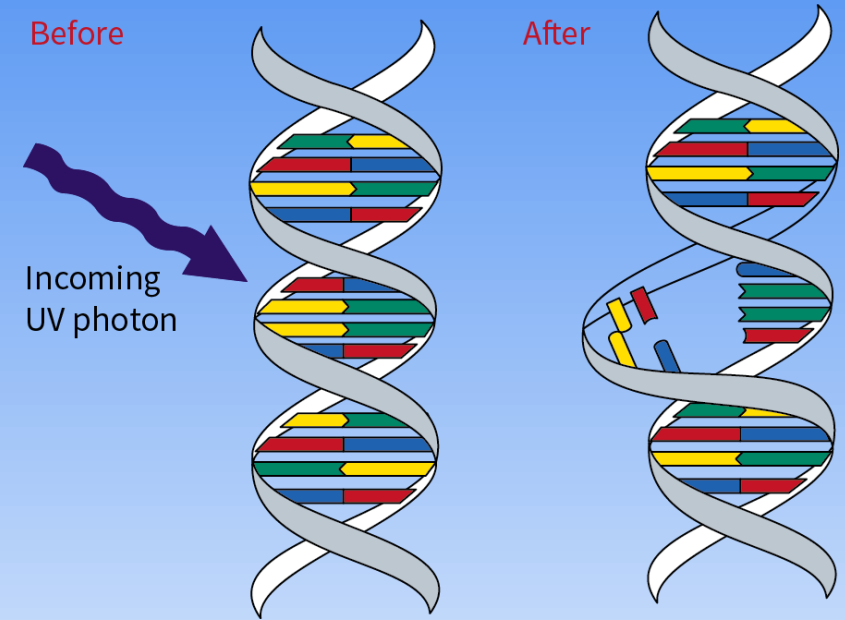
200-100 nm

Vacuum UV

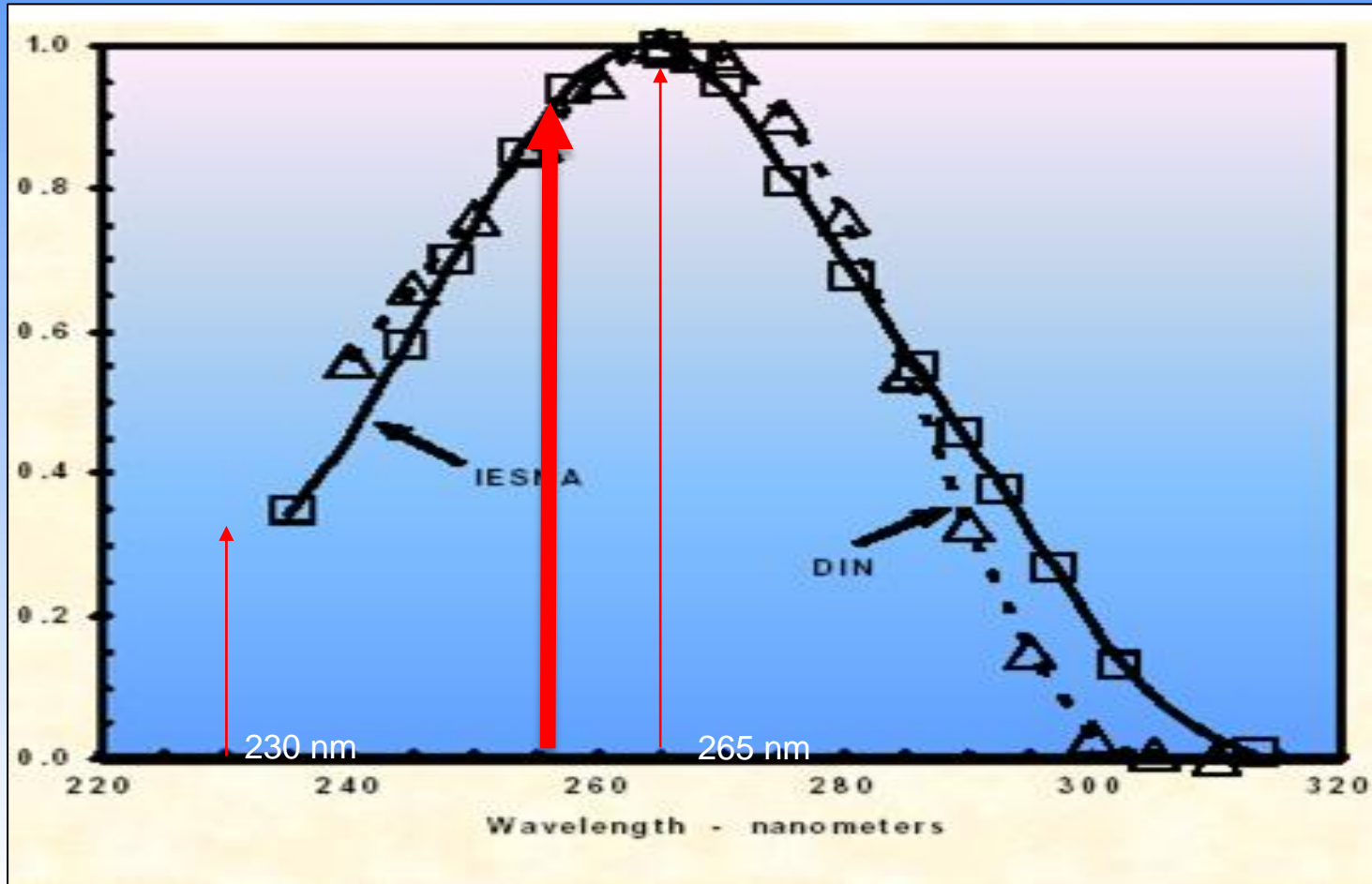
Can produce ozone (O₃) in air

253.7 NM WAVELENGTH

- ▶ Inactivates virtually all microbes
 - Damages nucleic acid & proteins = incapable of reproducing
 - Forms thymine dimer lesions in DNA
- ▶ Pathogens absorb UV-C at different rates (called rate constant “K”)



HOW DNA RESPONDS TO UV ENERGY



Low pressure mercury vapor lamps generate their energy at 253.7nm

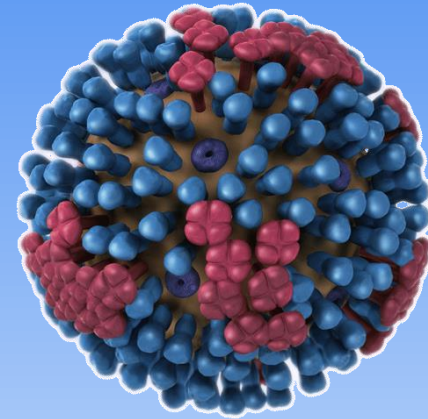
* SOURCE: DNA response to the electromagnetic wavelength; Illuminating Engineering Society of North America (IESNA)

INFECTIOUS DISEASES



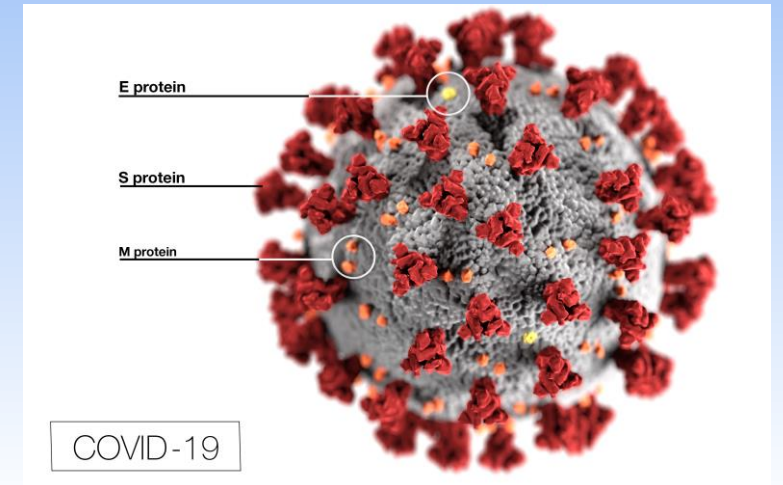
VIRUS SIZE*

- ▶ Coronavirus size
 - 0.06 to 0.15 microns (0.11 mean)
- ▶ Influenza
 - 0.08 to 0.12 microns (0.10 mean)
- ▶ SARS
 - 0.08 to 0.15 microns (0.11 mean)



Influenza †

Coronavirus †

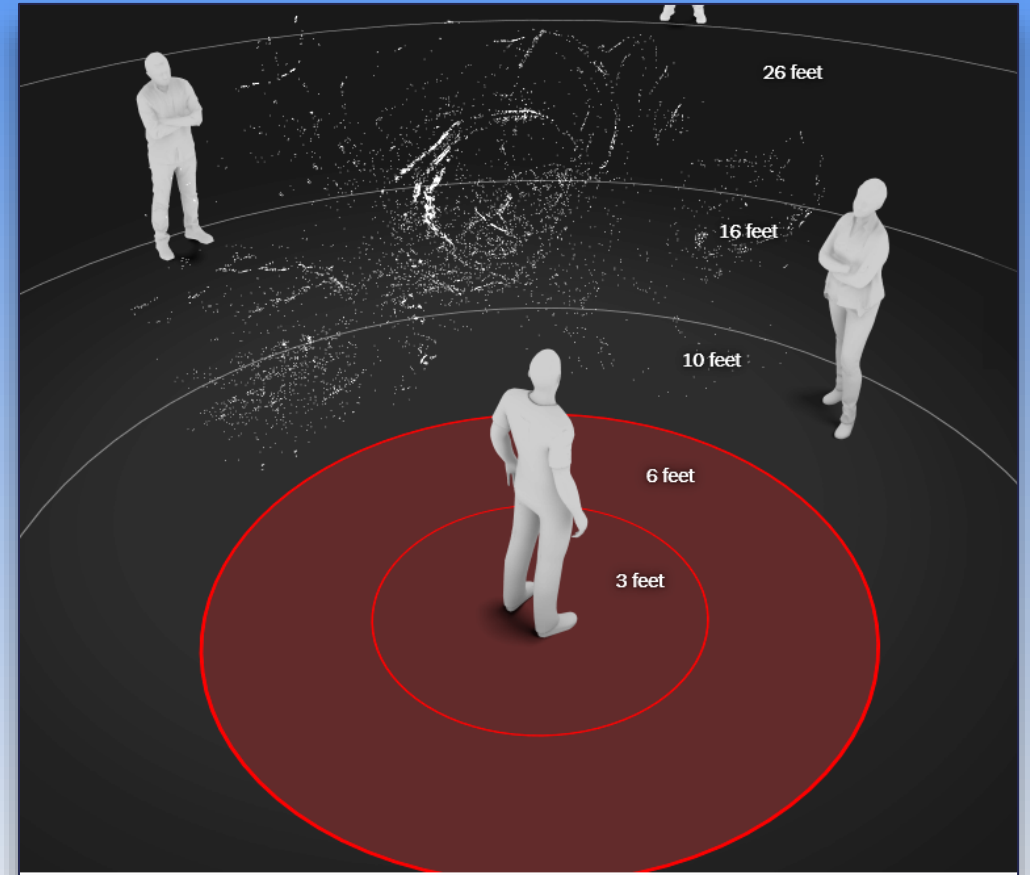


* Kowalski, Wladyslaw. (2009). Ultraviolet Germicidal Irradiation Handbook. 10.1007/978-3-642-01999-9_10.
<https://link.springer.com/book/10.1007/978-3-642-01999-9>

† Images courtesy CDC: <https://www.cdc.gov/media/subtopic/images.htm>

VIRUS TRANSMISSION

- ▶ M.I.T. Researchers observed particles from a **cough traveling as far as 16 ft** and those from a sneeze up to **26 ft***
- ▶ Can stay **airborne from 8 to 14 minutes†**

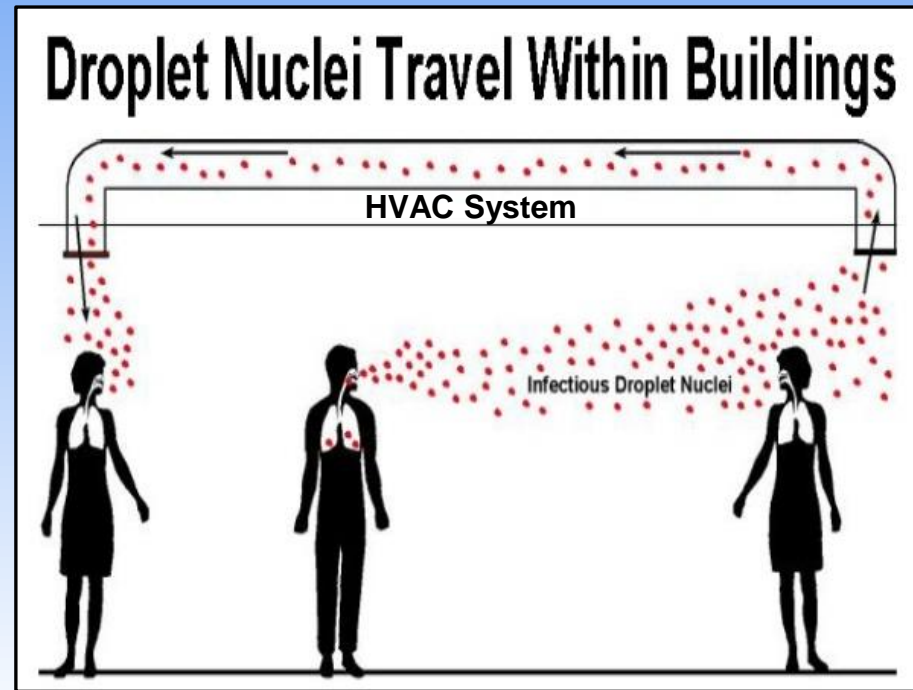


* The New York Times, 4/14/20 <https://www.nytimes.com/interactive/2020/04/14/science/coronavirus-transmission-cough-6-feet-ar-ul.htm>

† The airborne lifetime of small speech droplets and their potential importance in SARS-CoV-2 transmission <https://www.pnas.org/content/early/2020/05/12/2006874117>

BUILDING HVAC SYSTEMS

- ▶ In an office, every **7.5 to 10 minutes** the **air is recirculated** through the HVAC System



Residential	
Basements	3-4
Bedrooms	5-6
Bathrooms	6-7
Family Living Rooms	6-8
Kitchens	7-8
Laundry	8-9
Light Commercial	
Offices	
Business Offices	6-8
Lunch Break Rooms	7-8
Conference Rooms	8-12
Medical Procedure Offices	9-10
Copy Rooms	10-12
Main Computer Rooms	10-14
Smoking Area	13-15
Restaurants	
Dining Area	8-10
Food Staging	10-12
Kitchens	14-18
Bars	15-20
Public Buildings	
Hallways	6-8
Retail Stores	6-10
Foyers	8-10
Churches	8-12
Restrooms	10-12
Auditoriums	12-14
Smoking Rooms	15-20

<https://www.slideshare.net/anjumhashmi61/h1-n1-influenza-virus-its-transmission-indoor-air-role-hvac>

<https://www.contractingbusiness.com/service/article/20868246/use-the-air-changes-calculation-to-determine-room-cfm>

PATHOGEN SUSCEPTIBILITY TO UV-C

Fungal Spores	Bacterial Spores	Mycobacteria	Vegetative Bacteria	Viruses
Aspergillus versicolor Penicillium chrysogenum Stachybotrys chartarum	Bacillus anthracis Bacillus cereus Bacillus subtilis	Mycobacterium tuberculosis Mycobacterium bovis Mycobacterium leprae	Staphylococcus aureus Streptococcus pyogenes Escherichia coli Pseudomonas aeruginosa Serratia marcescens	Influenza viruses Measles Coronavirus Smallpox
LEAST SUSCEPTIBLE		253.7 nm	MOST SUSCEPTIBLE	

Viruses like influenza, measles, SARS and coronavirus tend to be **more susceptible to UV-C inactivation** in an airstream.

DATA SOURCE: ASHRAE 2019 Handbook-HVAC Applications Ch. 62

UV-C APPLICATIONS



UV-C APPLICATIONS

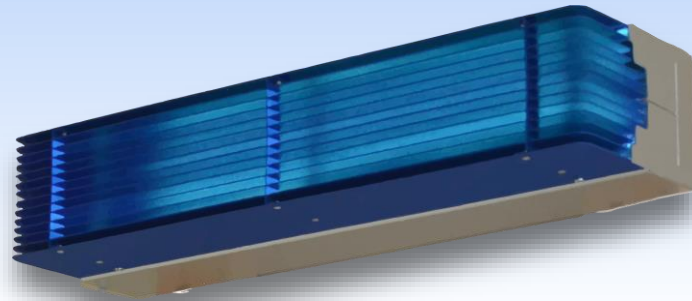
▶ Three primary means of applying UV-C for air and HVAC surface protection against infectious agents:



HVAC Airstream Disinfection



Upper-Air/Room



HVAC Coil/Surface Cleaning



AIRSTREAM DISINFECTION



AIRSTREAM DISINFECTION

Airstream Disinfection

Upper Air/Room

Coil/Surface Cleaning

1 Dimensions of duct and exposure time

$$E_t = \frac{VOL}{Q} = \frac{WHL}{Q}$$

2 UVGI removal rate

$$RR = 1 - e^{-kl_m E_t}$$

3 Rate constant (K or Z value)

Microbe	UVk m ² /J	Base Pairs kb
Coronavirus (Walker 2007)	0.37700	30.378

Exposure time

Vol = volume of UV chamber, m³
 Q = airflow, m³/s
 W = width, m
 H = height, m
 L = length, m

Removal rate

RR = removal rate, fraction or %
 e = efficiency (desired removal rate)
 k = UV rate constant, m²/J
 I_m = mean irradiance, W/m²
 E_t = exposure time in seconds

Data Source: Kowalski, Wladyslaw. (2009). Ultraviolet Germicidal Irradiation Handbook.

AIRSTREAM DISINFECTION

Airstream
Disinfection

Upper
Air/Room

Coil/Surface
Cleaning

Variables that Impact Airstream Disinfection Efficiency



UV-C Residence Time/Intensity

- Airflow (fpm)
- Air Temp & RH
- Exposure time
- Dimensions (H,W,D)
- Duct Reflectivity
- Lamp Output (end of life)



**DISINFECTION
DOSE**

AIRSTREAM DISINFECTION

Airstream
Disinfection

Upper
Air/Room

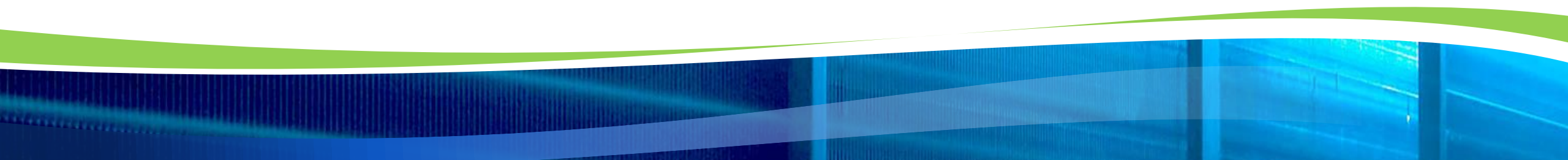
Coil/Surface
Cleaning

- ▶ Disinfect moving airstreams
“on-the-fly” to inactivate microorganisms
- ▶ Pathogens absorb UV-C energy at different rates (a.k.a. rate constant)
- ▶ Uniform 360° distribution provides best air treatment effectiveness*
- ▶ Match UV-C dose to target pathogen



* 2019 ASHRAE Applications Handbook, 62

ASHRAE POSITION



ASHRAE POSITION

Airstream
Disinfection

Upper
Air/Room

Coil/Surface
Cleaning



ASHRAE Position Document on Airborne Infectious Diseases

Approved by ASHRAE Board of Directors
January 19, 2014

Reaffirmed by Technology Council
February 5, 2020

Expires August 5, 2020



ASHRAE Position Document on Infectious Aerosols

Approved by ASHRAE Board of Directors
April 14, 2020

Expires
April 14, 2023

<https://www.ashrae.org/about/position-documents>

ASHRAE POSITION

Airstream
Disinfection

Upper
Air/Room

Coil/Surface
Cleaning

Table 1 Airborne Infectious Disease Engineering Control Strategies: Occupancy Interventions and Their Priority for Application and Research

Strategy	Occupancy Categories Applicable for Consideration*	Application Priority	Research Priority
Dilution ventilation	All	High	Medium
Temperature and humidity	All except 7 and 11	Medium	High
Personalized ventilation	1, 4, 6, 9, 10, 14	Medium	High
Local exhaust	1, 2, 8, 14	Medium	Medium
Central system filtration	All	High	High
Local air filtration	1, 4, 6, 7, 8 10	Medium	High
Upper-room UVGI	1, 2, 3, 5, 6, 8, 9, 14	High	Highest
Duct and air-handler UVGI	1, 2, 3, 4, 5, 6, 8, 9, 14	Medium	Highest
In-room flow regimes	1, 6, 8, 9, 10, 14	High	High
Differential pressurization	1, 2, 7, 8 11, 14	High	High

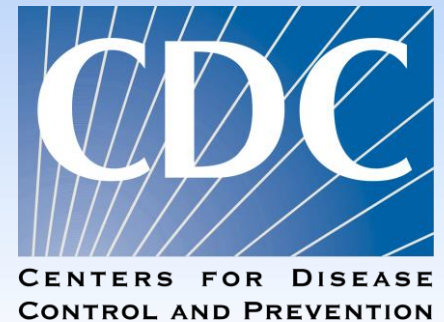
Note: In practical application, a combination of the individual interventions will be more effective than any single one in isolation.

*Occupancy Categories:

1. Health care (residential and outpatient)
2. Correctional facilities
3. Educational < age 8
4. Educational > age 8
5. Food and beverage
6. Internet café/game rooms
7. Hotel, motel, dormitory
8. Residential shelters
9. Public assembly and waiting
10. Transportation conveyances
11. Residential multifamily
12. Retail
13. Sports
14. Laboratories where infectious diseases vectors are handled

ASHRAE POSITION

- ▶ UVGI inactivates microbes by **damaging the structure of nucleic acids** & proteins
- ▶ Effectiveness depends on UV dose and microbe's susceptibility to UV-C
- ▶ **CDC has approved UVGI** as adjunct to filtration for reduction of Tuberculosis risk
- ▶ While UVGI is well researched and validated, **many new technologies are not***



*ASHRAE-Position document on infectious aerosols, April 2020

UPPER-AIR/ROOM



UPPER-AIR / ROOM

- ▶ Wall-mounted >7ft; inactivates airborne microbes in seconds
- ▶ Non-reflective baffles create collimated UV-C beam
- ▶ Natural air currents lift contaminated air into disinfection zone and inactivates pathogen
- ▶ Safe for occupied spaces

Airstream
Disinfection

Upper
Air/Room

Coil/Surface
Cleaning

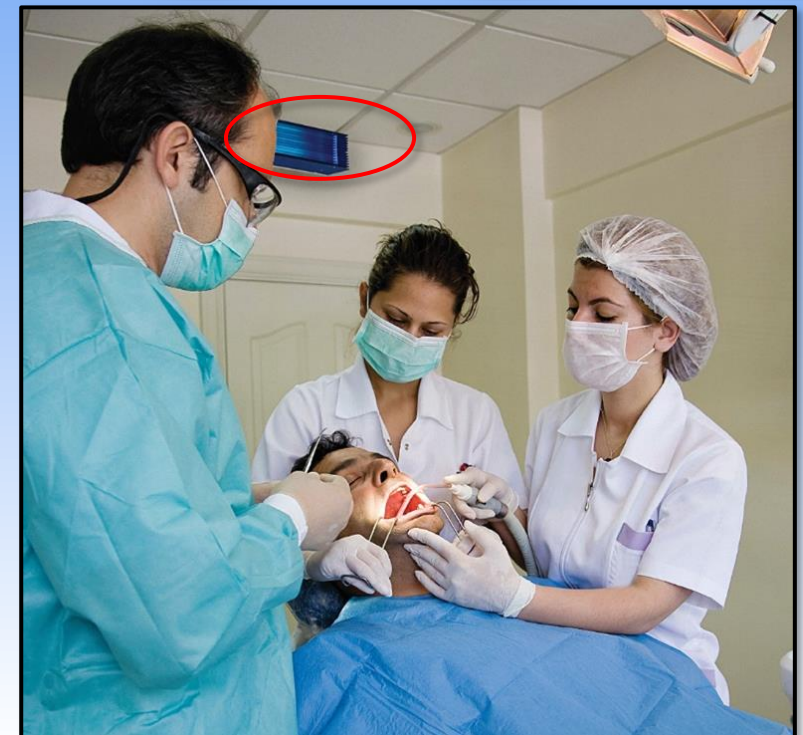


SAFE FOR OCCUPIED ROOM

Airstream
Disinfection

Upper
Air/Room

Coil/Surface
Cleaning



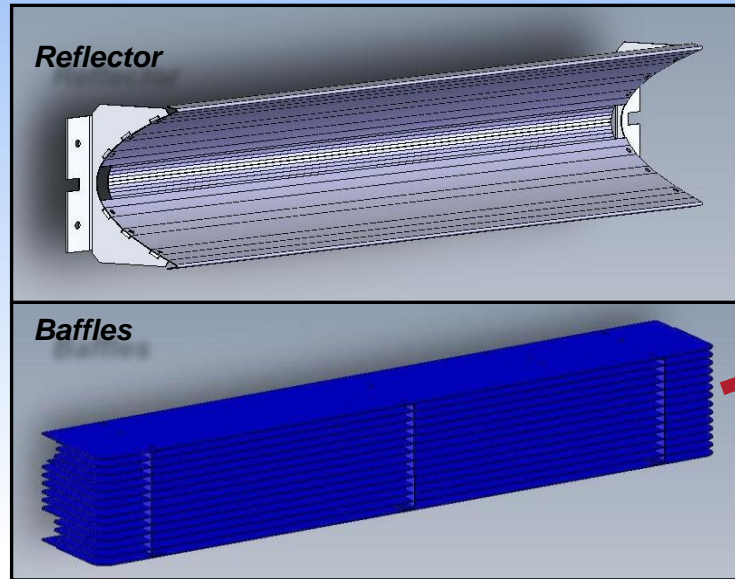
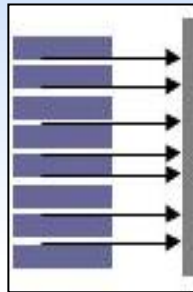
UPPER-AIR / ROOM

- ▶ Inactivate microbes and reduces disease transmission
- ▶ Inactivation ratios up to 99%+ have been modeled
- ▶ Collimated UV-C “band”
- ▶ Non-reflective baffles ensure occupant safety

Airstream
Disinfection

Upper
Air/Room

Coil/Surface
Cleaning



UPPER-AIR / ROOM

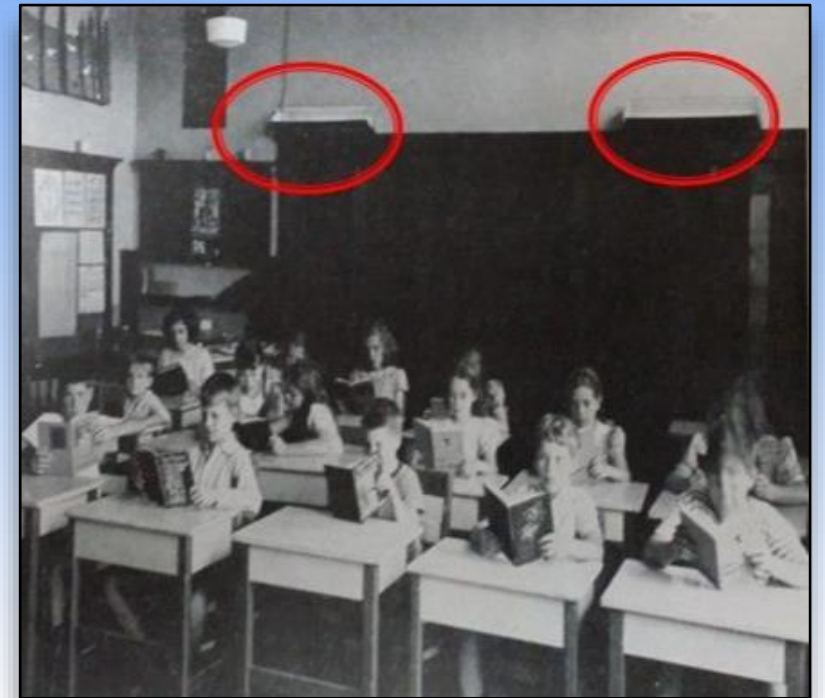
- ▶ Mycobacterium Tuberculosis (M.tb)
 - 1.8B people are infected - one quarter of the world's population*
 - Resulting in **1.5M TB deaths/year**
 - Most vulnerable are women, children, and those with HIV/AIDS
 - TB and coronavirus have similar inactivation rates
- ▶ **Pandemic Influenza**
- ▶ **Measles**

* www.tballiance.org/why-new-tb-drugs/global-pandemic

Airstream
Disinfection

Upper
Air/Room

Coil/Surface
Cleaning



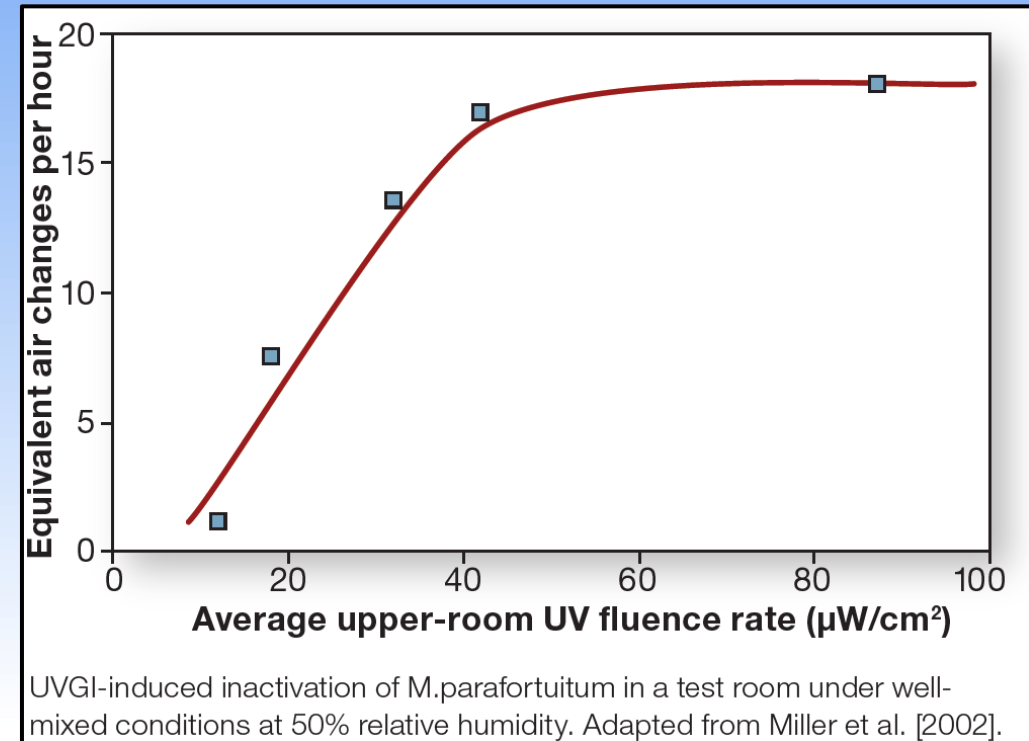
UPPER-AIR / ROOM

- ▶ Hospital Isolation & Procedure Rooms
 - (Supplemental Controls)
- ▶ When Air Changes per Hour (ACH) with ventilation Outside Air (OSA) can't be obtained

Airstream
Disinfection

Upper
Air/Room

Coil/Surface
Cleaning



UPPER-AIR / ROOM

Airstream
Disinfection

Upper
Air/Room

Coil/Surface
Cleaning



COIL-SURFACE CLEANING



COIL-SURFACE CLEANING

- ▶ Restoration and preservation of heat transfer efficiency & airflow capacity (1990s)
- ▶ Improves indoor air quality (IAQ) and reduces airborne pathogens
- ▶ Slash HVAC energy consumption by up to 25%
- ▶ Reduce coil fouling and system maintenance



Duct/Plenum Surface	UV-C Multiplier
Stainless Steel	1.40
Galvanized Steel	1.50
Aluminum	1.75

Use of reflective materials can increase germicidal UV disinfection dosage/fluence

COIL-SURFACE CLEANING

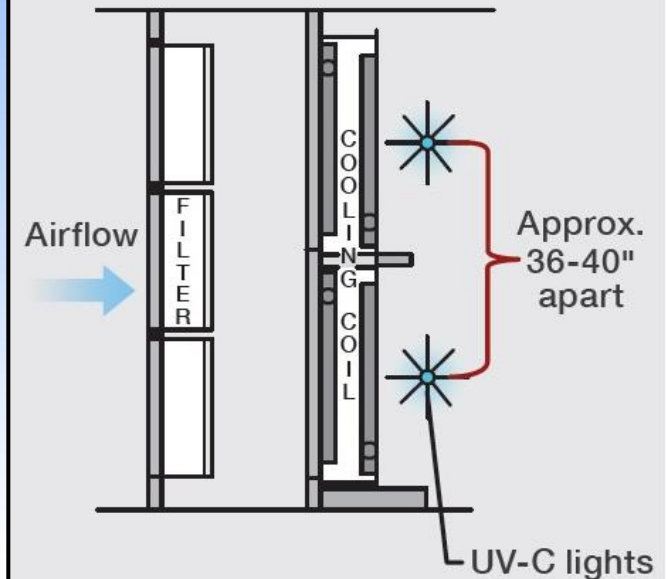
Airstream
Disinfection

Upper
Air/Room

Coil/Surface
Cleaning



Coil cleaning/HVAC efficiency
(Downstream of coil)



ASHRAE RP-1738

- ▶ This study measured **change in coil performance after treatment with UVGI** and UVGI benefits including:
 - first cost
 - energy cost
 - maintenance cost
 - collateral health benefits

Airstream
Disinfection

Upper
Air/Room

Coil/Surface
Cleaning

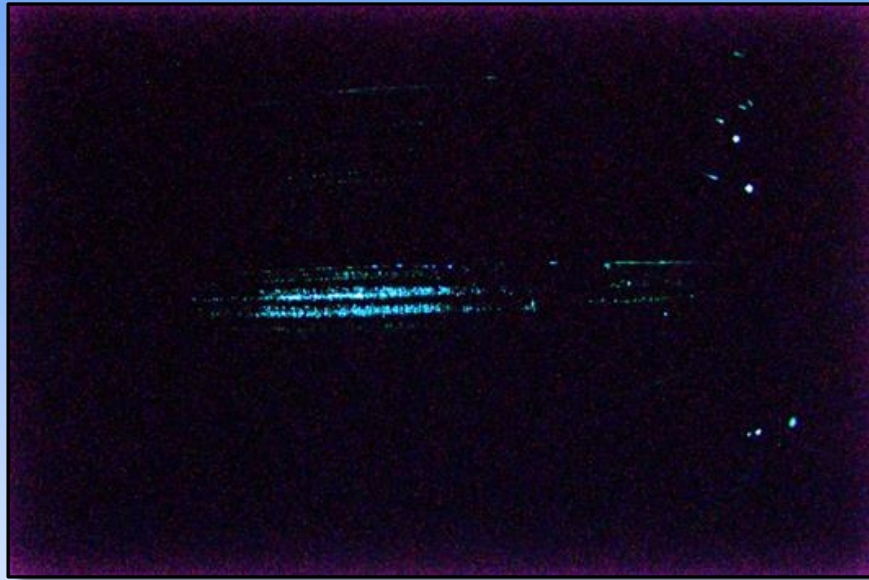


ASHRAE RP-1738 - TAMPA

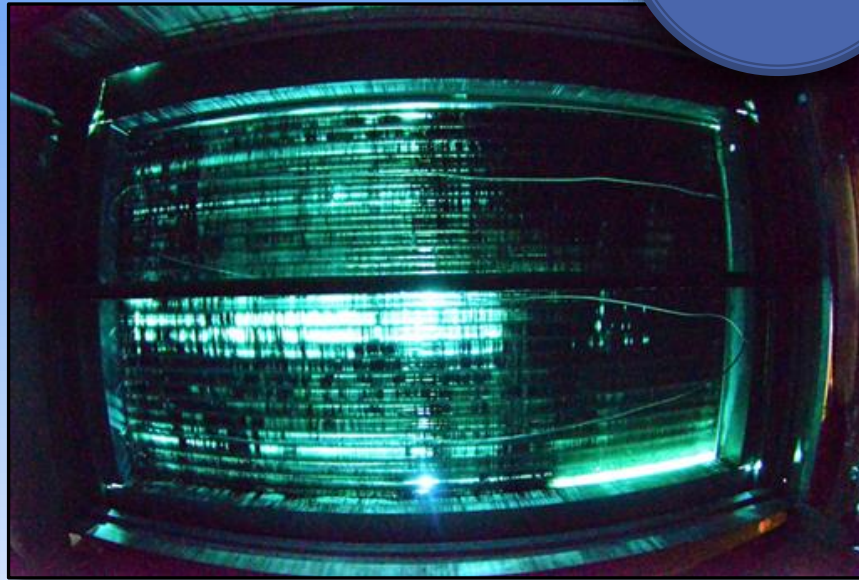
Airstream
Disinfection

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Coil/Surface
Cleaning



PRE UV-C



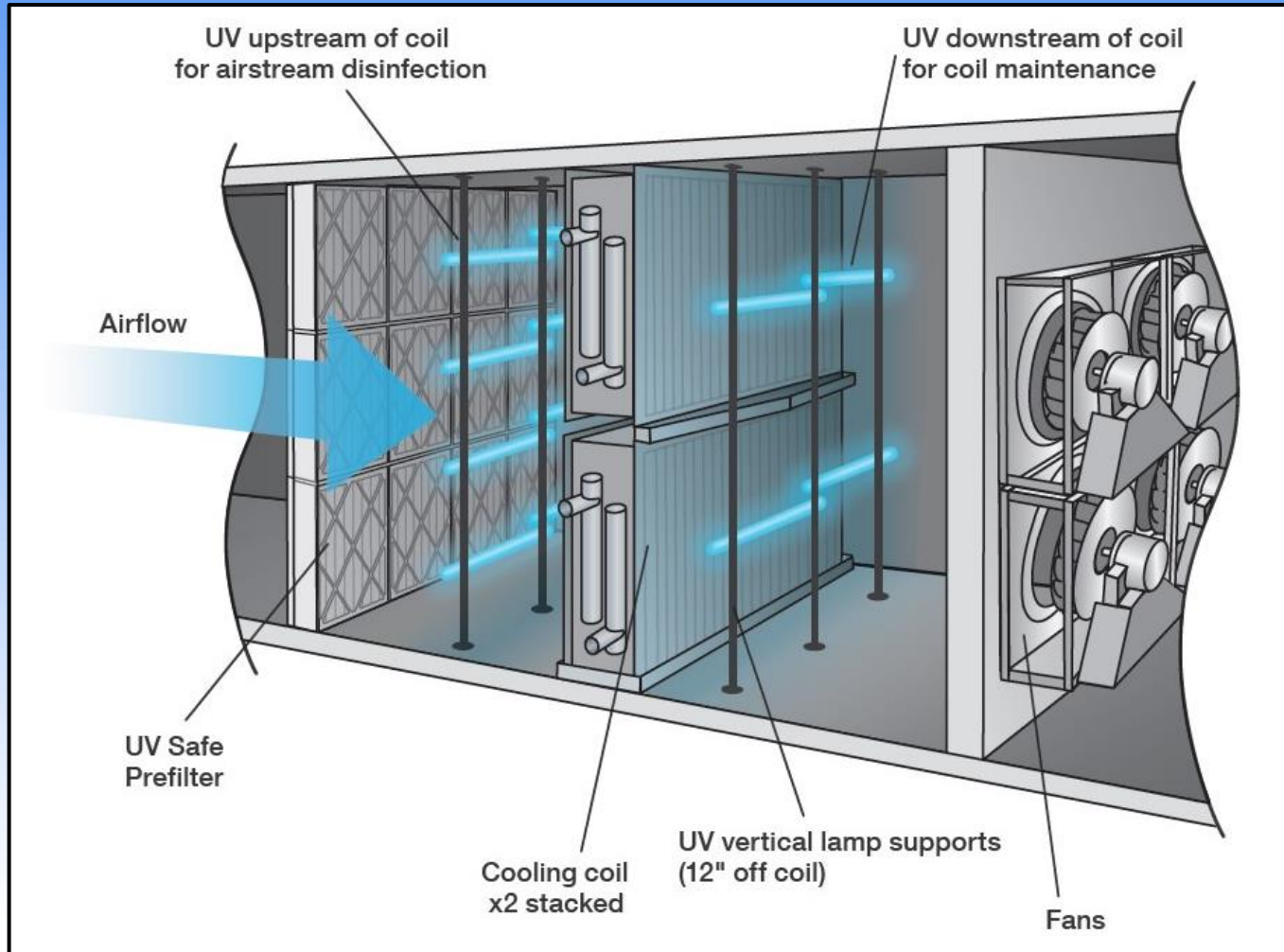
POST UV-C

- ▶ **21% decrease** in mean coil airside pressure drop
- ▶ **14% increase** in mean overall heat transfer coefficient (UA)

REVIEW

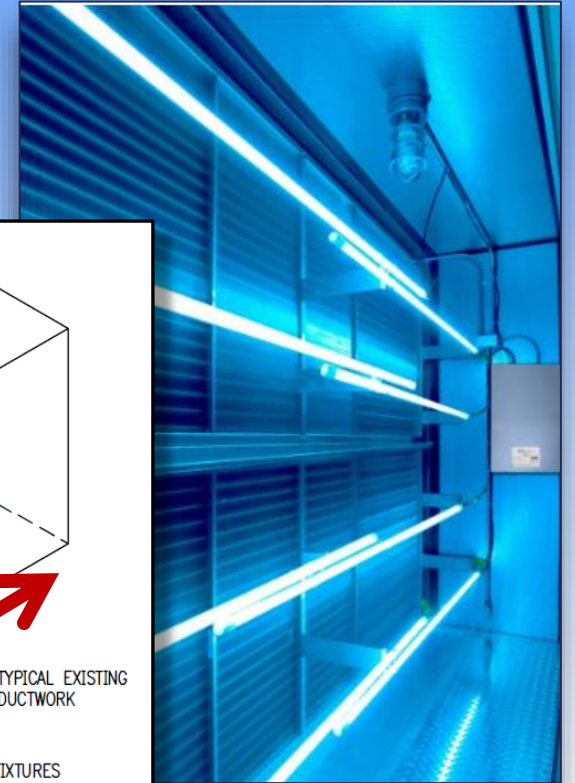
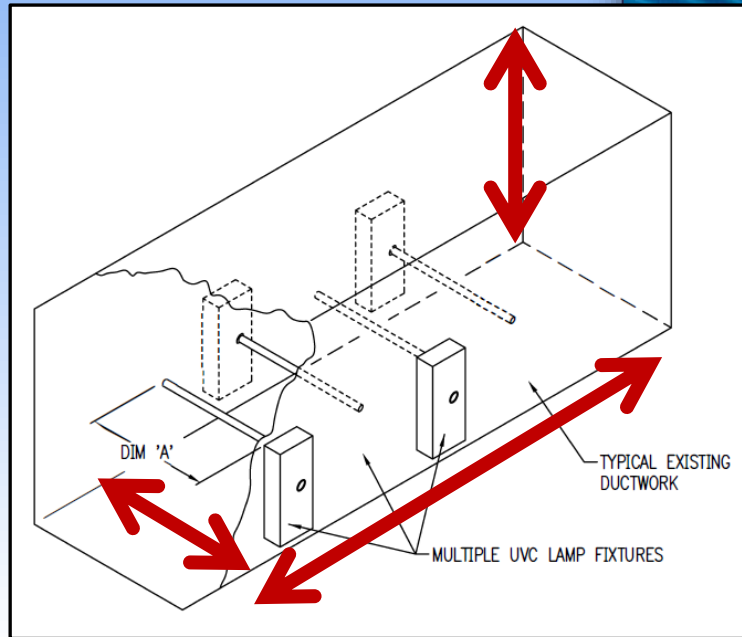


UV LAMP PLACEMENT OPTIONS



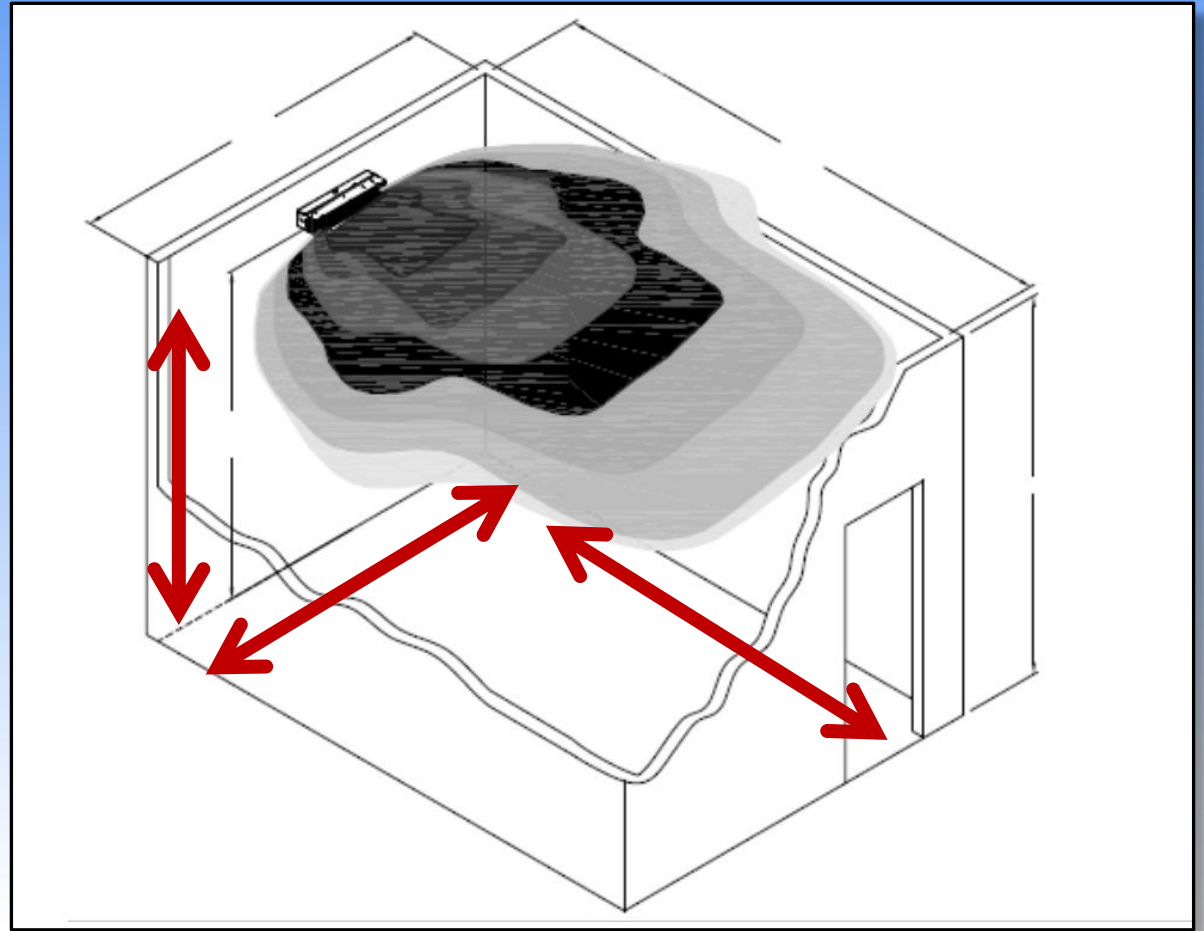
SIZING AN AIRSTREAM DISINFECTION SYSTEM

- ▶ Duct or Plenum Dimension (H x W x D)
- ▶ Target Microorganism
- ▶ Plenum Construction
- ▶ Airflow (FPM)
- ▶ Temperature



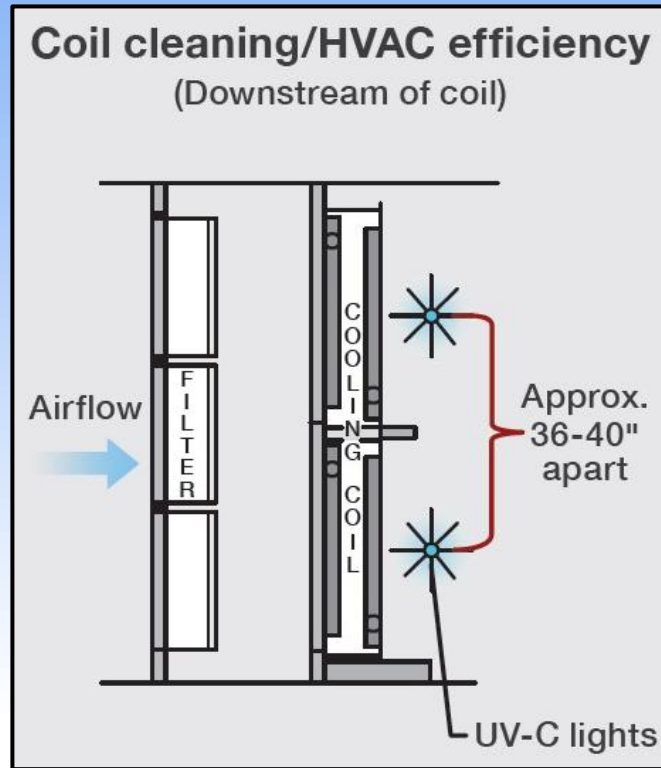
SIZING AN UPPER-ROOM/AIR SYSTEM

- ▶ Room dimensions
 - Ceiling Height
 - Width
 - Depth



SIZING A COIL CLEANING SYSTEM

- ▶ Plenum dimensions
(downstream side of cooling coil)
 - Height
 - Width



SUMMARY

- ▶ UV-C proven
 - 80+ years of Upper Room (1940s)
 - 30+ years of proven “in-duct” applications
- ▶ ASHRAE recognized
 - 2 Handbook Chapters (Applications and Systems and Equipment)
 - 2 Test Standards (ANSI/ ASHRAE 185.1 and 185.2)
 - 3 Position Documents (Airborne Infectious Diseases; Infectious Aerosols; Filtration & Air Cleaning)
- ▶ Extensively peer reviewed
- ▶ Other “disinfection” technologies are not well researched and validated (ASHRAE 2020)

QUESTIONS?



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