Making indoor environments safer during Covid-19 pandemics

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Thanking colleagues Dr. Kim Hagström,
Dr. Andrey Livchak and Ms. Sarah Marcotullio

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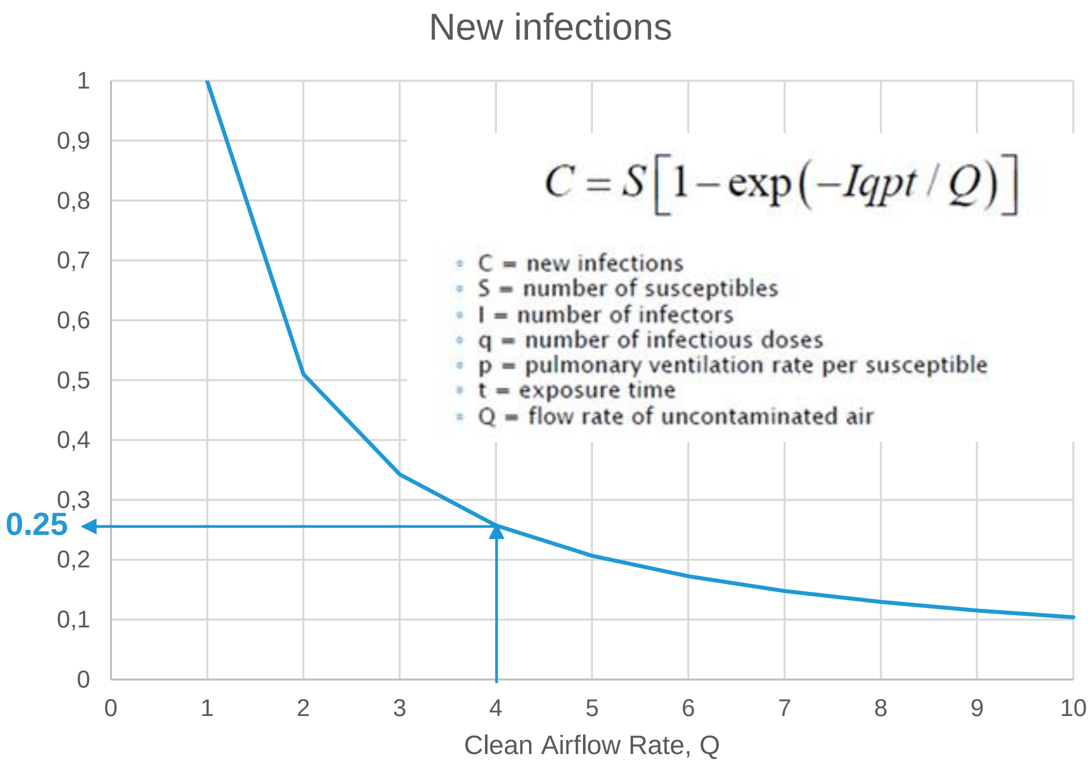
Risk Assessment

According to Wells-Riley model airborne infection risk[4] halves when the clean airflow is doubled

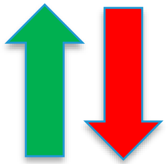
Wells-Riley equation



Higher ventilation rate reduces probability of infection

Increasing clean airflow 4 times reduces infection probability by 75%

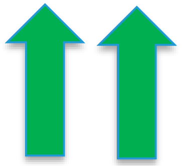
Clean airflow rate



Infection Rate

# of People, time are Constant

# of People Or Time



Infection Rate

Clean Air Constant

Wells-Riley equation corresponds to real life situations with Covid-19

Birthday Party, Charlton,Texas, USA

- Birthday party (2 hours) was attended by 25 persons out of which one person was ill with Covid 19
- 18 persons got ill after the party (72%)
- Estimated airborne infection risk in this situation, when a basic dwelling ventilation is assumed: 75%

Choral practice, Mount Vernon, Washington, USA

- 61 persons were attending at the choral practice for 2,5 hours, one person had already captured Covid-19 prior the occasion.
- Risk of Covid exposure was recognized and people applied practices to avoid fomite and close contact infection
- 53 people got ill after the practice (87%)
- Estimated airborne infection risk in this situation, when a basic (ASHRAE) ventilation is assumed: 86%

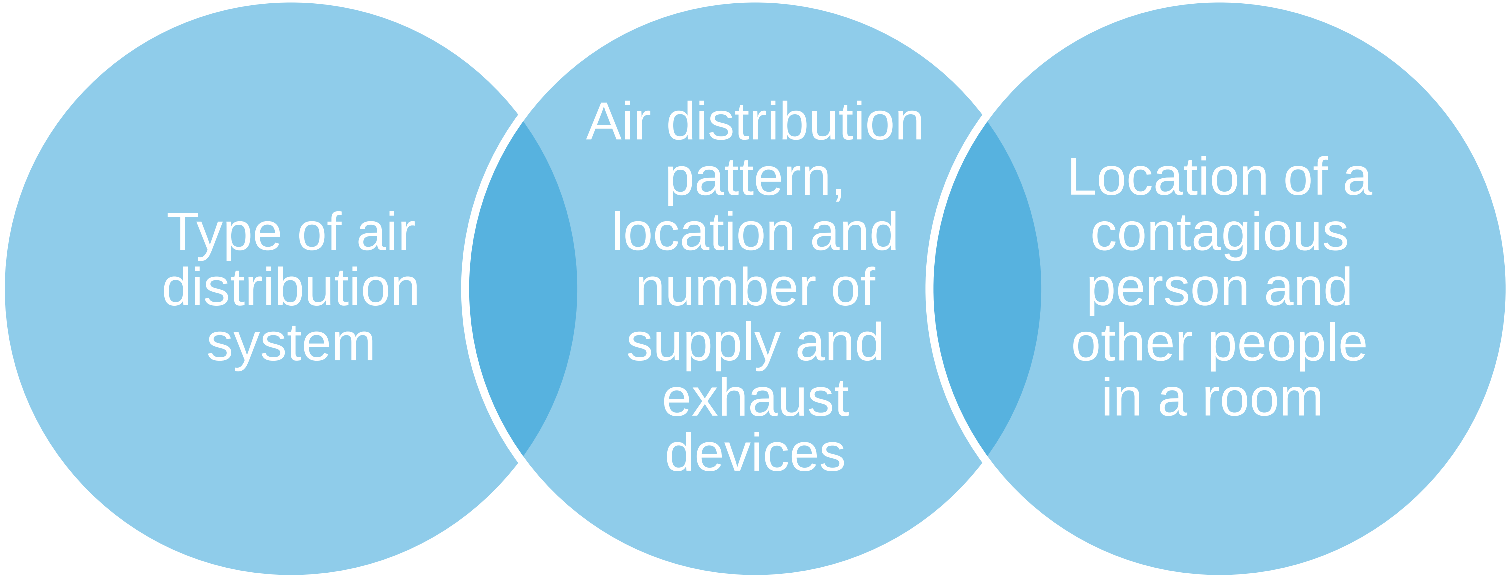
Estimation of infection risk using Wells-Riley equation in these documented cases demonstrate a possibility that infection risk could be explained even merely by airborne exposure. However, fomite and close proximity infection cannot be ruled out.

Effect of Air Distribution

Not only the clean airflow amount, but also the air distribution affects the airborne infection spread

Wells-Riley equation assumes perfectly mixed conditions when contaminants are evenly spread in the space and clean supply air immediately mixes with room air.

In real applications spread of aerosols from a contagious person will be affected by:



Air Filtration

Smallest particle size class (ePM1) does not identify entrapment efficiency for SARS-CoV-2 size particles (0,12 microns)

New Filter Classification Standard ISO 16890 is based on the average efficiency (in mass) over the range of certain particle sizes.

The smallest particle size range is 0,3-1,0 microns (ePM1), which does not include the size of SARS-CoV-2 virus (0,12 microns). It can, however, be reasoned that **about 40% of 0,12 micron particles are caught with MERV-13/ASHRAE (equivalent to F7) filter** (graph on the right).

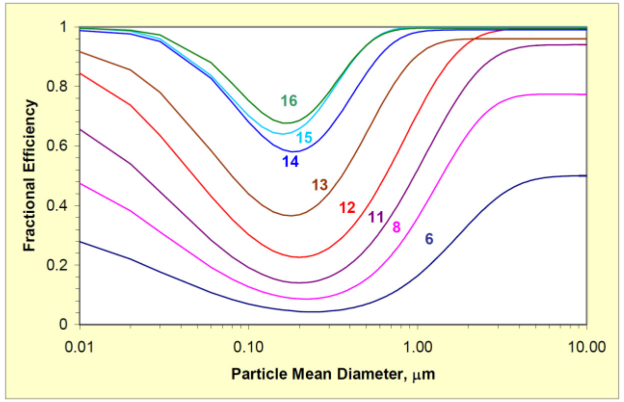


Figure 4: Composite of all MERV filter models, based on initial conditions.

Kowalski&Bahnfleth

EN 779:2012	ISO 16890		
Filter class	ePM 1	ePM 2,5	ePM 10
M5	5% - 35%	10% - 45%	40% - 70%
M6	10% - 40%	20% - 50%	60% - 80%
F7	40% - 65%	65% - 75%	80% - 90%
F8	65% - 90%	75% - 95%	90% - 100%
F9	80% - 90%	85% - 95%	90% - 100%

Source: Selection of EN ISO 16890 rated air filter classes for general ventilation applications (1st edition). Eurovent 4/23 – 2017, 09 January 2018, https://eurovent.eu

HEPA/ULPA filters capture over 99,9% of all particles including SARS-CoV-2

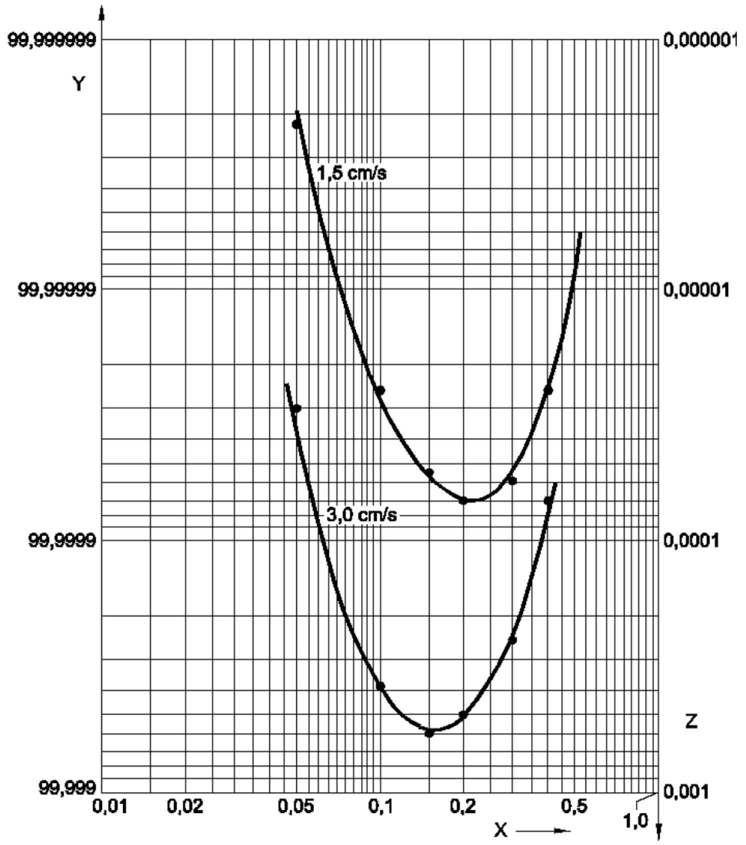
HEPA/ULPA filter media is tested for MPPS (Most Penetrating Particle Size) and the minimum efficiency

MPPS for HEPA/ULPA filters is between 0,1 - 0,2 microns. For other particle sizes the efficiency is the same or better.

For example the efficiency of H14 filter is >99,99% for SARS-CoV-2 size particles.

- Each HEPA filter is factory tested
- Each HEPA filter installation is tested

Figure 2 — Particle size efficiency E and penetration P of an ULPA-filter medium as function of the particle diameter d_p for two different filter medium velocities (example)



Mobile HEPA air purifier w/1250 m^3/h air flow cleans the room in 5 minutes

Air cleaning time with and w/o high efficiency HEPA air purifier

Room ventilation:150 m^3/h Air purifier: 1250 m^3/h (45% Capacity)

Electric/Electronic filters may be effective in capturing the SARS-CoV-2, but ozone generation needs to be addressed

Consider filters with documented single pass filtration efficiency and reported Clean Air Delivery Rate only.

All electric filters potentially generate ozone. As ozone is harmful to people it is necessary to have information of the amount of ozone generated by an electric filter.

- Room ventilation rate has to be high enough to keep the ozone level below the threshold value

Optimum performance of the electric air filters requires regular maintenance.

Electric filters include a wide variety of electrically powered air-cleaning devices that are designed to remove particles carried in air.

Removal is based on electrically charging the particles using corona wires or alternatively by generation of ions and by collecting the particles on oppositely charged precipitators. Alternatively the particles’ may be collected to a mechanical filter or even to room surfaces.

UVC and UVGI Purification

Both exposure time and irradiation intensity affect the performance of UVC purification

UVC purification is based on inactivating micro-organisms in air and surfaces.

Inactivation rate depends on the type of microbe, irradiation efficiency and exposure time

A proof of specific efficiency for the microbe in concern should be provided, especially when used for moving air, where it is challenging to reach sufficient exposure time.

UV does not remove particles – a supplementary mechanical final filter is needed for capturing the particles

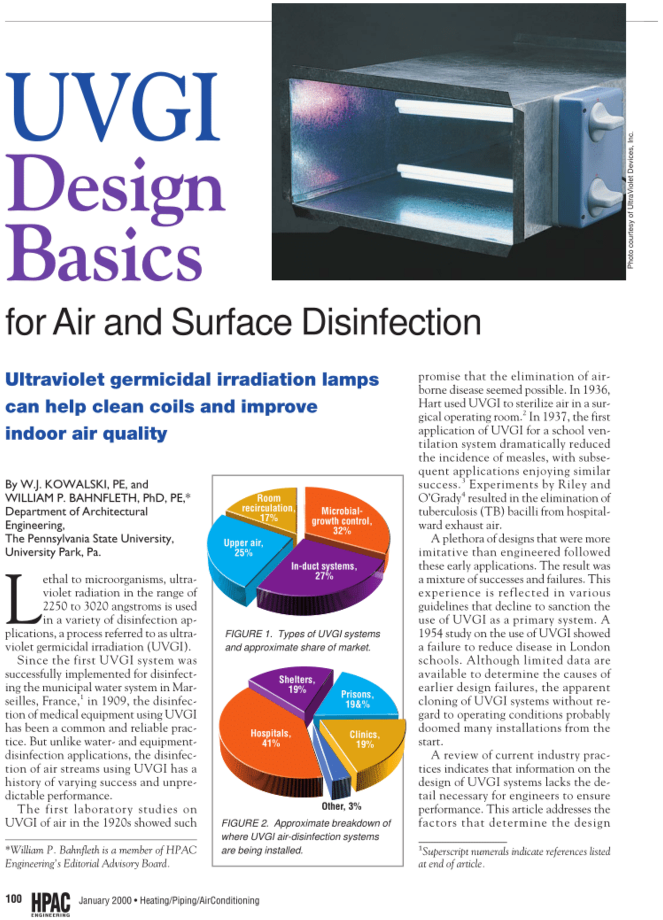

UVGI Design Basics for Air and Surface Disinfection

Photo courtesy of UltraViolet Devices, Inc.

Ultraviolet germicidal irradiation lamps can help clean coils and improve indoor air quality

By W.J. KOWALSKI, PE, and WILLIAM P. BAHNFLETH, PhD, PE,*
Department of Architectural Engineering,
The Pennsylvania State University,
University Park, Pa.

Lethal to microorganisms, ultraviolet radiation in the range of 2250 to 3020 angstroms is used in a variety of disinfection applications, a process referred to as ultraviolet germicidal irradiation (UVGI).

Since the first UVGI system was successfully implemented for disinfecting the municipal water system in Marseilles, France,[1] in 1909, the disinfection of medical equipment using UVGI has been a common and reliable practice. But unlike water- and equipment-disinfection applications, the disinfection of air streams using UVGI has a history of varying success and unpredictable performance.

The first laboratory studies on UVGI of air in the 1920s showed such promise that the elimination of airborne disease seemed possible. In 1936, Hart used UVGI to sterilize air in a surgical operating room.[2] In 1937, the first application of UVGI for a school ventilation system dramatically reduced the incidence of measles, with subsequent applications enjoying similar success.[3] Experiments by Riley and O'Grady[4] resulted in the elimination of tuberculosis (TB) bacilli from hospital-ward exhaust air.

A plethora of designs that were more imitative than engineered followed these early applications. The result was a mixture of successes and failures. This experience is reflected in various guidelines that decline to sanction the use of UVGI as a primary system. A 1954 study on the use of UVGI showed a failure to reduce disease in London schools. Although limited data are available to determine the causes of earlier design failures, the apparent cloning of UVGI systems without regard to operating conditions probably doomed many installations from the start.

A review of current industry practices indicates that information on the design of UVGI systems lacks the detail necessary for engineers to ensure performance. This article addresses the factors that determine the design

FIGURE 1. Types of UVGI systems and approximate share of market.

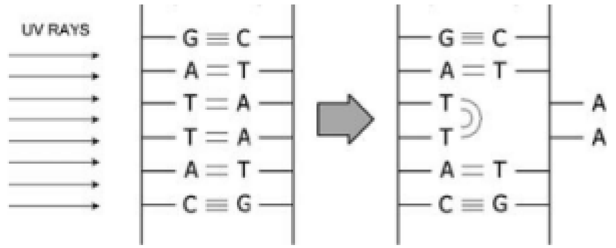
FIGURE 2. Approximate breakdown of where UVGI air-disinfection systems are being installed.

*William P. Bahnfleth is a member of HPAC Engineering's Editorial Advisory Board.

[1]Superscript numerals indicate references listed at end of article.

UVGI inhibits pathogens’ ability to replicate

- Ultraviolet Germicidal Irradiation (UVGI) affects the DNA/RNA of pathogens and inhibits their ability to replicate
- Safety measures
  - Avoid eyes and skin exposure to UVC radiation
  - Use very low ozone UVGI lamps (when radiation is over 200nm, ozone is practically blocked[1])
  - Verify that the room air ventilation rate is high enough to keep the possible ozone concentration under the threshold value



Thymine dimers caused by UV absorption in adjacent nucleotides

Intensity or Exposure Time ↑ → Pathogen Survival Rate ↓

[1]Most germicidal lamps, are produced with doped quartz glass which allows the 254 nm radiation to pass through, but it blocks the 185nm wavelength from escaping. Ozone is produced when oxygen molecule is radiated with wavelengths below 200 nm, therefore, germicidal lamps with doped glass CANNOT produce ozone. (William Bahnfleth at ASHRAE webinar “Reducing Infectious Disease Transmission with UVGI”)

Clean Air Delivery Rate

Clean Air Delivery Rate determines the effectiveness of an air cleaning device

Defining CADR for recirculating devices

- CADR = Airflow x Device Cleaning Efficiency
- For filter devices cleaning efficiency (entrapment efficiency) is defined by filter efficiency in three particulate ranges
- For combination filter/UVGI devices inactivation efficiency is defined by a combination of UV inactivation efficiency and filter entrapment efficiency.[1]

Important to understand that **CADR, not Device Cleaning Efficiency determines effectiveness of a solution** in a space.

Which device is more effective in protecting from airborne contaminants?

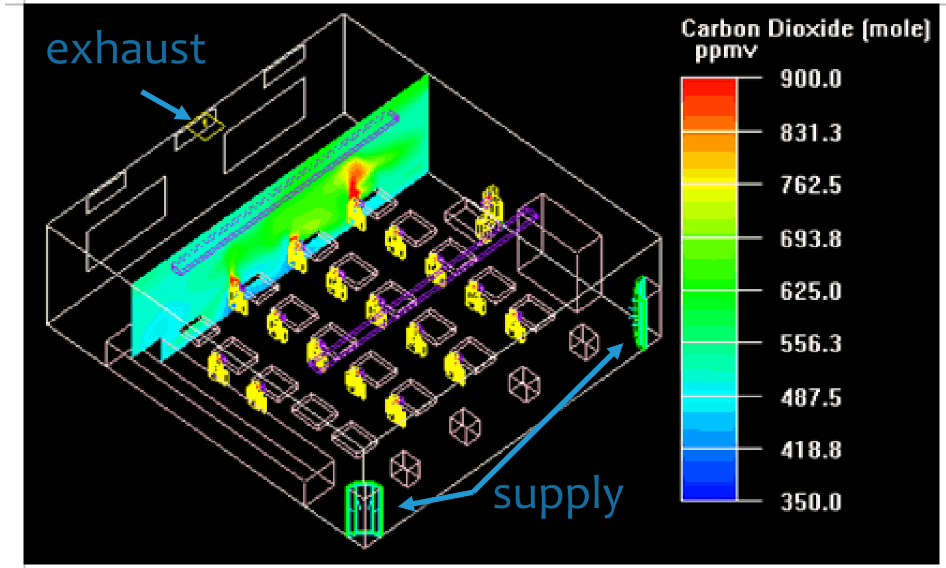
A. 99.99% efficient running at 100 l/s
B. 85% efficient running at 120 l/s

Answer:
They are virtually identical with Device B slightly better, with CADR = 102 l/s vs 100 l/s for device B.

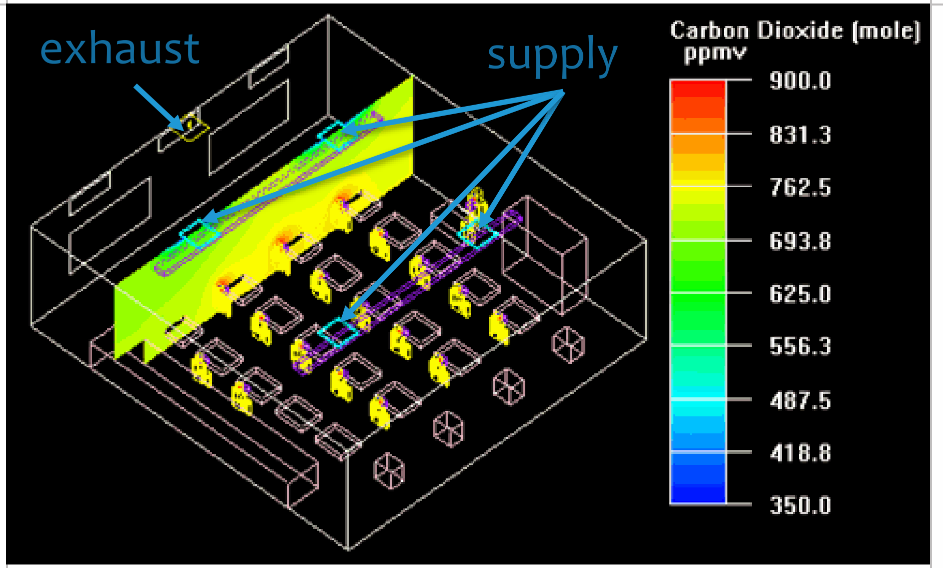
[1] More studies are needed to assess the UV inactivation efficiency in an air stream

Mixing or displacement ventilation?

When compared to mixing ventilation, displacement ventilation provides better IAQ in a classroom



Displacement ventilation



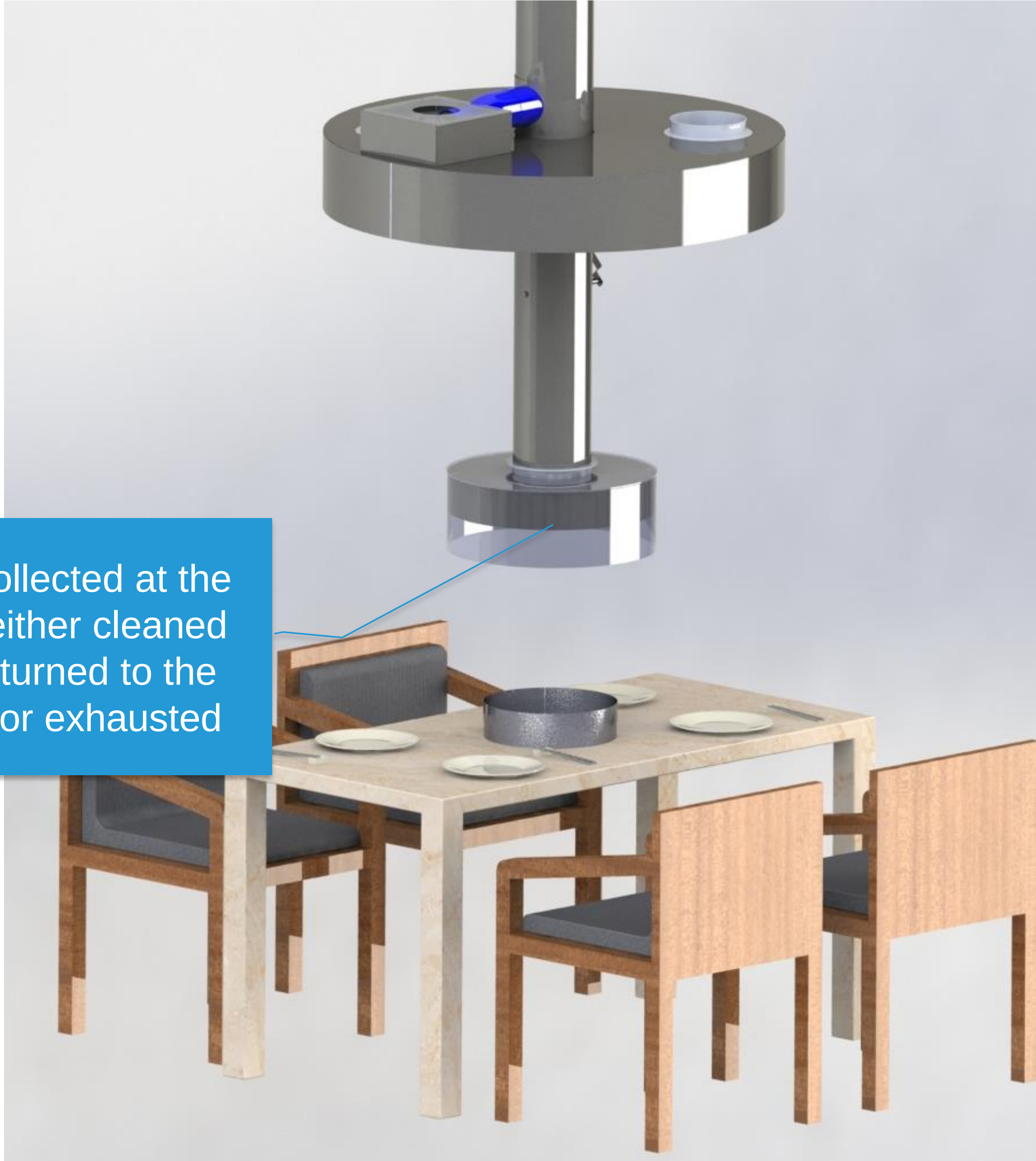
Mixing ventilation

CO_2 distribution is representative of distribution of exhaled aerosols < 1.0µm in size
CO_2 concentration is lower in the occupied zone in displacement ventilation case

Displacement ventilation and local exhaust/air cleaning provide a compelling alternative for dining areas

New construction

- Displacement Ventilation used for air distribution
- Air is exhausted directly above the table
- Or the air is collected above the table, cleaned and returned to the space
- Displacement diffusers can be integrated under seats in “booth” seating layouts



Al fresco dining – Displacement Ventilation for cooling of partially enclosed spaces

Taking tables outdoors

Click once to initiate animation

New developments in virus detection

New technologies under development making possible airborne virus detection in real time:

https://www.kontrolenergy.com/kontrol-biocloud-sensor

If proven successful, this will enable new ventilation control and mitigation strategies.

Thank you!