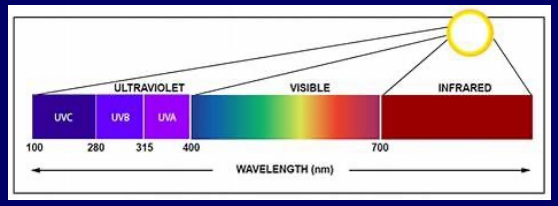
GUV Energy Implications vs. Increased Ventilation, - Including far UV-C

Edward Nardell, MD
Professor of Medicine,
Harvard Medical School



Division of Global Health Equity
Brigham & Women's Hospital

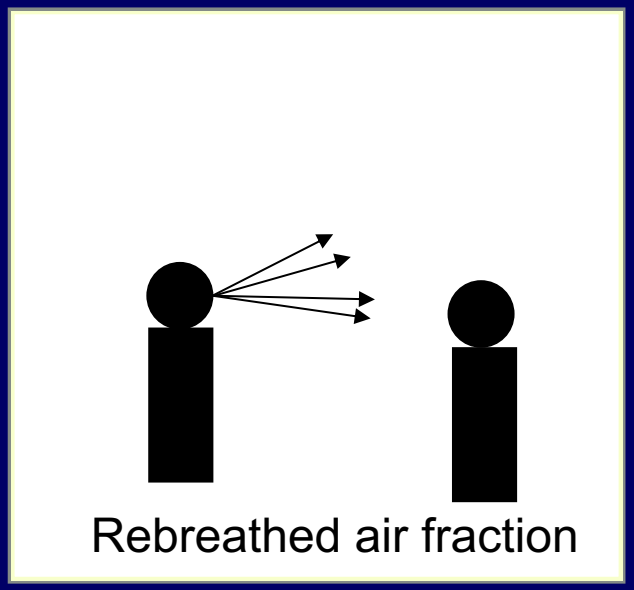
Harvard School of Public Health
Department of Environmental Health
Partners In Health, Boston, MA

Conflicts of Interest

- Dr. Nardell has been conducting research of GUV for almost 40 years following an outbreak of TB in a Boston homeless shelter
  - He has published and freely shared research findings - and provided advice to companies on safe and effective GUV technology
- He currently has formal (paid) and informal research and consulting agreements with:
  - Signify
  - Big Ass Fans
  - Rzero
  - PlanLED
  - USHIO
- *Harvard and Brigham & Women's Hospital policy strictly prohibits profiting from companies other than appropriate consulting fees.*

Where is most SARS-CoV-2 transmission occurring?

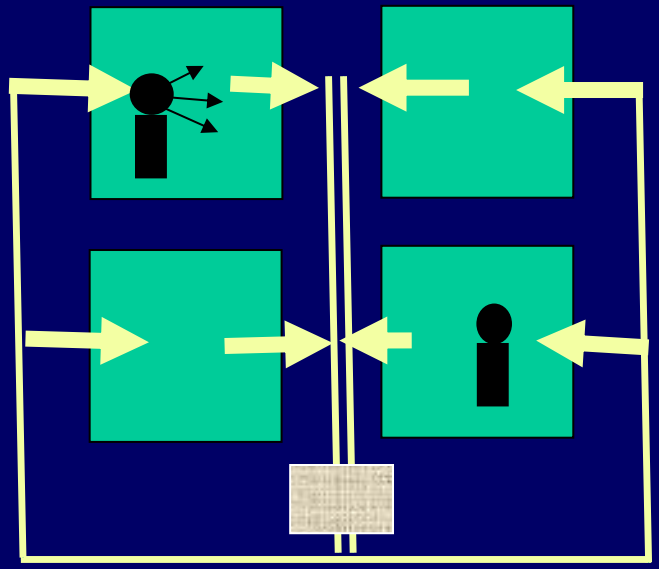
- In the room?



High volume ventilation, Room air cleaners
Upper room UV air disinfection

- Throughout the ventilation circuit?

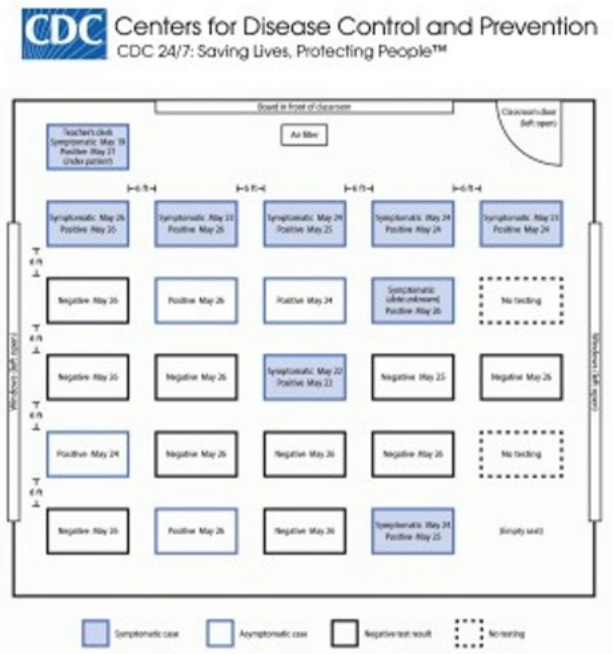
No good evidence so far….
? Dilution/inactivation in return air



Air filter or UV in return duct?

Covid in a Classroom
June, 2021

Outbreak Associated with SARS -CoV-2 B.1.617.2 (Delta) Variant in an Elementary School — Marin County, California, May –June 2021

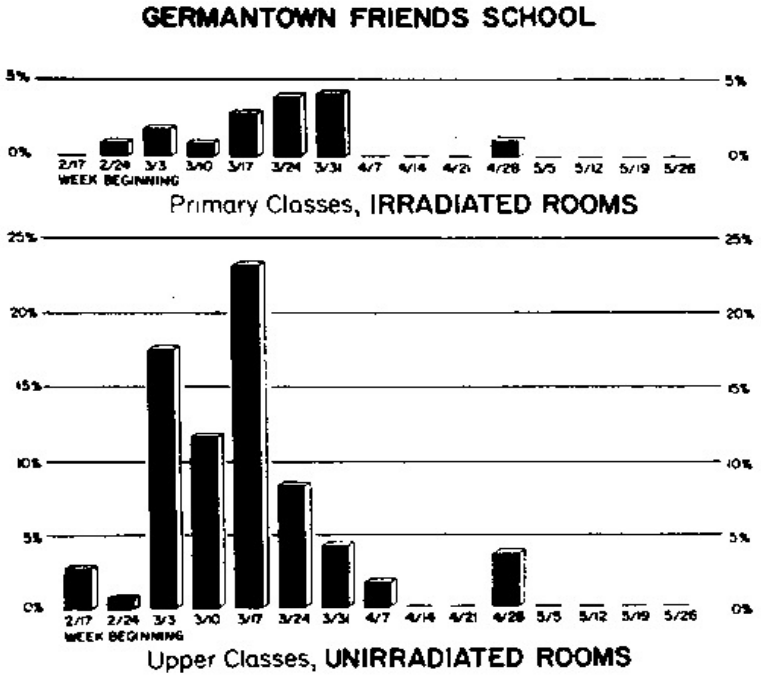


- Unvaccinated index patient
  - (i.e. teacher with Delta variant)
- Students wearing masks
- Natural ventilation: windows and doors open
- Portable HEPA air filter unit in front of classroom
- 50% of students infected with Delta

- Case confirms our Wells-Riley example:
  - Vaccines are effective, but transmission risks remains high
  - Key to strive for high Air Changes (ACH)

It is little comfort to know that the air in this room would be disinfected AFTER it leaves the exhaust duct! ***Rapid air disinfection must happen in the room.***

Upper room UVGI reduced measles in day schools, (Wells, Am J Hygiene, 35:97-121, 1942)



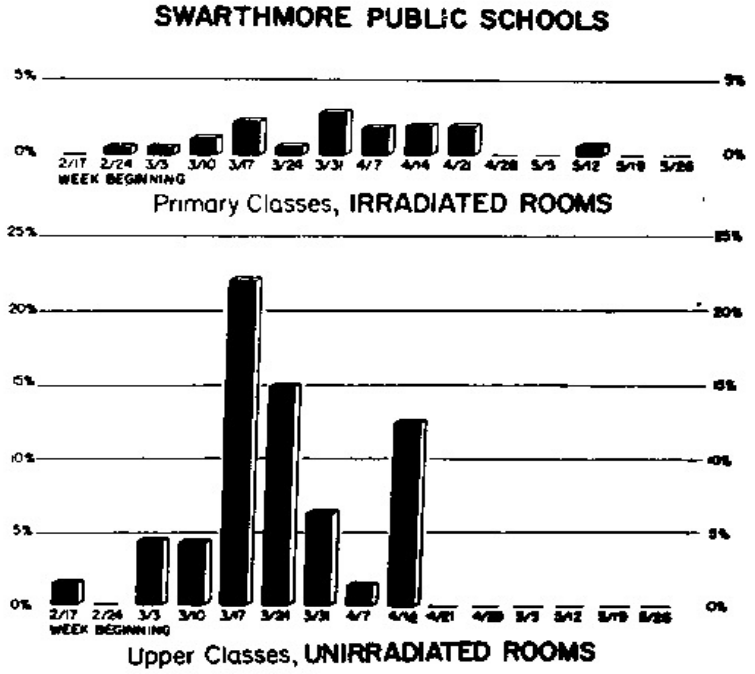


FIGURE 1. Measles epidemic in Philadelphia, 1941. Weekly attack rate among susceptibles (home secondaries excluded).

Riley: Airborne Infection Prevention

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Measles is the most infectious respiratory virus

UV fixtures

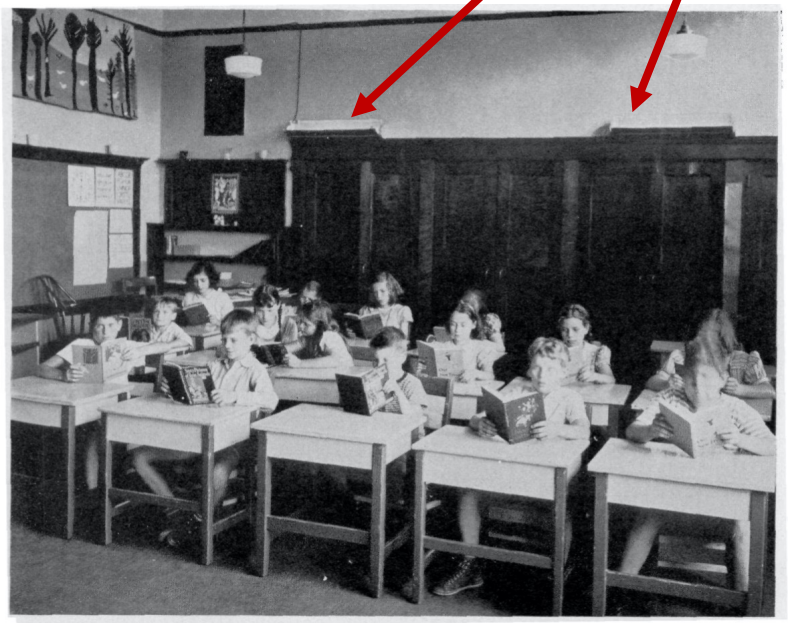


FIGURE 3. Classroom, Swarthmore public schools, slide wall fixtures.

Mercury GUV lamps consume the same energy as comparable fluorescent lights. With lower modern ceilings, louvers must be added that reduce total fixture output. LED GUV sources are less efficient, but UV output can be directed more precisely without louvers - recapturing efficiency. Far-UVC may soon be the most efficient form of GUV.

Effect of UV-C on SARS-Covid-2 Virus

Corona virus inactivation requires little UV energy and is independent of viral variants

(low Z value compared to bacteria)

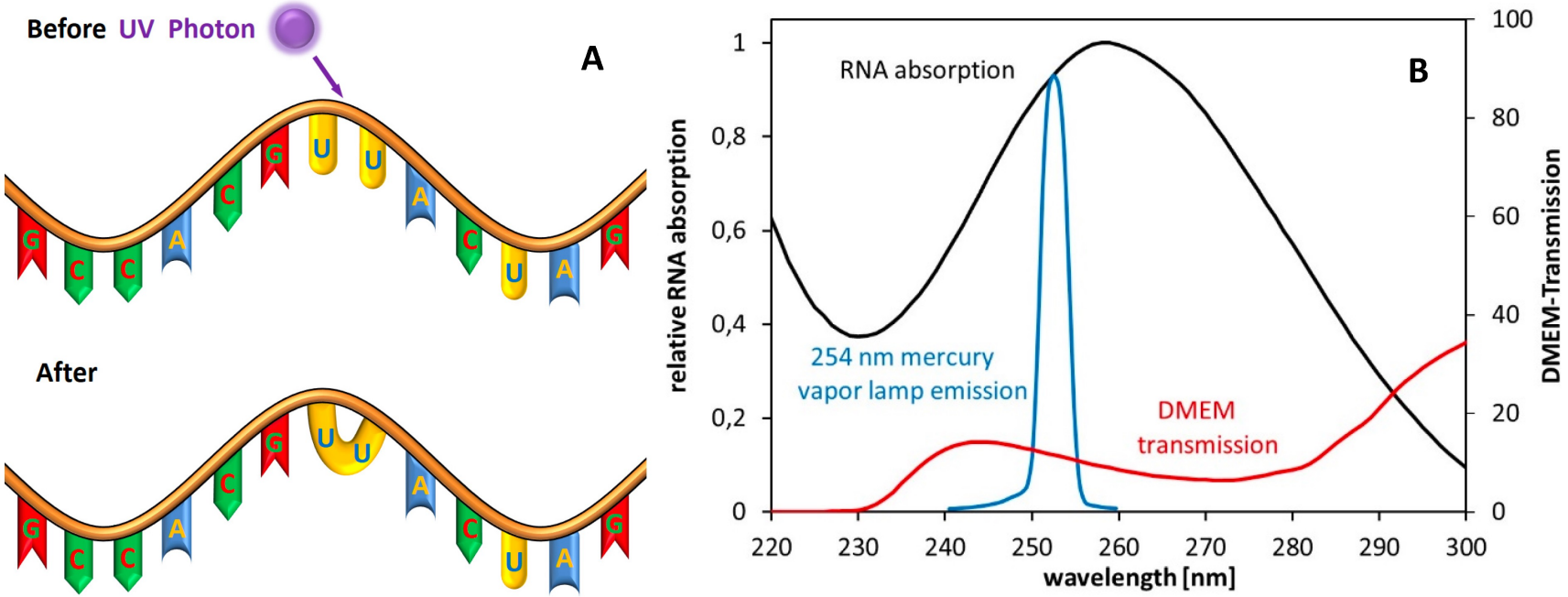


Figure 1: A) Scheme of UV-RNA-damaging mechanism by dimer formation. B) Relative absorption spectra of RNA, relative emission spectrum of a low-pressure mercury vapor lamp and transmission of a typical (Eagle) cell culture medium. From GMS Hygiene and Infection Control 2020, Vol. 15, ISSN 2196-5226 2

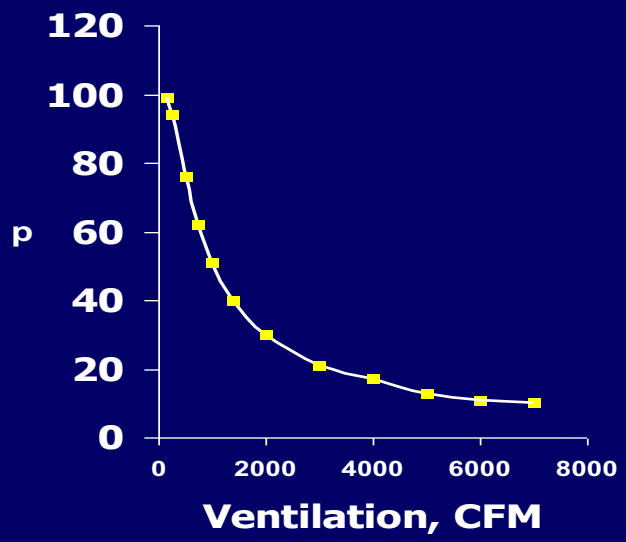
Note: UV-induced viral mutations outside the body cannot be successfully propagated. GUV does not cause viral variants – unchecked viral replication in unvaccinated humans does (and in pigs/poultry re. annual and pandemic influenza)

How much air disinfection is needed?

- CDC recommends 6-12 ACH ventilation for hospital isolation and procedure rooms
  - Somewhat arbitrary – *no one safe level of air disinfection*
- The greater the infectiousness, the greater the EqACH needed for protection
  - More is better if feasible and affordable
  - Super-spreaders account for most transmission
  - **Omicron > Delta > original SARS-CoV-2**

Airborne infection. Theoretical limits of protection achievable by building ventilation
E A Nardell[1], J Keegan, S A Cheney, S C Etkind. Am Rev Respir Dis. 1991 Aug;144(2):302-6. doi: 10.1164/ajrccm/144.2.302.

Limitation common to all air disinfection strategies



Survival Curve

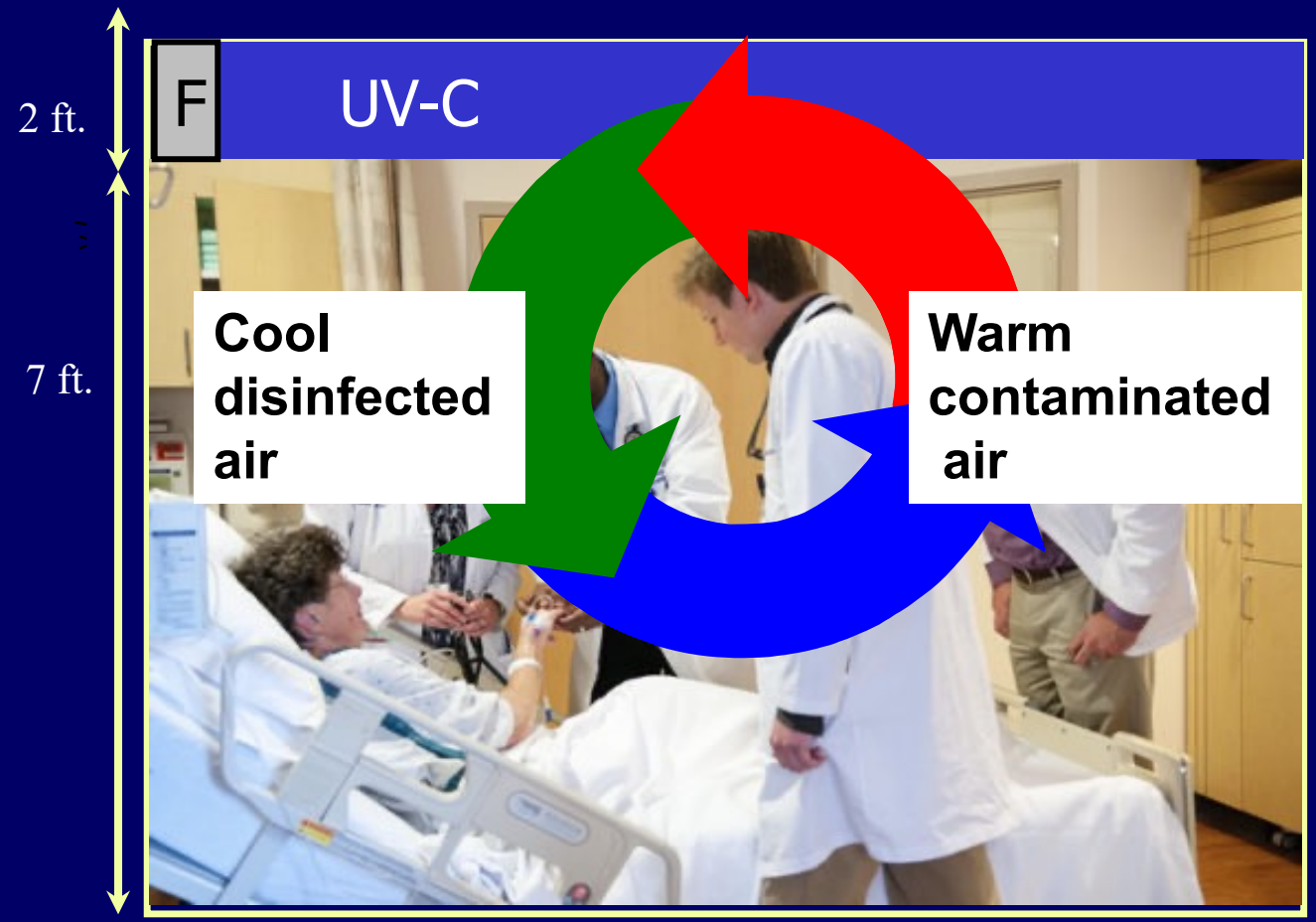
- Similar to ventilation where
  - 1st AC removes 63% of contaminated air
  - 2nd AC removes 63% of what is left
  - 3rd AC removes 63% of what is left, etc.
- Makes it possible to equate ventilation and effects of UVGI
  - When UVGI inactivates 63% of infectious organisms in a room, one Equivalent Air Change has occurred.

Important to compare various air disinfection strategies in terms of Equivalent Air Changes (Eq ACH) per hour.

Why is GUV So Efficient?

- GUV treats a large volume of air at once
  - UV rays are effective until absorbed
  - Upper room – upper 20% or more of room volume
  - Whole room Far UVC – most of the room around occupants
- Upper room GUV requires effective vertical air mixing – usually easily achieved
  - occupant convection currents
  - Vent registers, mixing fans, occupant motion
- HVAC and room air cleaners require air capture and treatment – flow limited (noise, energy cost)
- Far UVC is <u>less</u> dependent on air movement
  - decontaminates air around room occupants

Upper Room GUV Disinfects a Large Volume of Air at Once



Low velocity ceiling fans assure good air mixing

Theoretical vs Real

Permutt 2-compartment model

32 μW/cm^2 avg.= 480 Eq AC
1 Eq ACH/7.2 sec.

25 ACH mixing

20 Eq ACH in the lower rm

*Mphaphelele, et al, 2011

AIR Facility Study*

30 μW/cm^2 avg, upper room

57 ACH mixing**

24 Eq ACH in the lower rm

**Ceiling fan air turnover rate estimated, not measured

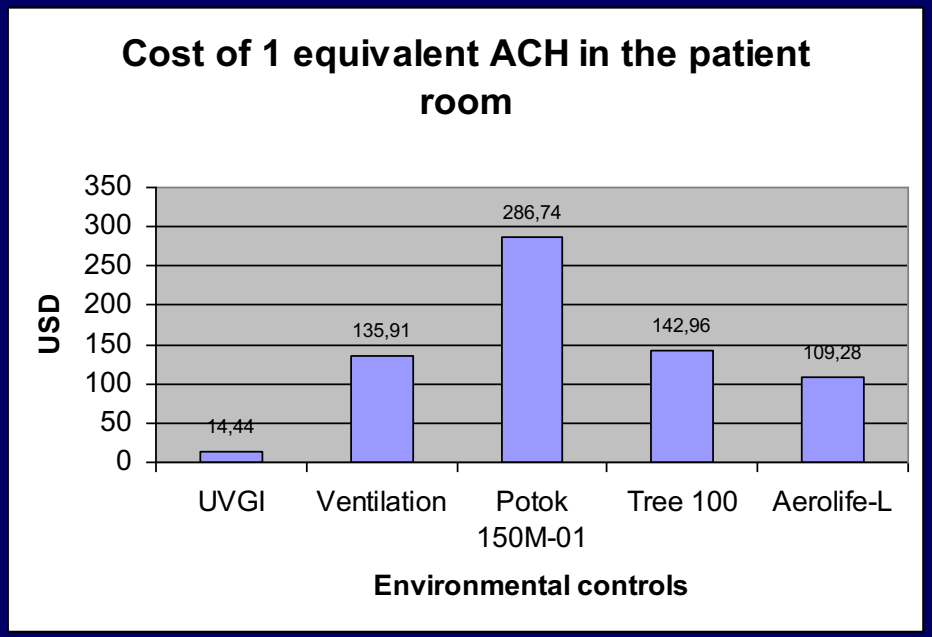
Head-to-head Comparison
Volchenkov/Jensen Study, Vladimir, Russia
(unpublished)

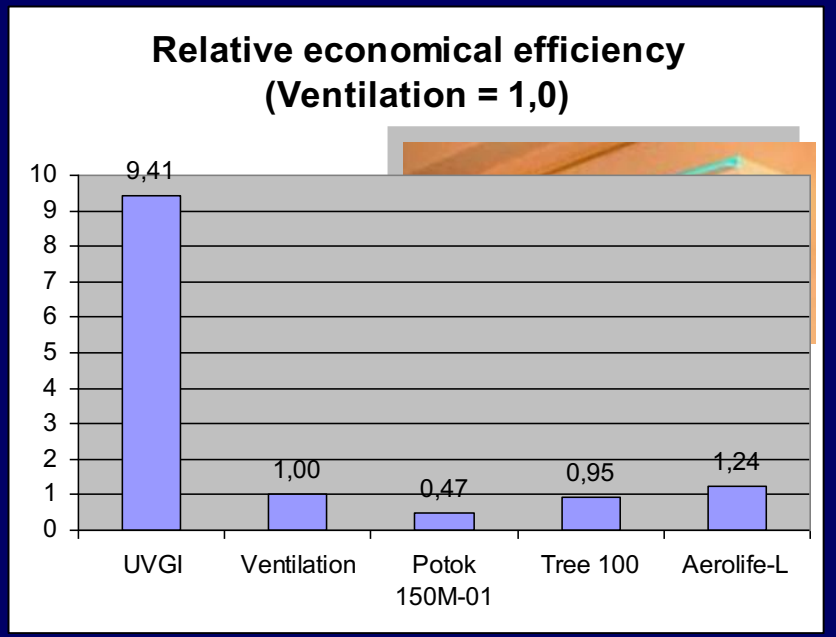
- Vladimir Oblast Drug Resistant TB Center ward being reengineered to reduce transmission to health care workers.
  - HVAC system installed – all installation and operating costs known.
  - One patient room used for bioaerosol and quantitative air sampling studies before occupied Several test organisms used (PAJ – CDC, PhD, PE)
  - HVAC system and 3 room air cleaners selected for comparison with Russian-made upper room GUV fixtures (not the most efficient design)

Cost effectiveness: ventilation vs 3 different room air cleaners vs GUV

Grigory V. Volchenkov, MD, Oblast TB Dispensary, Vladimir, Russia
in collaboration with Paul Jensen, PE, IH, PhD (CDC)

Test chamber studies: aerosolized 2 test bacteria, mechanical air sampling



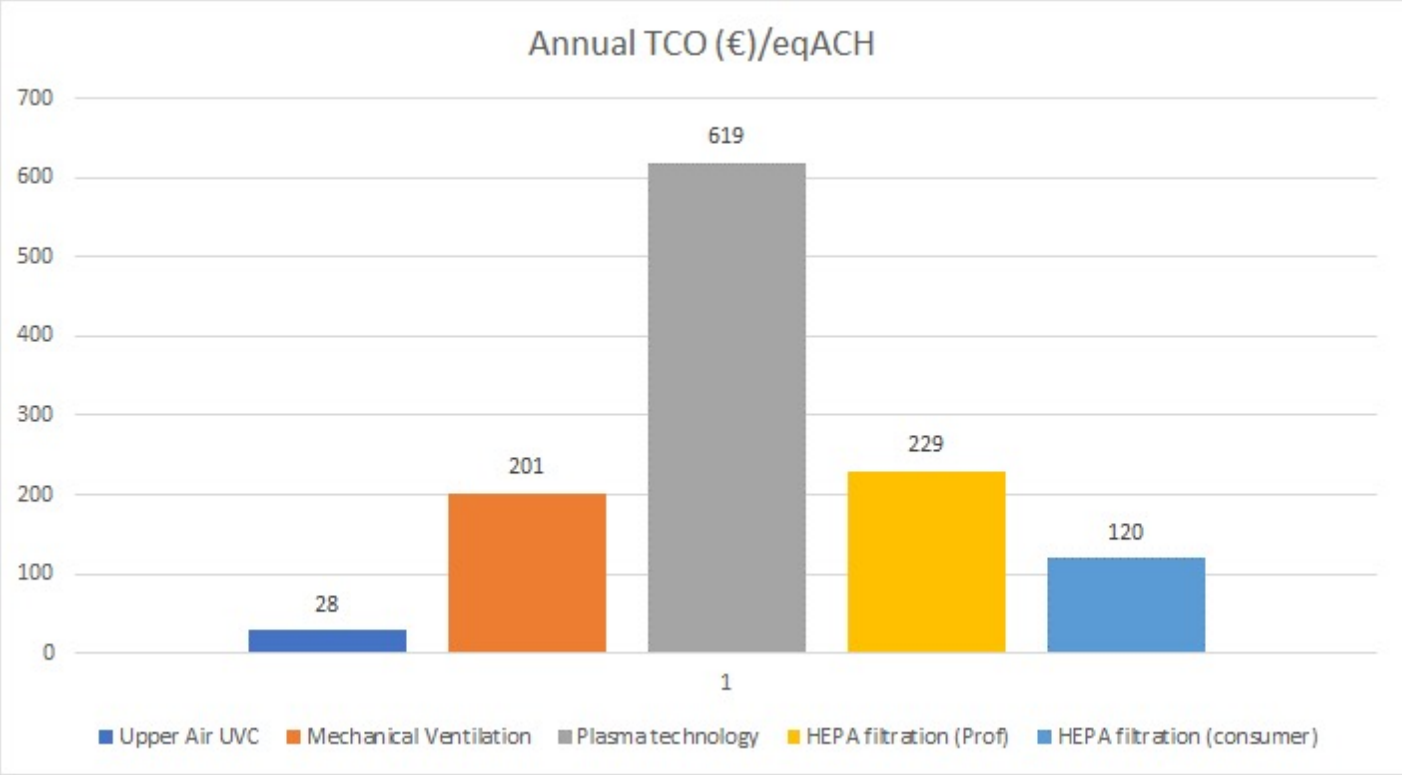


Operating cost per year per Eq ACH

Another Cost Comparison

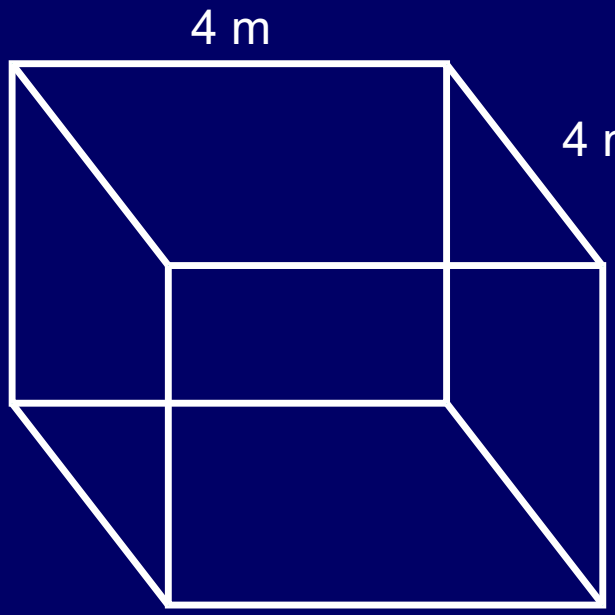
Calculated not experimental, based on Dutch market data (price, performance, maintenance, energy use). Based on producing 5 EqACH in a 175 m^3 classroom, but upper room (GUV produced 10 EqACH). *Thanks to Martin Creusen, Signify*

Similar 10 to 1 ratio to mechanical ventilation



Comparison:
Room air cleaner vs upper room GUV

(Pretoria meeting, July, 2016)



48 m^3
1 ACH = 48 m^3/h
1 ACH = 13.3 l/s

Room Air cleaner (RSA) = 60 cfm CADR
= 28.3 l/s

= 2.1 ACH (assuming no re-capture and good air mixing)

Upper room UVGI – avg 30 uW/cm^2
For TB, Z = 41
With good air mixing,
= approx 20 ACH!

ORIGINAL ARTICLE

Institutional Tuberculosis Transmission

Controlled Trial of Upper Room Ultraviolet Air Disinfection: A Basis for New Dosing Guidelines

Matsie Mphaphlele[1], Ashwin S. Dharmadhikari[2], Paul A. Jensen[3], Stephen N. Rudnick[4], Tobias H. van Reenen[5], Marcello A. Pagano[6], Wilhelm Leuschner[7], Tim A. Sears[8], Sonya P. Milonova[4], Martie van der Walt[9], Anton C. Stoltz[10], Karin Weyer[11], and Edward A. Nardell[2,12]

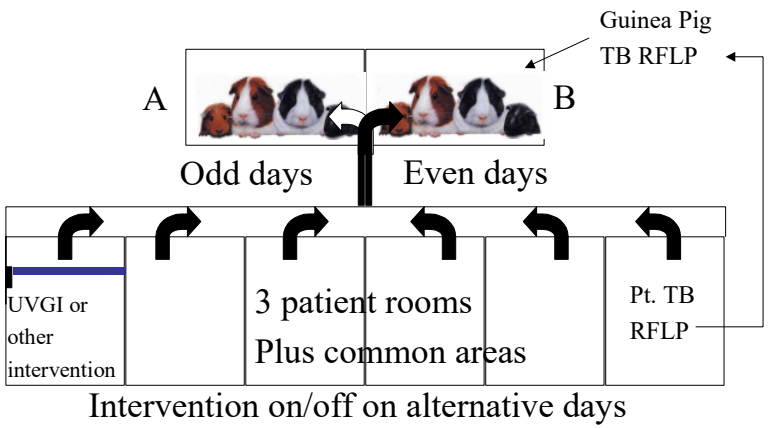
Upper Room Germicidal Ultraviolet Systems for Air Disinfection Are Ready for Wide Implementation

Shelly Miller editorial

80% effective

Added 24 equivalent ACH

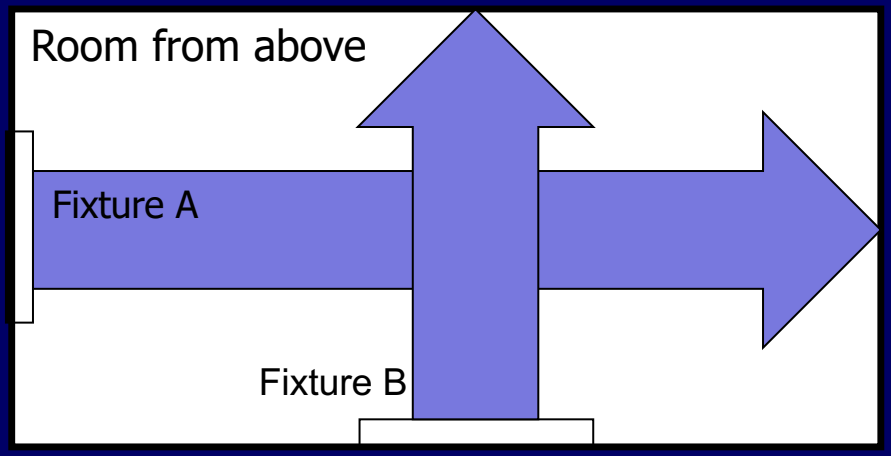
AIR, Experimental Plan



Fundamental Factors Affecting Upper-Room Ultraviolet Germicidal Irradiation—Part II. Predicting Effectiveness

Stephen N. Rudnick and Melvin W. First
Harvard School of Public Health, Boston, Massachusetts
Journal of Occupational and Environmental Hygiene, 2007; 4: 352–362 ISSN: 1545-9624 print

1. GUV Fluency rate for the entire room volume.



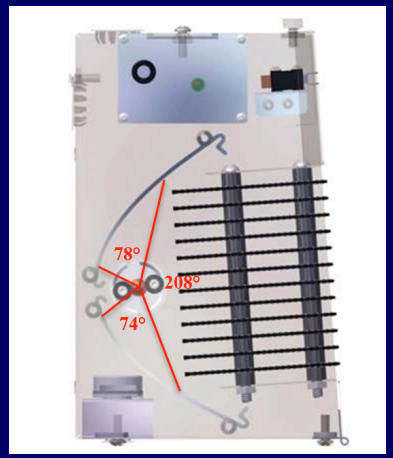
3. Mean UV ray length – effective until it is absorbed by a wall or ceiling.

2. Room vertical air mixing – assumed to be "good" with the use of low-velocity paddle fans – direction and velocity do not appear to be critical.

Current GUV Louvered Fixtures – designed for modern low ceilings

Nardell, E. and Riley, R. A new ultraviolet germicidal irradiation (UVGI) fixture design for upper air disinfection with low ceilings. 1992; World Congress on Tuberculosis, Bethesda, MD, NIH.

0.6% efficient



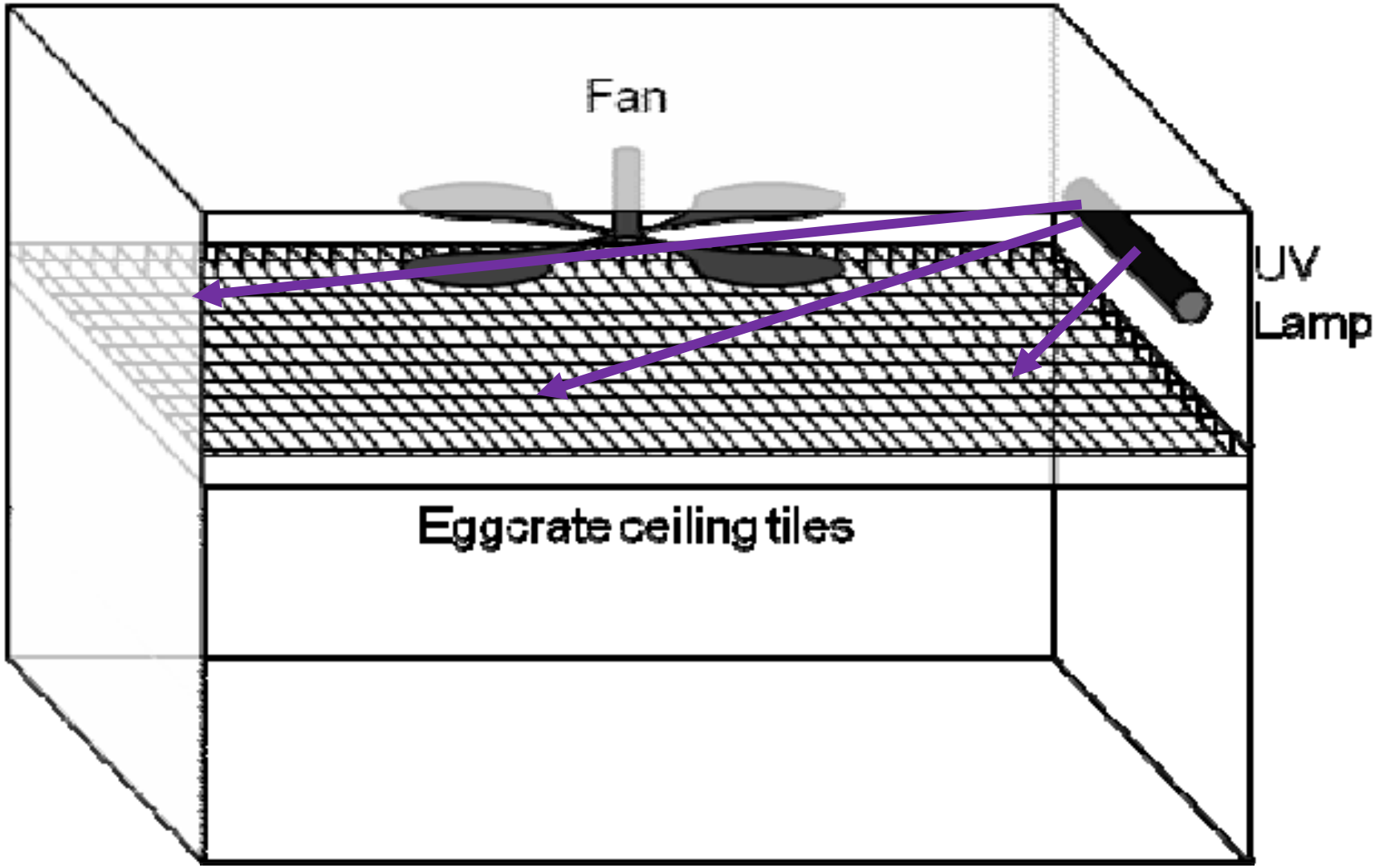
Almost all GUV from the back of the lamp

5.7% efficient

Is there a more efficient way to use upper room GUV?

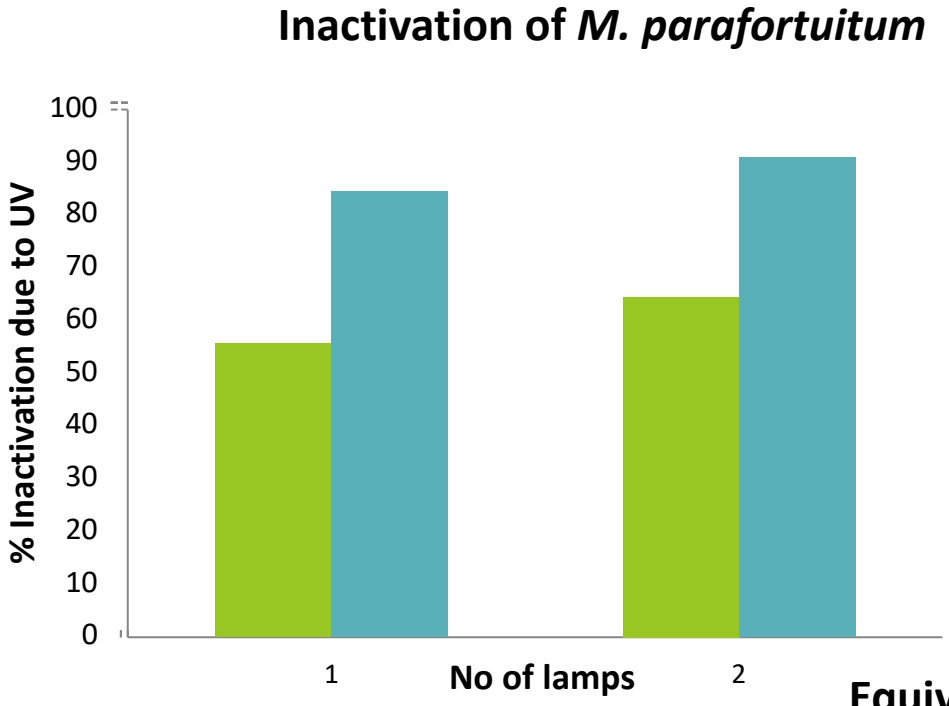
- Open UV fixtures (eggcrate UV)
- LED fixtures require little or no louvers
- Whole room Far-UV – no louvers

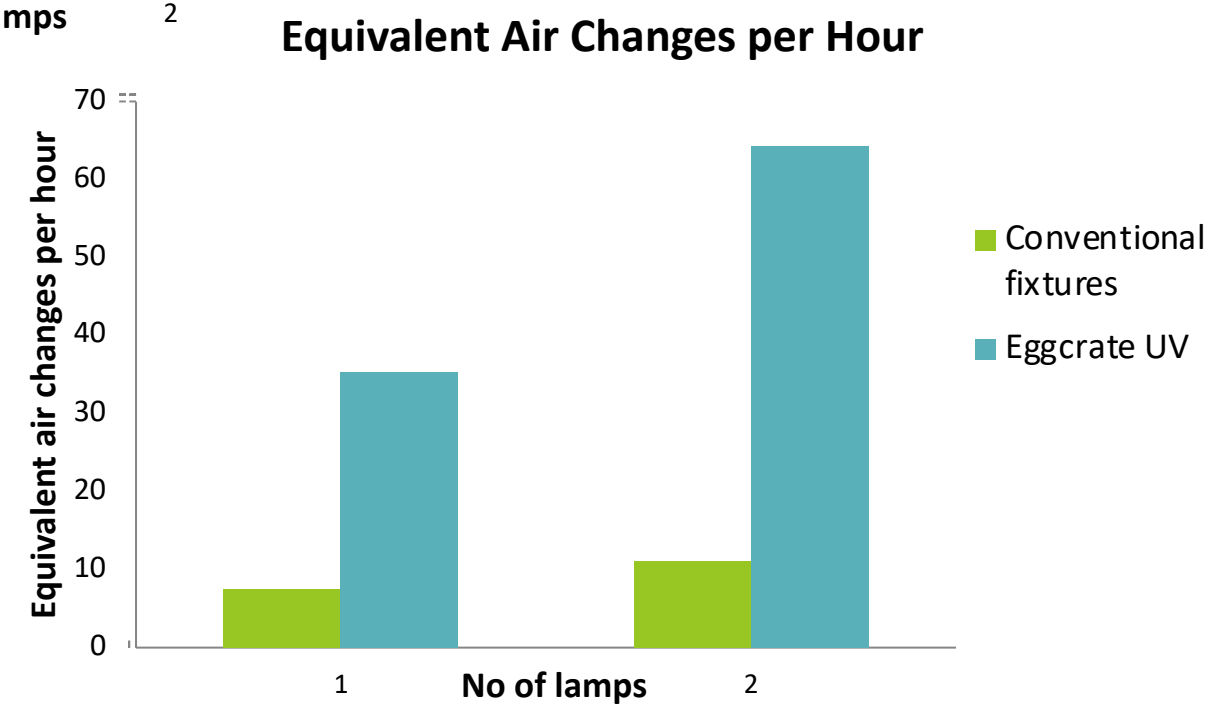
The “Egg-crate” GUV Concept



Baffles lower room UVGI <u>after</u> air disinfection, not before

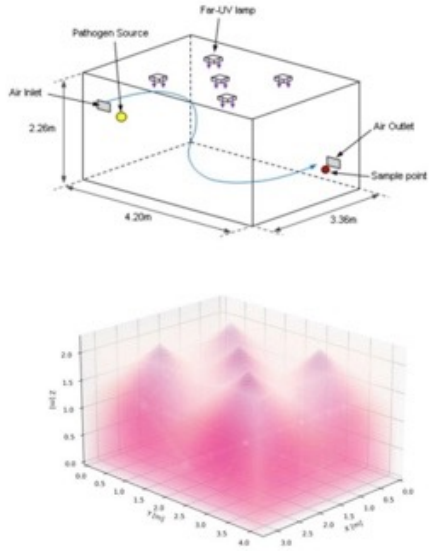
Results

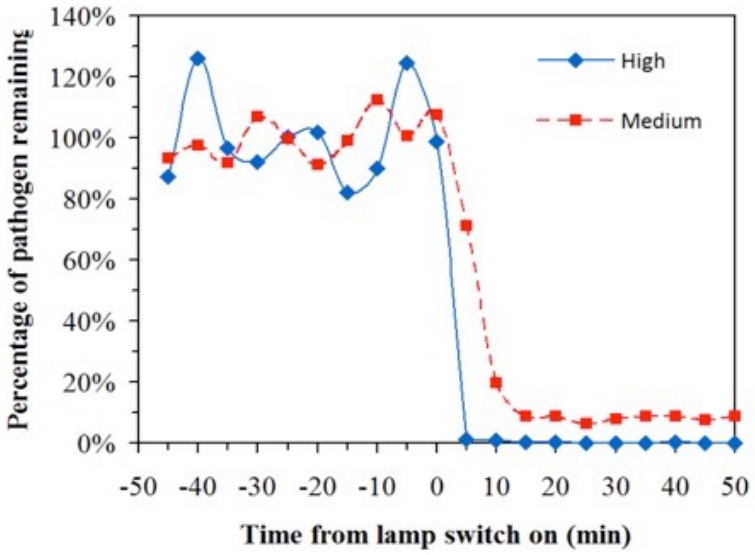

Inactivation of *M. parafortuitum*
% Inactivation due to UV
100
90
80
70
60
50
40
30
20
10
0
1
No of lamps
2
Conventional fixtures
Eggcrate UV


Equivalent Air Changes per Hour
Equivalent air changes per hour
70
60
50
40
30
20
10
0
1
No of lamps
2
Conventional fixtures
Eggcrate UV

Far UV-C:
Even safer and more effective

Is 222 nm UV-C the way forward?





- Current safety limits: reduction in steady-state airborne *S. aureus* of 92.1%
- Equivalent to an additional 35 Air Changes per Hour
- Would outperform a portable air cleaner (15.5 eACH)

PREPRINT Eadie et al. (2021)
https://www.researchsquare.com/article/rs-908156/v1

Deployment of Far UV-C

Deployment Example

Bluestone Lane, NY coffee shop

https://healtheinc.com/project/bluestone-cafe/

Current Research

- A pilot study in the Clark County School System (Las Vegas)
  - Comparing wastewater samples for covid-19 from 4 schools with GUV throughout to schools without GUV (scheduled to start early 2022)
- Human-to-Hamster transmission model in Pretoria, South Africa
  - Comparing the efficacy of conventional upper room GUV, LED upper room GUV, and Far UV-C under identical real-life conditions (scheduled to start early 2022)