Physics of Pathogen Transmission

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Introduction

- **Education:**
  - University of Arizona – Chemical Engineering
    - 1974 thru 1976
  - University College London – BFA Degree (Sculpture)
    - 1978 thru 1983
  - Boston University – MFA Degree (Sculpture)
    - 1983 thru 1985

- **Industry:**
  - Norman S. Wright SW: Estimator/Sales
    - 1985 thru 1999
  - Air Specialty Products/ThermAir Systems – Outside/Engineering Sales
    - 2000 thru 2008
  - **Varitec Solutions:**
    - Senior Sales Engineer/Educator (High Performance HVAC)
    - 2016 thru present

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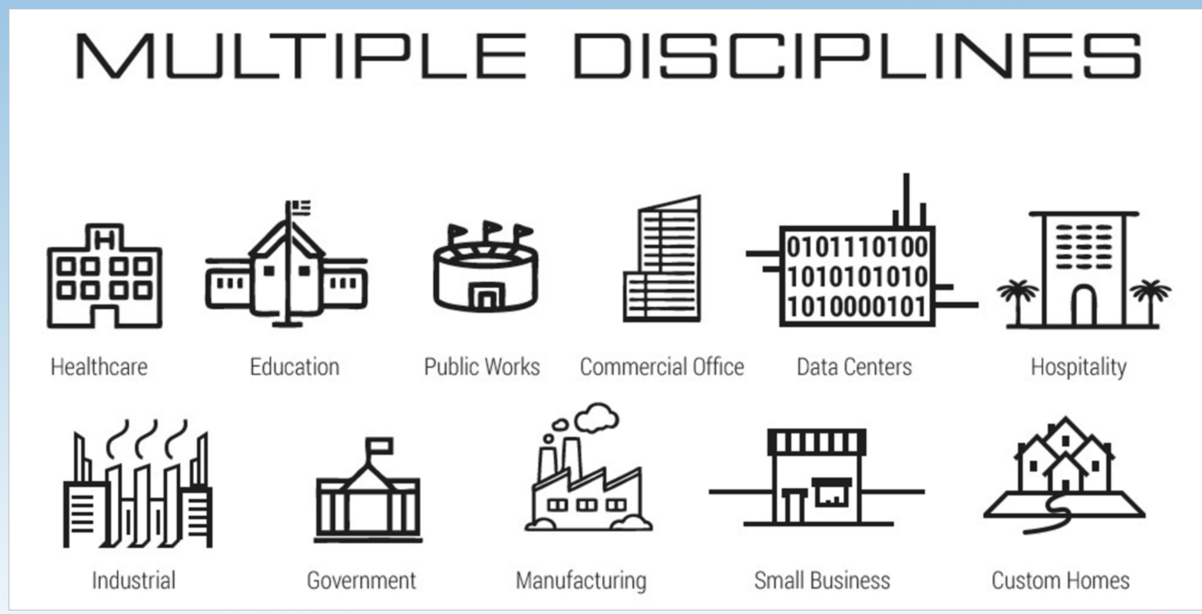
Varitec: The HVAC System Solution

Varitec: The HVAC System Solution



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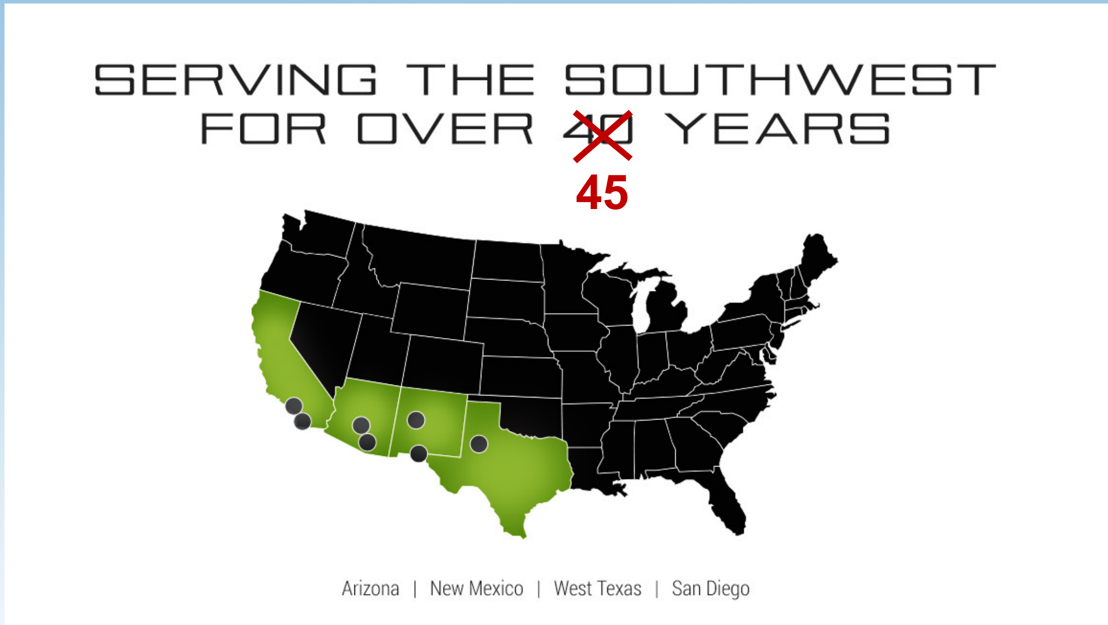
Varitec: The HVAC System Solution



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Varitec: The HVAC System Solution

System Solutions:

- Variable Refrigerant Systems
- Mixed Air VAV Systems
- Package Central Plants (Air & Water Cooled Designs)
- Cloud Based Controls
- Humidity Control
- Underfloor Air Systems
- Displacement Ventilation
- 100% OSA Systems
    - DOAS Technology
    - Active Chilled Beams
    - Passive Hydronic Cooling & Heating Systems

Varitec: The HVAC System Solution

Shaping
The Future
Of HVAC

Mission:

(New Horizons Launch, January 9, 2006)

To provide an educational platform for continued learning in the HVAC industry with a focus on high performance buildings and innovative technologies for a better built environment.

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2021 Educational Webinar Schedule

▶ Wednesday, March 17 at 11:00 am PST
ASHRAE 62.1 2019

▶ Wedensday, April 14 at 11:00 am PST
Humidification - Technology and Application

▶ Wednesday, May 12 at 11:00 am PST
UV Lights - Technology and Application

▶ Wednesday, June 9 at 11:00 am PST
Needlepoint Bipolar Ionization - Technology and Application

▶ Wednesday, July 14 at 11:00 am PST
Dilution and Thermal Stratification - Displacement Ventilation

▶ Wednesday, August 11 at 11:00 am PST
Pathogen Mitigation: HVAC System Design Concepts

▶ Wednesday, September 8 at 11:00 am PST
ASHRAE 90.1 2019 and 189 2019

▶ Wednesday, October 13 at 11:00 am PST
Low-Pressure VAV Systems

▶ Wednesday, November 3 at 11:00 am PST
100% OSA Systems Part 1

▶ Wednesday, December 8 at 11:00 am PST
100% OSA Systems Part 2

▶ Wednesday, January 12, 2022 at 11 am PST
ASHRAE 170 2017

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Physics of Pathogen Transmission

Presentation Resources:

References:

- Dr. Clifford Ho (Sandia National Laboratories)
- Dr. Yuguo Li (University of Hong Kong)
- Steve Taylor et. al. (Taylor Engineering)
- Jon Ziegler (GLHN)
- Stanley Yellowhair (GLHN)

Physics of Pathogen Transmission

Agenda:

- Review: ASHRAE Epidemic Task Force
- The Physics of Falling Objects
- The Expiratory Event: Discharge of Pathogen
- Environmental Impacts on Pathogen Travel
- Probability of Infection
- Prescriptive Measures & The Future

ASHRAE Epidemic Task Force Review

ASHRAE: Epidemic Task Force Review

SARS-CoV-2 Transmission: Evolution

World Health Organization

CENTERS FOR DISEASE CONTROL AND PREVENTION

SARS-CoV-2 Infection Pathways
(Original Statements)

- Fomitic Transmission: Surface to Surface
- Large Droplets:
  - Social Distancing Guidelines of 6 Feet.

ASHRAE: Epidemic Task Force Review

- **William Wells – Tuberculosis Transmission Study (1930's)**

"…small droplets transition from the warm and moist conditions of the respiratory system to the colder and drier outside environment, they evaporate and form residual particulates made of the dried material from the original droplets."

CENTERS FOR DISEASE CONTROL AND PREVENTION

"Residual particulates are referred to as *droplet nuclei or aerosols*."

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ASHRAE: Epidemic Task Force Review

The Center for Disease Control (CDC):

(October 2nd, 2020)

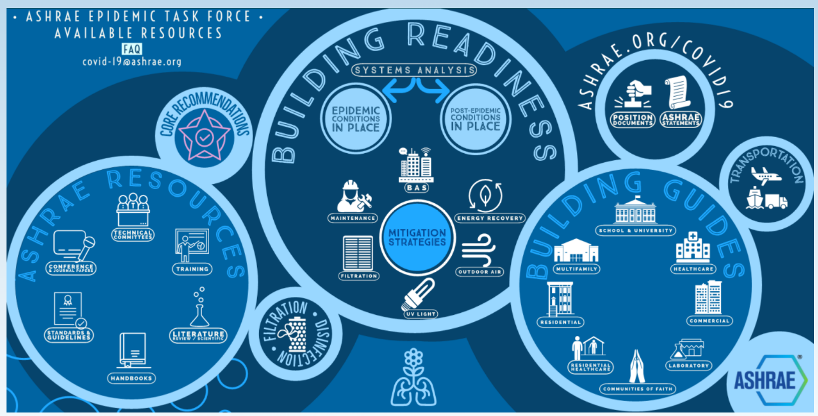
- "COVID-19 can sometimes be spread by airborne transmission."
- "Some infections can be spread by exposure in small droplets and particles that can linger in the air for minutes or hours."

    - "These viruses may be able to infect people who are further than 6 feet away from the person who is infected….
    - This kind of spread is referred to as **airborne transmission**…

ASHRAE: Epidemic Task Force Review

Statements &
Position Documents on Infectious Aerosols

(April 2020)



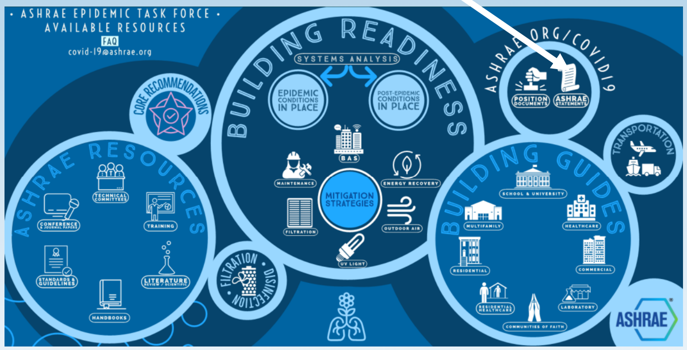
ASHRAE.ORG/COVID19

ASHRAE: Epidemic Task Force Review

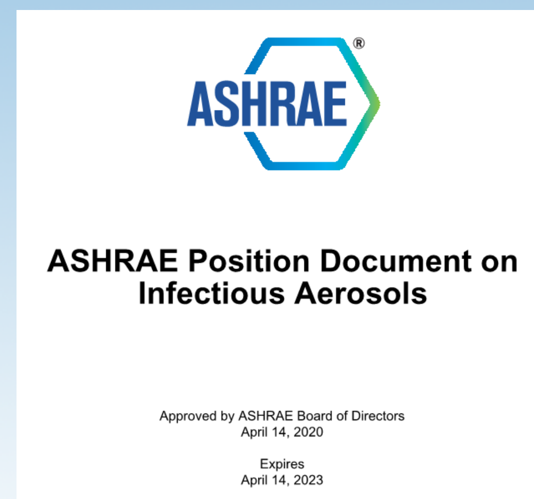
Position Documents on Infectious Aerosols

ASHRAE.ORG/COVID19

- Position Documents on Infectious Aerosols



ASHRAE.ORG/COVID19


ASHRAE

ASHRAE Position Document on Infectious Aerosols

Approved by ASHRAE Board of Directors
April 14, 2020

Expires
April 14, 2023

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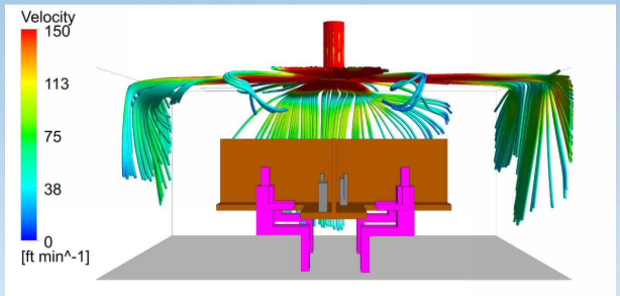
ASHRAE: Epidemic Task Force Review

ASHRAE: Position Document on Infectious Aerosols

3.2 Ventilation and Air-Cleaning Strategies:

- “Ventilation with effective airflow patterns is a **primary infectious disease control strategy through dilution of room air** around a source and removal of infectious agents” (CDC 2005).



(Acutherm: CFD Model)

- However, it remains unclear by how much infectious particle loads must be reduced to achieve a measurable reduction in disease transmissions **(infectious doses vary widely among different pathogens)…**

ASHRAE: Epidemic Task Force Review

ASHRAE: Position Document on Infectious Aerosols

- **Executive Summary:**
  - **"…HVAC systems … do impact the distribution and bio-burden of infectious aerosols:**
  - "This position document covers strategies through which HVAC systems modulate aerosol distribution and can therefore increase or decrease exposure to infectious droplets, droplet nuclei, surfaces, and intermediary fomites…"

3. Virus transmission: routes, measurements, and modeling

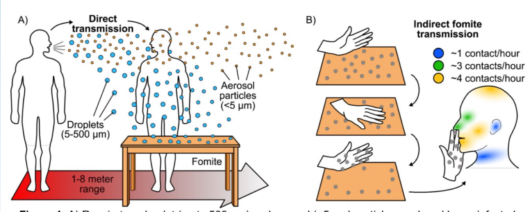


Figure 1. A) Respiratory droplet (up to 500 μm) and aerosol (<5 μm) particles produced by an infected host during coughing/sneezing, talking, or exhaling can infect fomites or another individual directly. Droplets settle and adsorb onto fomites while aerosol particles can remain suspended in air for minutes to hours.[41,42] B) Indirect fomite-mediated transmission to a new human host occurs through contact with the fomite and subsequent contact with regions through which a virus can enter the body. Contact times can range from ~1-50 s.[43]

The Physics of Airborne Motion

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The Physics of Airborne Motion

Today's Discussion:

- Per **ASHRAE, "air patterns" and "dilution":** Two HVAC strategies for reducing pathogen concentrations in a building
- **Understanding "expiratory" particle travel in a space will support HVAC design solutions to achieve pathogen mitigation goals.**

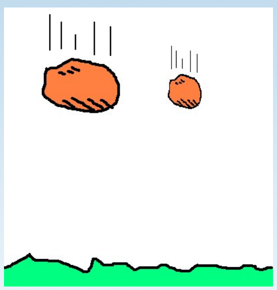
Webinar Goal:

How expelled pathogens move in a building and why

The Physics of Airborne Motion

The Physics of Falling Objects

- **Definitions:**
  - **Size: "the relative extent of something, a things overall dimensions or magnitude, how big something is."** (Oxford Dictionary of English)



Will two objects of different sizes, but equal mass, fall at the same acceleration rate?

- Answers?
  - In a vacuum, **Yes**
  - In an environment filled with a gas (air): **NO**

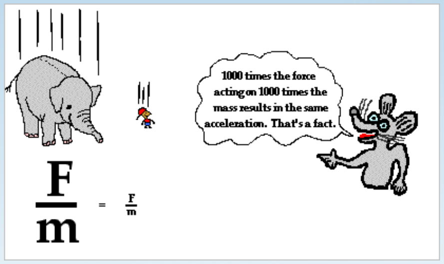
Why: The resistance of the gas beneath a falling object. The larger the object **SIZE** the greater the resistant force of displaced gas.

The Physics of Airborne Motion

The Physics of Falling Objects

Mass ≠ Weight

- **Definitions:**
  - **Mass:** "the quantity of matter which a body (of defined magnitude) contains



Will two objects of different mass, but equal size, fall at the same velocity (i.e. have the same acceleration rate)?

- Answers?
  - In a vacuum, **YES**
  - In an environment filled with a gas (air): **Yes**

Gravity: the force of attraction between two objects of mass.

The Physics of Airborne Motion

The Physics of Falling Objects

- **Size, Mass and Gravity**

Particles Relative Sizes:

- Human Hair: 50 – 180 microns
- Fine Beach Sand: ~90 microns
- Grain of Pollen: ~15 microns
- Red Blood Cell: 7 – 8 microns
- Respiratory Droplets: ~5 – 10 microns
- Dust Particle: ~2.5 microns
- **Coronavirus: ~0.01 – 0.5 microns**

Steady State Environment (i.e. No Air Movement)

Size affects particle float time in the air due to air resistance between the falling object and the ground.

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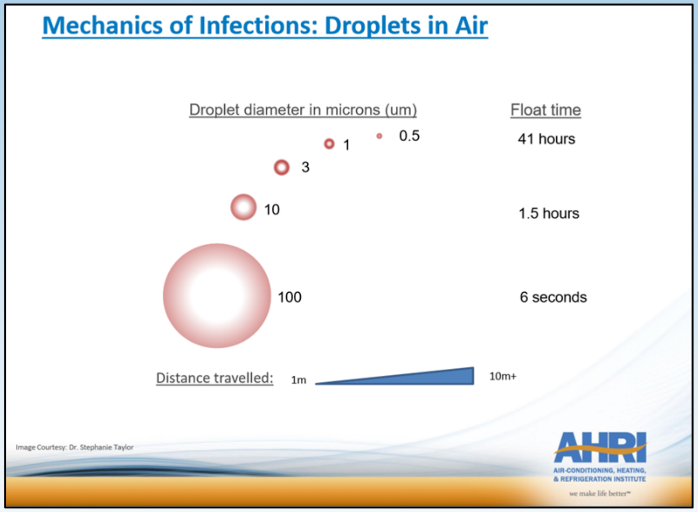
The Physics of Airborne Motion

The Physics of Falling Objects

- **Particle Size (Mass) & Buoyancy**
- **Buoyancy affects Float Time**

- **Droplets:** by definition larger than **20 microns**
- **Small droplets and aerosols:** range from **10-20 microns**
- **Droplet nuclei:** Below 10 microns (may be **0.5 microns or smaller**)



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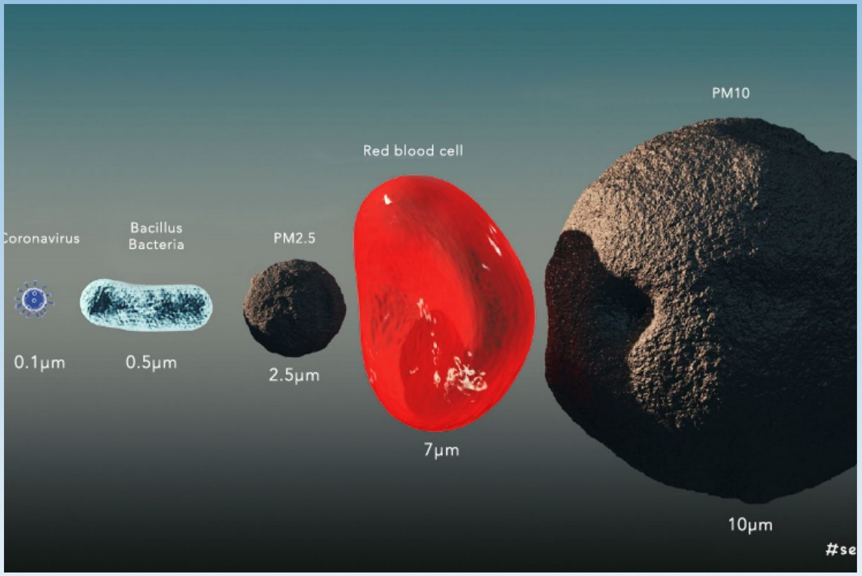
The Physics of Airborne Motion

The Physics of Falling Objects

Droplet Size, Buoyancy & Float Time

SARS-CoV-2 = ~0.125 microns

- Less mass = greater buoyancy and particle float time

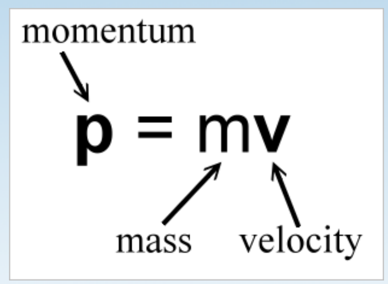


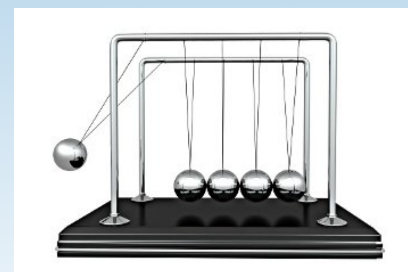
Desiccated (anhydrous) virus can remain airborne 72 hours, perhaps longer.

The Physics of Airborne Motion

The Physics of Falling Objects

- **Definitions:**
  - **Momentum:** “the quantity of motion (driving force) of a moving body as a product of mass and velocity





A body of greater mass moving at the same velocity as a body of lower mass has a greater “driving” force called momentum.

The Expiratory Event

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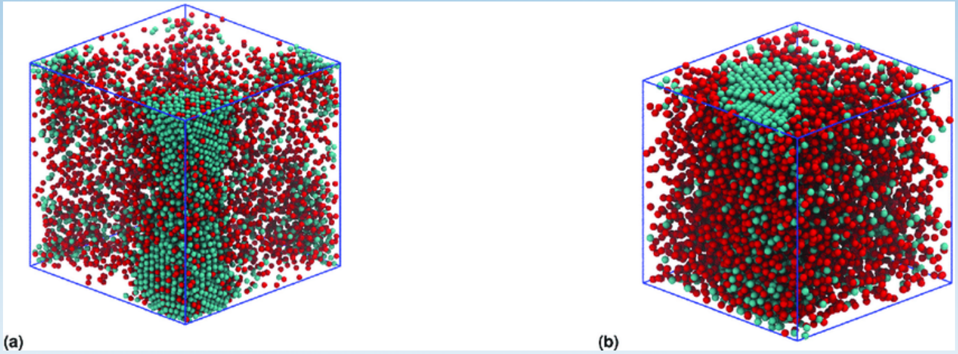
The Expiratory Event

Particles in Steady State:

- **No Air Turbulence within The Space**

- Room with uniform surface and air temperature
- Particle motion in a fluid is called **Brownian Motion**



(a) (b)

Brownian motion: the erratic random movement of microscopic particles in a fluid, as a result of continuous bombardment from molecules of the surrounding medium

The Expiratory Event

Pathogenic Particles in a Room:

- **Risk of Infection:**

$$P = 1 - e^{\frac{-Ipqt}{Q}}$$

P = *Probability of infection*

I = *Number of infector individuals in the space*

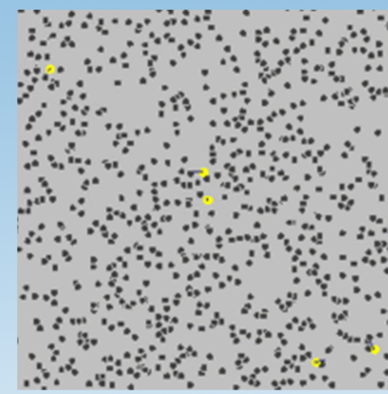
p = *Average breathing rate of individuals in the space*

q = *Quanta generation rate*

t = *Exposure time*

Q = *Air flow rate from HVAC system*

Wells-Riley Equation



- Derived in 1978 to model measles outbreaks in schools.
- **"Provides a simple and quick assessment of the infection risk".**

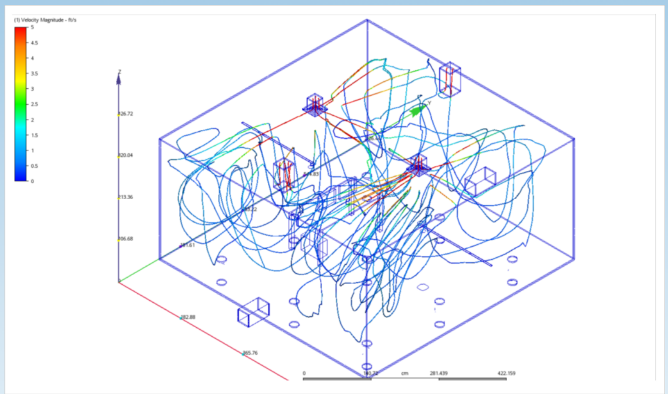
(Lowry, AJ (KW Engineering))

The Expiratory Event

Pathogen Expiration & Motion In a Space?

Airflow moves particles in space:

- **Convection** (Warm Air Rises, Cold Air Falls)
- **Pressure differentials**
    - Supply Air Jets (Positive Pressure)
    - Return Air (Negative Pressure)
- **Forces of expulsion** (Expiratory Events)
    - Occupants (Sneezing, Talking, etc.)



(CFD Model: GLHN Architects)

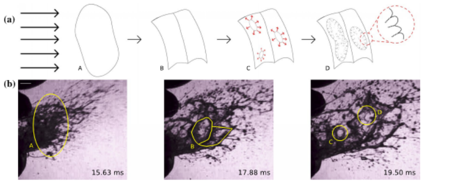


Fig. 1 **a** Schematic of the fragmentation process of a liquid volume in response to applied aerodynamic forces and **b** photographs recorded shortly after the first appearance of sneeze ejecta. The initial liquid volume (*A*) is flattened into a sheet (*B*), followed by hole formation (*C*) and subsequent destabilization into ligaments, and, finally, droplets (*D*). *Scale bar* in (**b**) is 1 cm. We provide the associated video SIV1 in the electronic supplementary materials

The Expiratory Event

Expiratory Events:

- **Active Pathogen Ejected into a Space**

- Breathing
- Talking
- Singing
- Coughing
- Sneezing

(Scharfman, Techet, Bush, Bourouiba)

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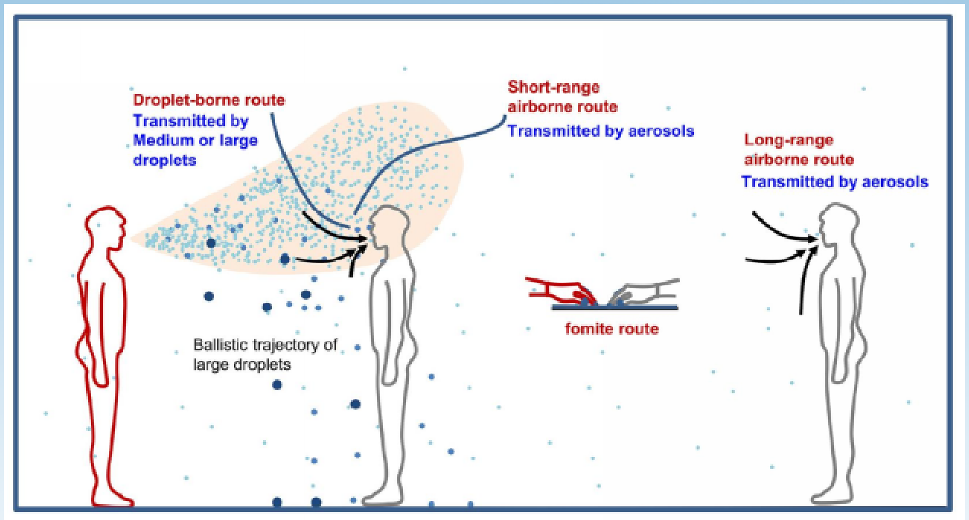
The Physics of Airborne Motion

Expiratory Events: Pathogen Routes



(*Wei J and Li Y (2016) American Journal of Infection Control*)

Routes of Transmission

- Ballistic Trajectory of large droplets
- Fomite Route
  - Droplet Sedimentation
- Droplet-Borne Route
  - Aerosols
- Short-Range Airborne Route
  - Aerosols
- Long-Range Airborne Route
  - Aerosols

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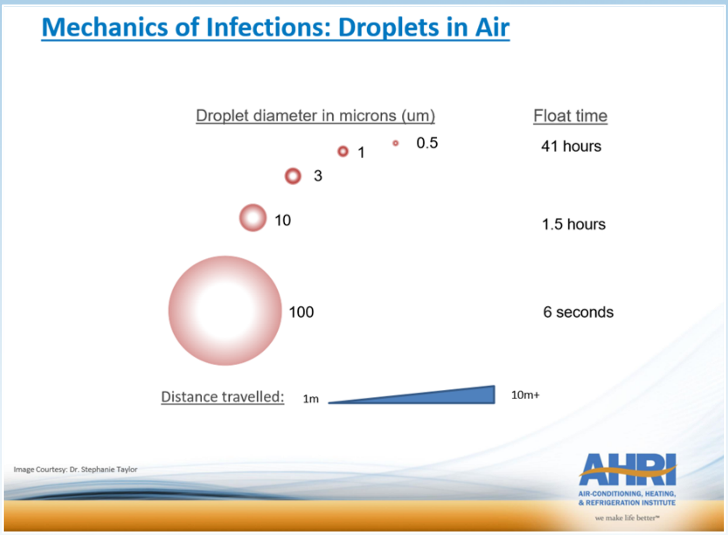
The Expiratory Event

Expiratory Events: Pathogen Buoyancy

- **Active Ejected Pathogen**



Pathogenic Medium:
Mucous and Saliva Droplets

Large Droplets: **>100 microns**

Medium Droplets: **5 to 100 microns**

Droplet Nulcei or Aerosols: **< 5 microns**

Pathogens are expelled from the lungs and respiratory tract at 100% RH condition

Note: Various studies use different reference sizes for terms.

The Expiratory Event

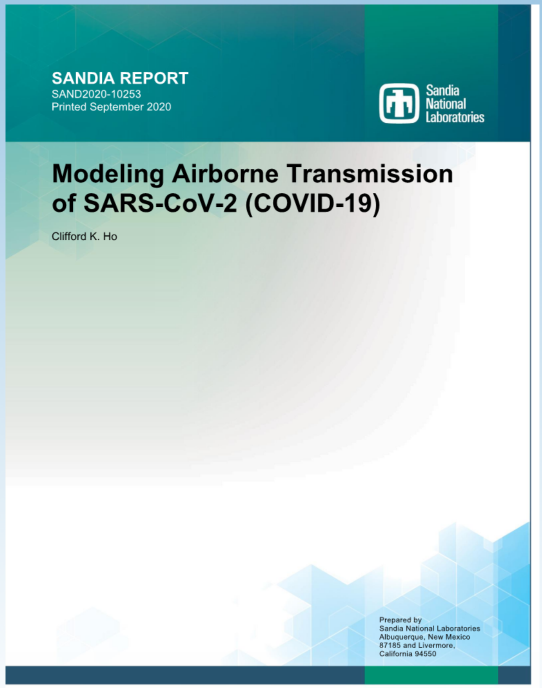
Expiration, Velocity, Momentum & Distance

Dr. Clifford Ho:

(Senior Scientist Sandia Labs)

Sandia Report:

Modeling Airborne Transmission of SARS-CoV-2 (Covid-19)


SANDIA REPORT
SAND2020-10253
Printed September 2020

Sandia National Laboratories

Modeling Airborne Transmission of SARS-CoV-2 (COVID-19)

Clifford K. Ho

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico
87185 and Livermore,
California 94550

Sandia National Laboratories

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The Expiratory Event

Expiration Events: Velocity, Momentum & Distance

- **Expiratory Event:**
  - **Breathing**
  - **Talking**
  - Coughing
  - Sneezing

- **Talking & Breathing:**
  - **Droplet Sizes: several to several tens of microns**
  - **Discharge Velocities:**
    - **2.2 mph**
  - Pathogen count: 100’s to 1000’s particle count
  - Laminar flow discharge

- **Talking: 10 times more droplets than breathing**

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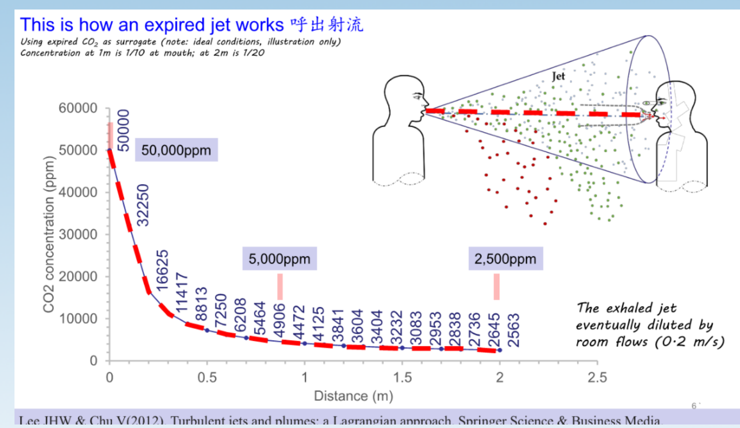
The Expiratory Event

Expiration Events: Velocity, Momentum & Distance

- **Expiratory Event:**
  - **Particulates expelled while breathing**

- **CO_2 Tracer Gas:**
  - **Large Droplets: 20 microns or greater drop out 1.5 meters**
  - **Small Droplets & Aerosols: 5 – 10 microns aerosolized**
  - **Droplet Nuclei: 0.5 to 10 microns aerosolized**



(LEE JHW & Chu, V. (2012) Turbulent Jets & Plumes…)

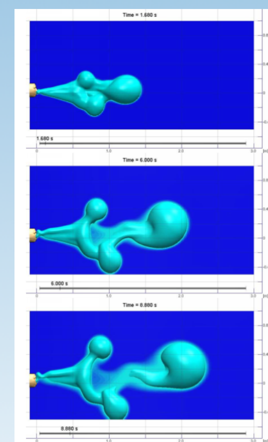
- **Concentration at 1m is 1/10 at mouth**
- **At 2m 1/20th concentration**

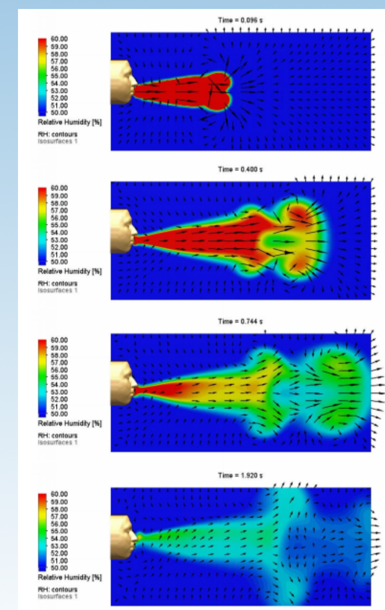
The Expiratory Event

Expiration Events: Velocity, Momentum & Distance

- **Expiratory Event:**
  - Breathing
  - Talking
  - **Coughing**
  - Sneezing

Ballistic Trajectory





- **Coughing:**
  - Droplet Sizes: <10 - ~20 microns
  - Pathogen Droplets: ~ 3,000
  - **Discharge Velocities: 21.5 mph**
  - Bifurcated plume

The Expiratory Event

Expiration Events: Velocity, Momentum & Distance

- **Expiratory Event:**
  - Breathing
  - Talking
  - Coughing
  - **Sneezing**

Ballistic Trajectory

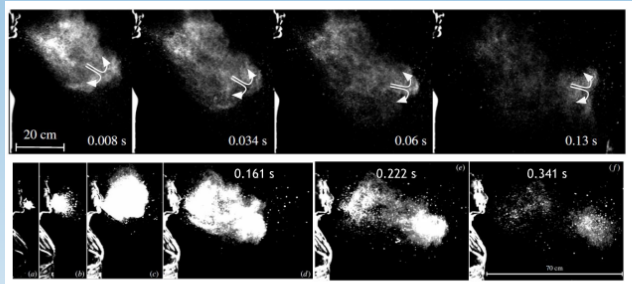


Figure 7. High-speed camera images of a sneeze illustrating salient processes of counter-rotating flow at the leading edge and bifurcation of the droplet plume (Bourouiba et al. [6]).

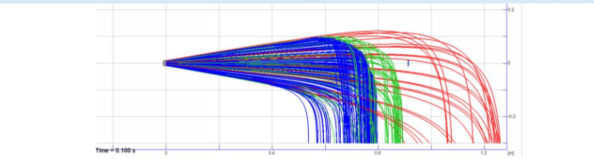


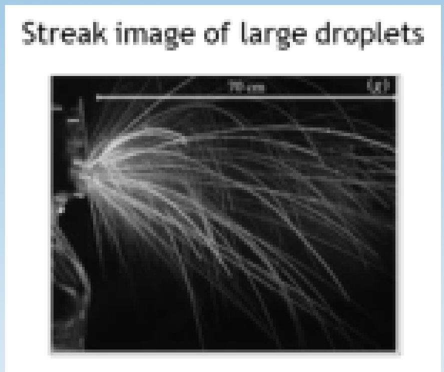
Figure 9. Top: Droplet trajectories observed using high-speed imaging during a sneeze [6]. Bottom: Simulated droplet trajectories at 0.1 s for different water droplet sizes (blue = 100 microns, green = 200 microns, red = 300 microns). Both images are scaled to the same size.

- **Sneezing:**
  - Droplet Sizes: ~1 – 100 microns
  - Pathogen Count: ~40,000 droplets
  - **Discharge Velocities: 44 mph @ 0.25 seconds**
  - Bifurcated plume

The Expiratory Event

Expiration Events: Velocity, Momentum & Distance

Sandia National Laboratories



- "Initially, **larger droplets can be propagated further than smaller droplets** due **to increased momentum**…"

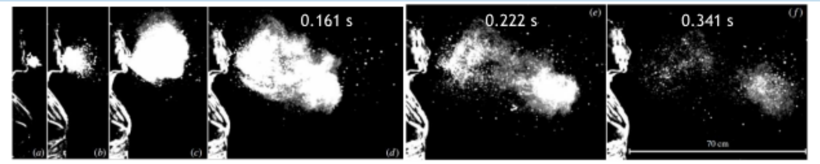


Figure 7. High-speed camera images of a sneeze illustrating salient processes of counter-rotating flow at the leading edge and bifurcation of the droplet plume (Bourouiba et al. [6]).

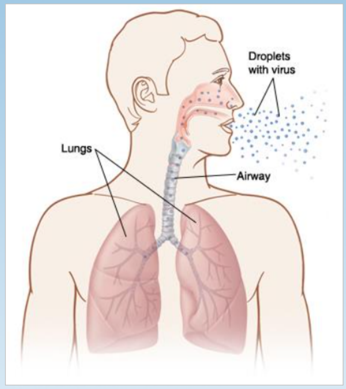
(Large droplet travel distance: 23-26 feet)

"…but they fall out faster due to gravity."

The Expiratory Event

Expiration, Velocity, Momentum & Distance

- **Expiratory Event:**
  - **Dr. Clifford Ho (2020):**
    - "…because the size of the droplets that are emitted during tidal breathing are small, the exhaled aerosol plume can remain suspended for long periods."

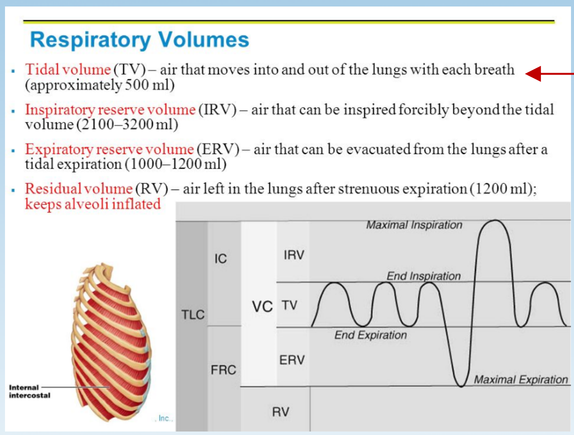


"Thus, despite the lower viral load per exhalation event relative to coughs or sneezes, the persistence of the small aerosolized droplets and continuous nature of breathing and/ or talking can increase the potential for transmission, especially in enclosed spaces with low fresh-air exchange."

The Expiratory Event

Breathing:

- **Continual doses of aerosolize pathogen into a space**



Tidal breathing exhales approximately 500 ml (0.5 liter) of air each breath.

Do the Math!

16 breaths/min * 0.5 Liters
= 8 Liters / Min / Person

Age	Respiratory rate (breaths per minute)
Newborns	44
Infants	20-40
Preschool children	20-30
Older children	16-25
Adults	12-20
Adults during strenuous exercise	35-45
Athletes	60-70(**Peak**)

(Respiratory Rate Chart by Damba)

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Environmental Impacts of Pathogen Travel

Environmental Impacts of Pathogen Travel

Space Conditions & Migration

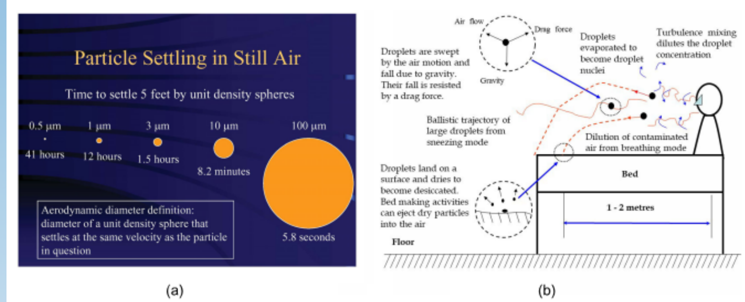


Figure 1 (a) Comparative settling times by particle diameter for particles settling in still air (Baron n.d.) and (b) theoretical aerobiology of transmission of droplets and small airborne particles produced by an infected patient with an acute infection (courtesy Yuguo Li).

HVAC System and Droplet Migration:

- "The majority of larger emitted droplets (>100 microns) are drawn by gravity to land on surfaces within about 3-7 feet from the source"

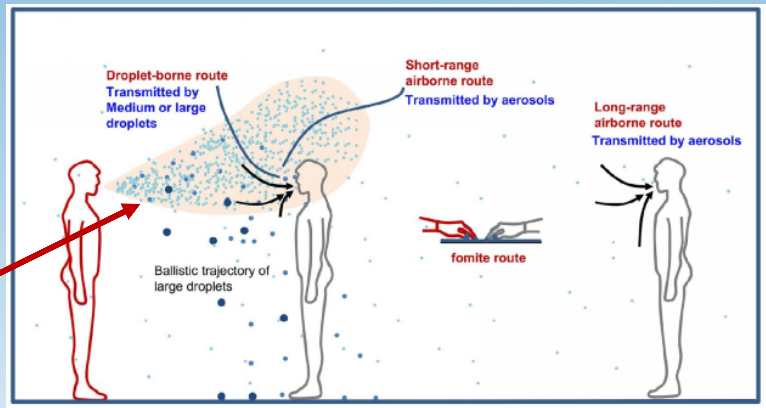
"General dilution ventilation and pressure differentials do not significantly influence short-range transmission"
(ASHRAE Position Document on Infectious Aerosols")

Environmental Impacts of Pathogen Travel

Space Conditions & Migration

Temperatures:
- Room Temperature: 75F db
- Occupant Temperature:
  - 98.6F (hopefully), 101F…

Forces of Convection:
- Discharge Plume Rises in Space
- Particles more buoyant



- **The cooler the room the greater the temperature differential between the room & effluent plume (~ 98F- 100F+)**
- **Discharged particles more buoyant.**

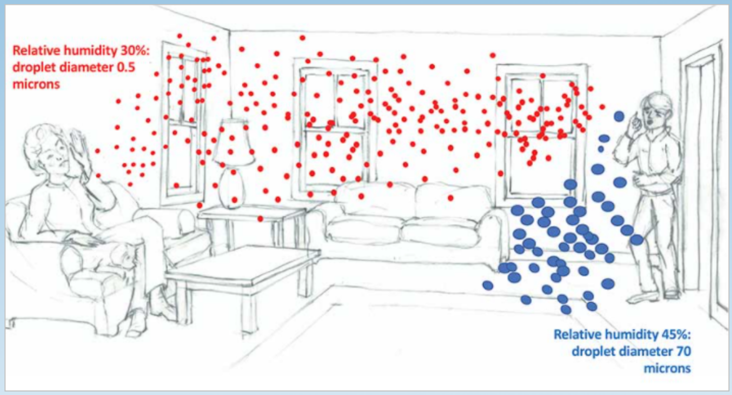
Environmental Impacts of Pathogen Travel

Space Conditions & Migration

Humidity:

- **Space Humidity** affects droplet desiccation rates

- "…humidifying the indoor air to between **40%-60% RH** decreases the number of infectious particles in the air." (Taylor, Stephanie M.D.)



(ES Magazine, May 2020

- **Relative humidity at 30%: droplet diameter 0.5 microns**
- **Relative humidity at 45%: droplet diameter 70 microns**

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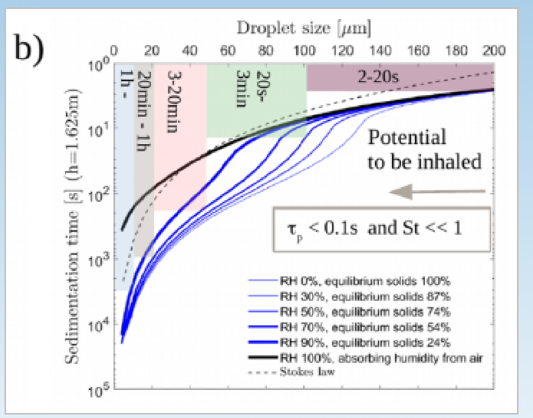
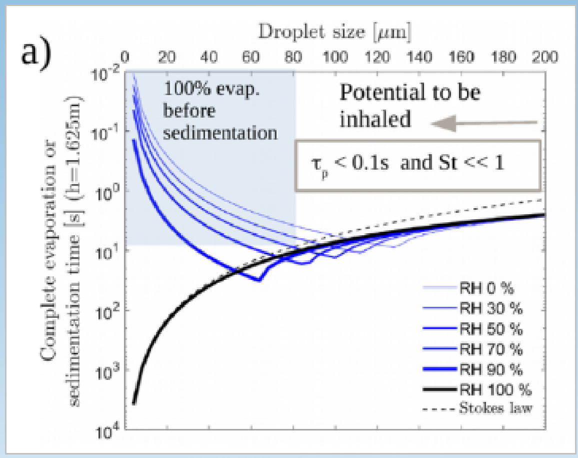
Environmental Impacts of Pathogen Travel

Space Conditions & Migration

- **Humidity: Pathogen Sedimentation Rates**



(Elsevier: October 2020)



(Elsevier: October 2020)

- **Higher humidity**, slower desiccation rates of mucous and saliva droplets
- **Low humidity**, high droplet desiccation rates
  - Pathogen aerosolization rate increases
  - Viral nuclei formed, less massive, more buoyant, longer float times.

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Environmental Impacts of Pathogen Travel

Space Conditions & Migration

Air Velocity at the Breathing Zone:

- **ASHRAE Standard 55 - 2017:**
  - ~40-50 FPM Supply Air Velocity (Occupant Clothing & Metabolic Rates)

ASHRAE®

ANSI/ASHRAE Standard 55-2017
(Supersedes ANSI/ASHRAE Standard 55-2013)
Includes ANSI/ASHRAE addenda listed in Appendix N

Thermal Environmental Conditions for Human Occupancy

Sandia National Laboratories

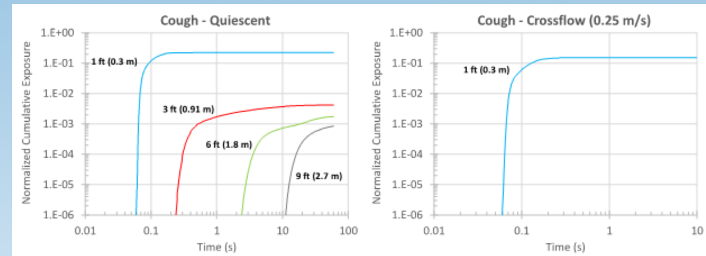

Figure ES-1. Cumulative exposures from a simulated cough under quiescent (left) and crossflow (right) conditions as a function of time and distance between the source and receptor (located in line and downstream of the cough direction). Cumulative exposure is normalized to a maximum exposure immediately next to the source.

(Ho, Clifford, PHD: Sandia Labs)

Quiescent: Steady State

Crossflow: 0.25 m/s = 49.12 FPM

"…air crossflow conditions (0.25 m/s) …, the simulated aerosol plume was not able to propagate a distance of 3 feet or more in the direction of the cough before being dispersed by the air current." (Ho, Clifford PHD: Sandia Labs 2020)

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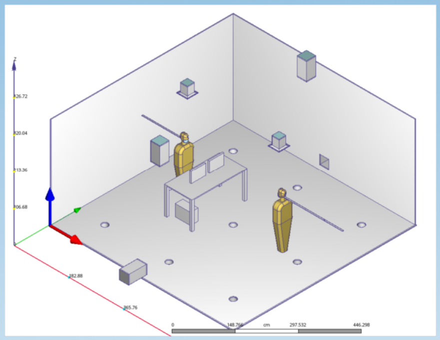
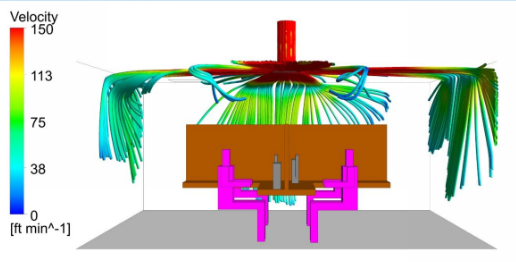
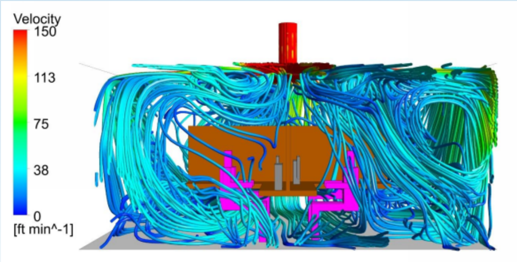
Environmental Impacts of Pathogen Travel

Space Conditions & Migration

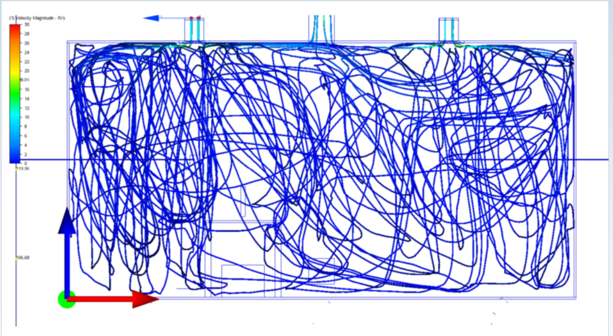
- **Supply Air Injection and Droplet Migration**
- **Mixed Air VAV System Models:**
    - Objective – To mix room air to achieve uniform temperature throughout the cubic volume of space
    - CFD suggests otherwise (furniture & occupant locations)







(Acutherm: VAV Max & Min Flow Velocities)



(GLHN Architects: CFD Model 2020)

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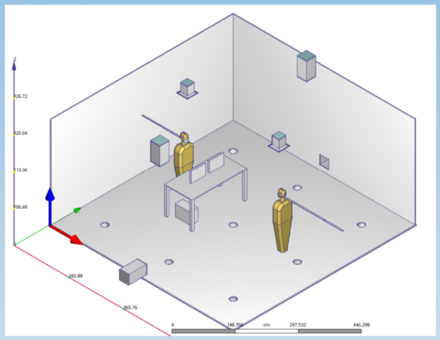
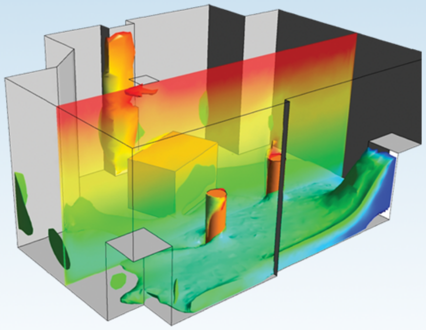
Environmental Impacts of Pathogen Travel

Space Conditions & Migration

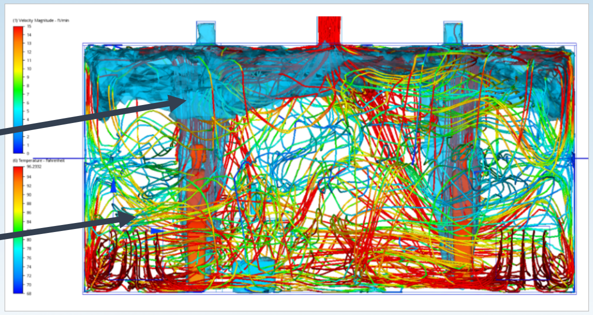
- **Supply Air Injection and Droplet Migration**
- **Displacement Ventilation Model:**
  - Objective – To mix room air to achieve uniform temperature throughout the cubic volume of space





Temperature Gradients:
(Clouds)

Velocity Vectors:
(Spaghetti)



(GLHN Architects: CFD Model 2020)

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Environmental Impacts of Pathogen Travel

Displacement Ventilation

Types of Air Distribution

Nearly all schools currently use the mixed-airflow method for distribution and dilution of the air within the occupied space. Designers should investigate a method called vertical displacement ventilation or thermal displacement ventilation. This approach successfully uses natural convection forces to reduce fan energy and carefully lift air contaminants up and away from the breathing zone.

Top of Page

Probability of Infection

The Expiratory Event

Risk of Infection:

- **Wells-Riley Equation**

$$P = 1 - e^{\frac{-Ipqt}{Q}}$$

P = *Probability of infection*

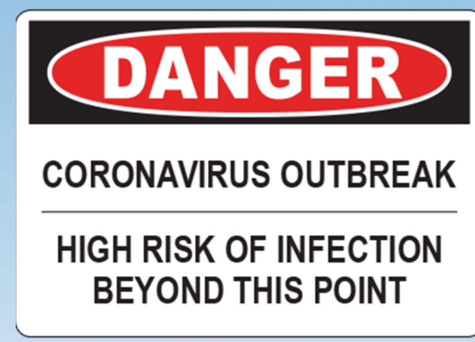
I = *Number of infector individuals in the space*

p = *Average breathing rate of individuals in the space*

q = *Quanta generation rate*

t = *Exposure time*

Q = *Air flow rate from HVAC system*



- Predictive model
- **"Provides a simple and quick assessment of the infection risk".**

(Lowry, AJ (KW Engineering))

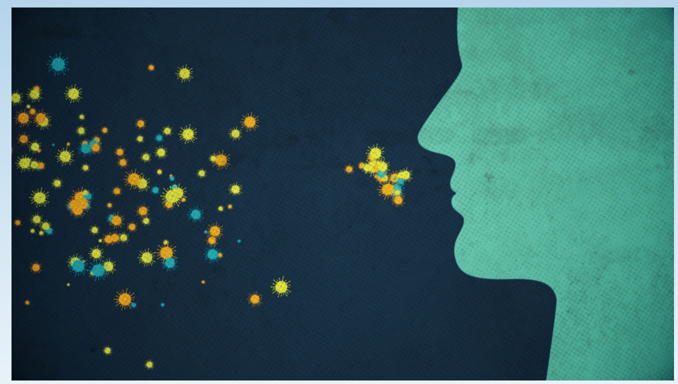
The Probability of Infection

Risk of Infection

Findings: Increase of infection in poorly ventilated spaces

Quantum: "…the dose of airborne droplet nuclei required to cause infection in 63% of susceptible persons)

(Elsevier: G. Buonanno, L. Stabile, L. Morawska; August 2020)



ELSEVIER

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The Probability of Infection

Causes of Infection:

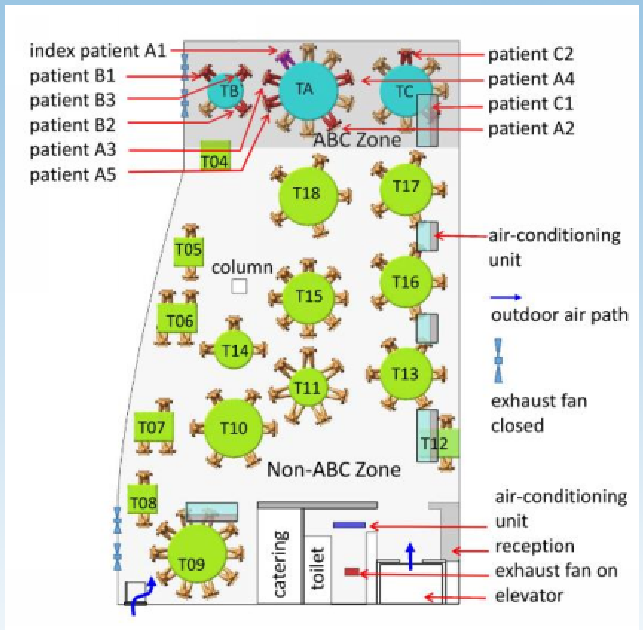
Poorly Ventilated Environments

- **Guangzhou Restaurant**
- January 24^{th}, 2020

Table TA: Family of 10 seated:

- (5) at Table were infected
- Table TB: (3) People Infected
- Table TC: (2) People Infected

Occupants at Tables TB and TC outside of social distancing guidelines



(Guangzhou Restaurant Table Layout)

The Probability of Infection

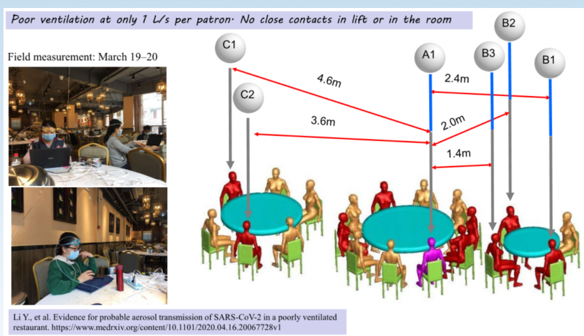
Causes of Infection:

Poorly Ventilated Environments

- **Guangzhou Restaurant**

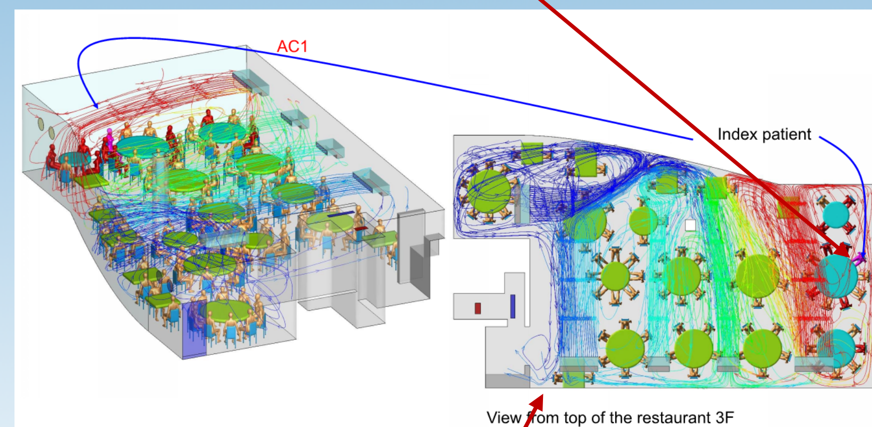
Ventilation Rate per occupants

- ~0.57 to 1.02 liters/person



(Li. Y., et al. Evidence for probable aerosol…)

Index Patient (Infected Occupant)



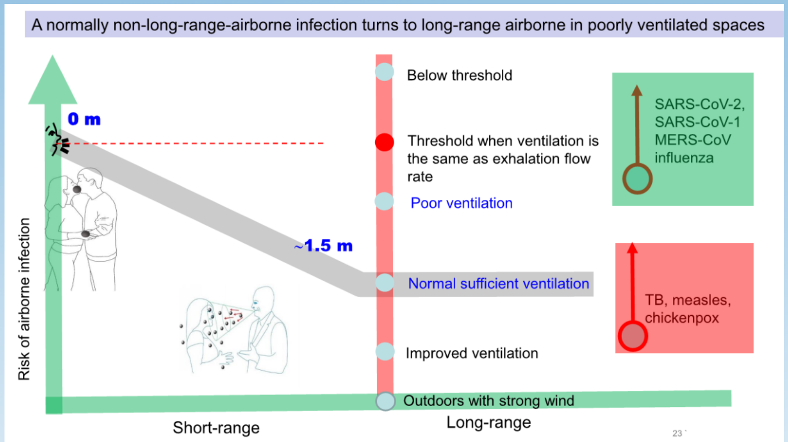
Ventilation only from open door

The Probability of Infection

Causes of Infection:

Ventilation Rate and Infection:

- “Non-long-range airborne infection turns to long-range airborne in poorly ventilated spaces”
- (Yuguo Li, SARS-CoV-2 Airborne Transmission is Opportunistic & Ventilation Works)



Dr. Li’s Ventilation Recommendations:

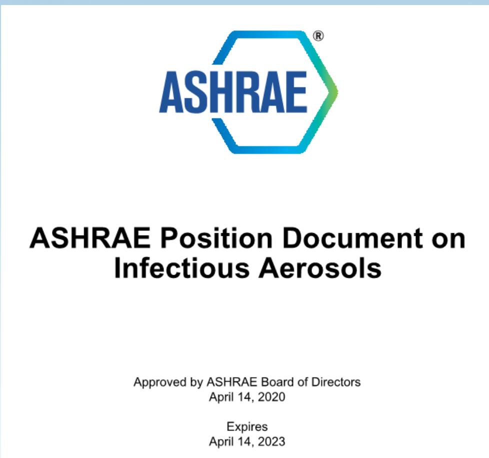
- “Ventilation less than 3.0 liters/second leads to long-range aerosol infection, but greater than 8-10 liters/sec per person (speculative) probably do not lead to long range aerosol infection
- No data exists for between 3-8 liters/sec.
- However, this does not rule out the short-range transmission of other routes.”

Prescriptive Measures & The Future

Prescriptive Measures & The Future

ASHRAE Epidemic Task Force

- **Position Document on Infectious Aerosols**



ASHRAE Position Document on Infectious Aerosols

Approved by ASHRAE Board of Directors
April 14, 2020

Expires
April 14, 2023

Par. 3.2 Ventilation and Air-Cleaning Strategies

- Air distribution patterns
- Differential room pressurization
- Personalized ventilation
- Source capture ventilation
- Filtration (central or local)
- Controlling temperature & Humidity
- Ultra-violet germicidal irradiation (UVGI)

Prescriptive Measures & The Future

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2021 Educational Webinar Schedule

▶ Wednesday, March 17 at 11:00 am PST
ASHRAE 62.1 2019

▶ Wednesday, April 14 at 11:00 am PST
Humidification - Technology and Application

▶ Wednesday, May 12 at 11:00 am PST
UV Lights - Technology and Application

▶ Wednesday, June 9 at 11:00 am PST
Needlepoint Bipolar Ionization - Technology and Application

▶ Wednesday, July 14 at 11:00 am PST
Dilution and Thermal Stratification - Displacement Ventilation

▶ Wednesday, August 11 at 11:00 am PST
Pathogen Mitigation: HVAC System Design Concepts

▶ Wednesday, September 8 at 11:00 am PST
ASHRAE 90.1 2019 and 189 2019

▶ Wednesday, October 13 at 11:00 am PST
Low-Pressure VAV Systems

▶ Wednesday, November 3 at 11:00 am PST
100% OSA Systems Part 1

▶ Wednesday, December 8 at 11:00 am PST
100% OSA Systems Part 2

▶ Wednesday, January 12, 2022 at 11 am PST
ASHRAE 170 2017

Seminar Series

- ASHRAE Standard 62.1-2019
- Ultra-Violet Germicidal Irradiation (UVGI) Technology
- Humidification
- Needle Point Bi-Polar Ionization
- Dilution and Thermal Stratification
- HVAC System Concepts
  - Reduced Pathogen Concentrations in Occupied Space
  - Premium Energy Efficiency Designs
- ASHRAE Standard 90.1 & 189-2019

Questions?

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Thank you.

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The Probability of Infection

Outdoor Infection Rates are Minimal

Dr. Yugou Li

The Probability of Infection

Increase Ventilation Rates

- **Ventilation rate to exceed expiratory rate of 0.5 liters per breath**

Mass

Gravity

The Probability of Infection

The Physics of Falling Objects

The Relation

The Physics of Falling Objects

What Is The Goal Of An HVAC System?

The Physics of Falling Objects

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Questions?

Thank you.

The Expiratory Event

Expiration, Velocity, Momentum & Distance

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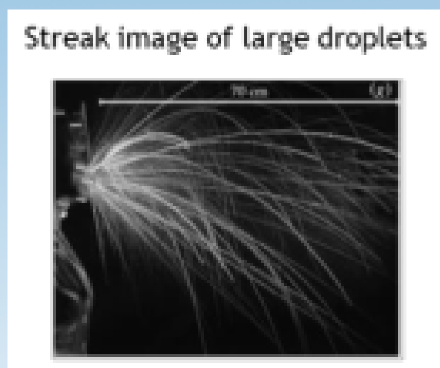


- "Initially, larger droplets can be propagated further than smaller droplets due to increased momentum…"

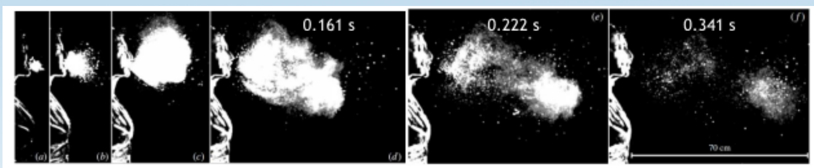


Figure 7. High-speed camera images of a sneeze illustrating salient processes of counter-rotating flow at the leading edge and bifurcation of the droplet plume (Bourouiba et al. [6]).

(Large droplet travel distance: 23-26 feet)

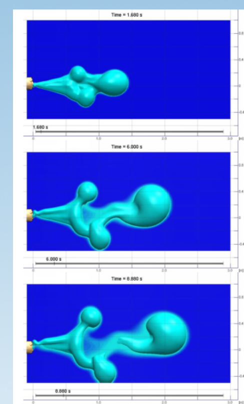
- **"…but they fall out faster due to gravity."**

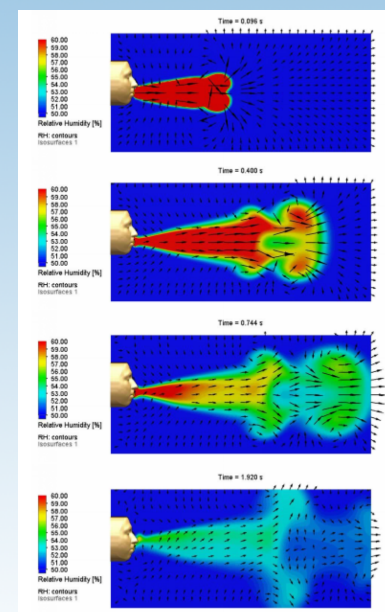
The Expiratory Event

Expiration, Velocity, Momentum & Distance

Sandia National Laboratories

- **Expiratory Event:**
  - Sneezing
  - **Coughing**
  - Talking
  - Breathing





- **Coughing:**
  - Droplet Sizes: <10 - ~20 microns
  - Pathogen Droplets: ~ 3,000
  - **Discharge Velocities: 21.5 mph**
  - Bifurcated plume

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The Expiratory Event

Expiration, Velocity, Momentum & Distance

- **Expiratory Event:**
  - Sneezing
  - Coughing
  - **Talking**
  - **Breathing**

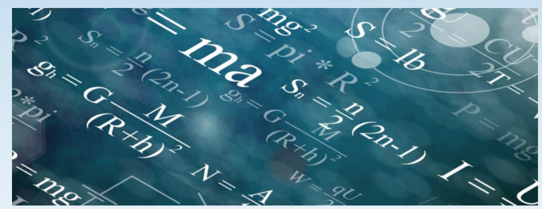
- **Talking & Breathing:**
  - Droplet Sizes: several to several tens of microns
  - **Discharge Velocities:**
    - **2.2 mph**
  - Pathogen count: 100's to 1000's particle count
  - Laminar flow discharge

- **Talking: 10 times more droplets than breathing**

The Physics of Falling Objects

Size, Mass and Gravity

High School Physics



Size of Object Affects the Rate of Falling

- Resistance from the air being displaced by the physical volume of the falling object

Mass of Objects Affects the Rate of Falling

- The more massive an object, the greater the falling force of an object

Gravity

- The attractive force between two bodies

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The Physics of Falling Objects

Mass, size and buoyancy

Mass, in **physics**, quantitative measure of inertia, a fundamental property of all matter. ... It is, in effect, the resistance that a body of matter offers to a change in its speed or position upon the application of a force. The greater the **mass** of a body, the smaller the change produced by an applied force.

Britannica

The more buoyant an object, the longer its float time

Gravity

- The attractive force between two bodies

The Physics of Falling Objects

Aerosolization & Precipitation:
Droplet Size, Buoyancy & Float Time

SARS-CoV-2 = ~0.125 microns

- Low Humidity desiccates the virus; i.e. H20 molecules are decoupled from pathogen
- Less mass the more buoyant a particle becomes