HVAC and Airborne Infectious Diseases

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HVAC AND AIRBORNE INFECTIOUS DISEASES

By William P. Bahnfleth, PhD, PE

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HVAC and Airborne Infectious Diseases

Concern regarding the risk of hospital acquired infections and the effect of the built environment on epidemics of drug-resistant diseases is increasing. The well-educated designer and owner needs to understand the mechanisms by which infectious disease is transmitted indoors, the extent to which HVAC system characteristics affect probability of infection, available means for controlling risk with demonstrated effectiveness. These topics are presented and discussed using the ASHRAE Board of Directors-approved Position Document Airborne Infectious Diseases as a framework. Pertinent scientific knowledge about modes of disease transmission is reviewed, its practical implications for control are discussed, and the three HVAC-related control methods identified by the Position Document: ventilation, particulate filtration, and ultraviolet germicidal irradiation, are presented and compared. General recommendations for reducing risk are provided and knowledge gaps that need to be filled are identified.

Learning Objectives

- Explain the purpose and scope of the ASHRAE Position Document on Airborne Infectious Diseases
- Define the three most important modes of infection transmission
- Describe the three HVAC-based technologies demonstrated to reduce risk of airborne infections
- Distinguish between administrative, environmental, and personal approaches to infection control

Outline

- ASHRAE Position Documents
- Airborne Infectious Diseases Position Document
  - Issue
  - Background
  - Practical Implications
  - Recommendations
- Summary

ASHRAE Position Documents

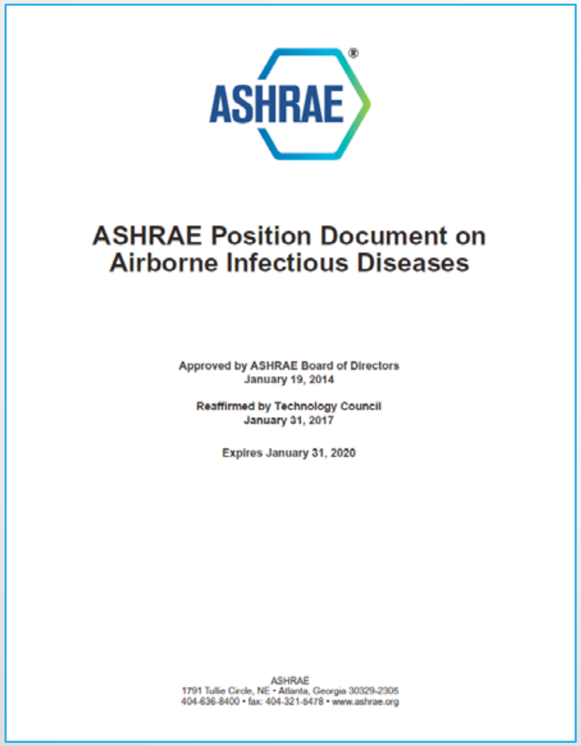
- Views of the Society on topic pertaining to public policy
- Approvals – Board of Directors, Technology Council, cognizant commitee
- Content – Summary, Supporting Documentation, Analysis and Recommendations
- Drafted by balanced committees of subject matter experts
- Expire after 30 months unless reaffirmed or revised
- Posted to ASHRAE web site https://www.ashrae.org/about-ashrae/position-documents

ASHRAE Position Documents

(Currently approved – others under revision)

- *Airborne Infectious Diseases*
- Ammonia as a Refrigerant
- Combustion of Solid Fuels and Indoor Air Quality in Primarily Developing Countries
- *Environmental Tobacco Smoke*
- *Filtration and Air Cleaning*
- *Indoor Air Quality*
- *Limiting Indoor Mold and Dampness in Buildings*
- Refrigerants and their Responsible Use
- *Unvented Combustion Devices and IAQ*

Airborne Infectious Diseases


ASHRAE Position Document on Airborne Infectious Diseases

Approved by ASHRAE Board of Directors
January 19, 2014

Reaffirmed by Technology Council
January 31, 2017

Expires January 31, 2020

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- Cognizant committee
  - Environmental Health
  - Pawel Wargocki, Ex Officio

First approval 2009, reaffirmed 2017

Issue

- Diseases may be transmitted from person to person by air as infectious aerosols – particles or droplets
- HVAC systems impact transport of and exposure to infectious aerosols
  - Increased risk – efficiently distribute air that may contain infectious microorganisms throughout a building
  - Decreased risk – ventilation, filtration, and air treatment my remove infectious material
- Owners, operators, designers need to understand practical implications scientific understanding of disease transmission

Background: Transmission Modes

- Multiple modes of transmission
  - Aerosol
    - Small particles - this document
    - Large droplets – not in scope
  - Direct physical contact – not in scope
  - Fomite (intermediate surface) – not in scope

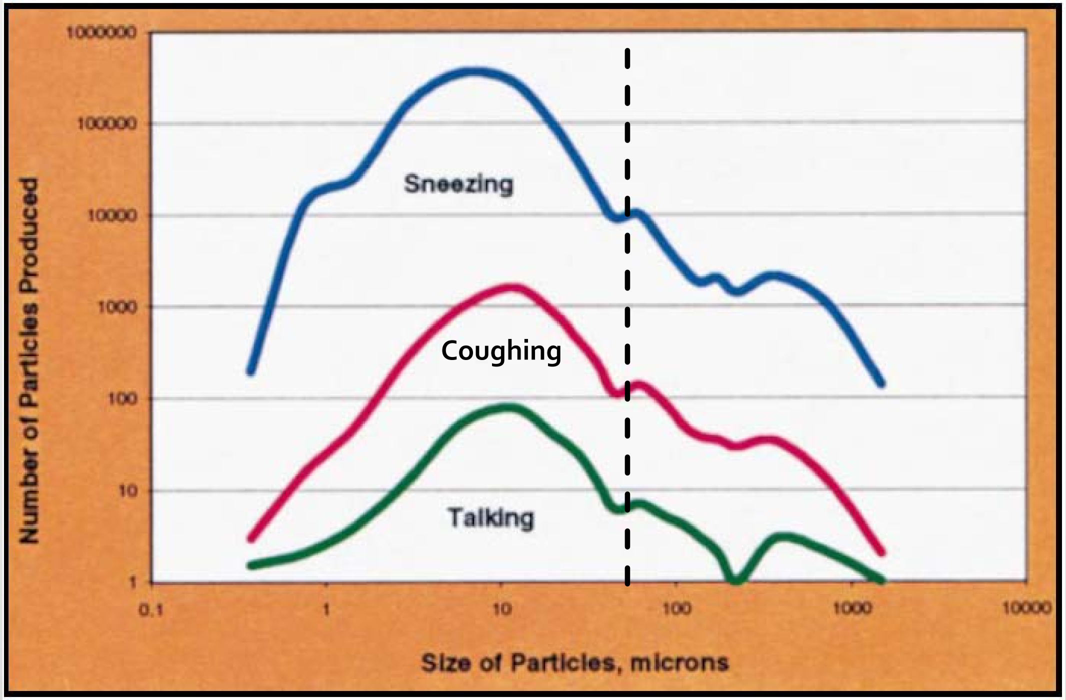
Background:
Droplets vs. Small Particles

- Droplets
  - Larger – settle rapidly, little affected by normal air movement
  - Smaller-evaporate to droplet nuclei (residues), remain airborne
  - Differing opinions about definitions of "small"
    - Final2.5 – 10 μm aerodynamic diameter (Duguid 1946, others)
    - Initial ≤ 60 μm, mass mean diameter < 10 μm (Tang, et al. 2006)
    - Evidence of suspension of 30 μm and larger (Cole and Cook 1998)
    - Large droplets initially 60 – 100 μm (Xie, et al. 2006)

Background: Droplet Generation

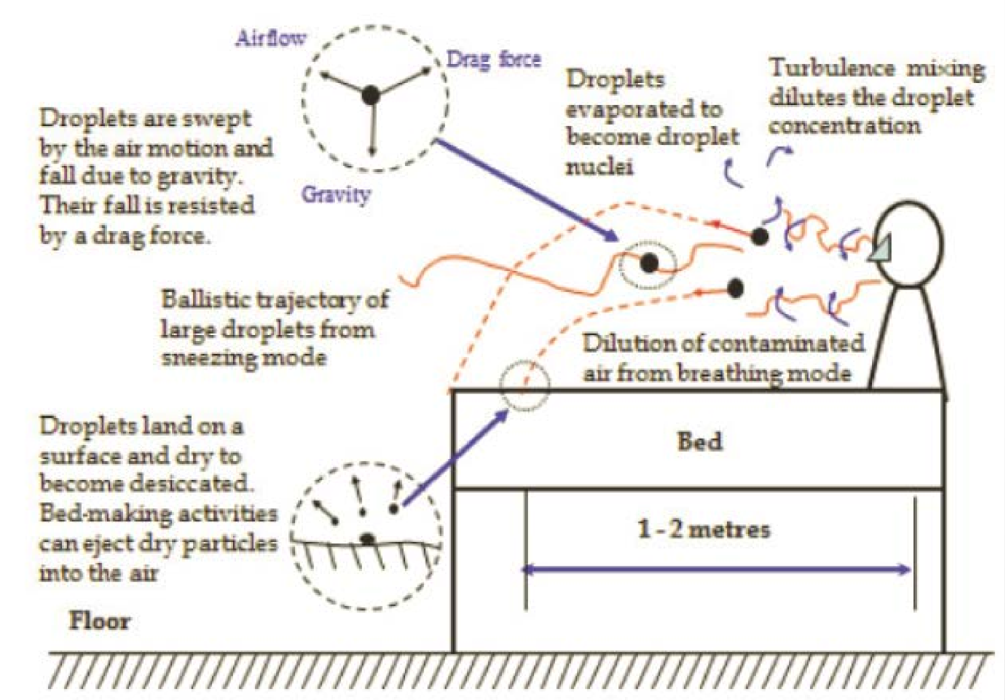
Credit: Prof. Andrew Davdhazy (ret.), RIT

Background: Droplet Generation

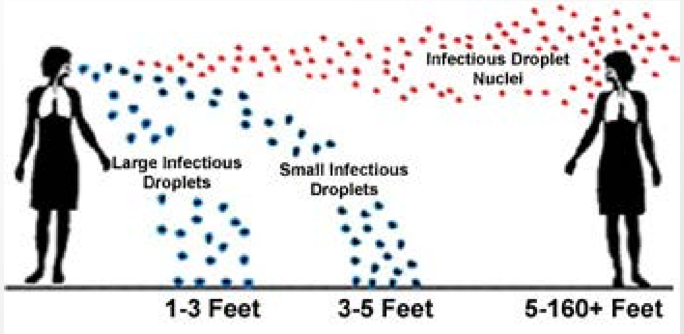


Human droplet production (Kowalski and Bahnfleth 1998) based on data in Duguid, et al. 1945

Background: Droplet Suspension



Airborne Infectious Diseases PD, figure 1



1 m ≈ 3 ft

Background – Modeling Risk

- Wells-Riley equation

$$C = S\left[1 - \exp\left(-Iqpt / Q\right)\right]$$

  - C = new infections
  - S = number of susceptibles
  - I = number of infectors
  - q = number of infectious doses
  - p = pulmonary ventilation rate per susceptible
  - t = exposure time
  - Q = flow rate of uncontaminated air
- Qualitatively, ventilation reduces risk, filters and air cleaner performance can be expressed as equivalent ventilation rate

Background: Significance of Airborne Route

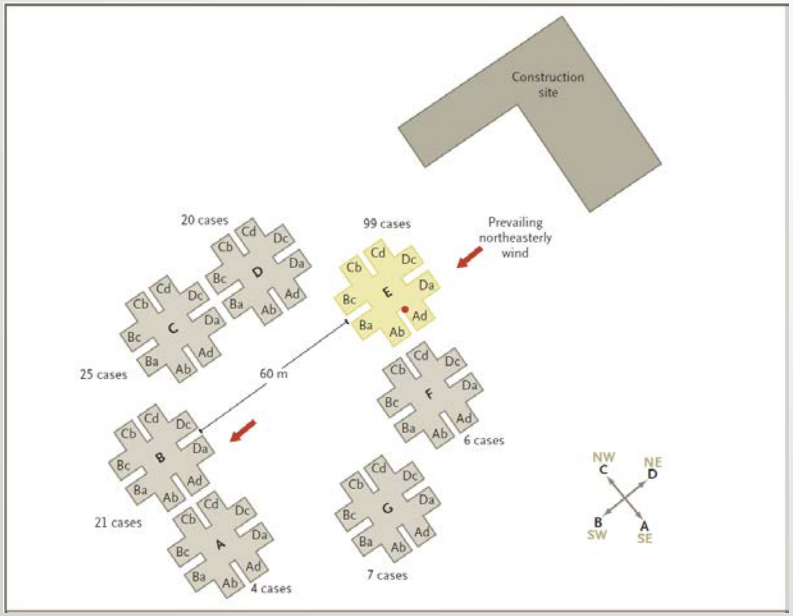
- Classification (Roy and Milton, 2004)
  - Obligate – only aerosol (tuberculosis)
  - Preferential – mainly aerosol (measles, chicken pox)
  - Opportunistic – one of multiple options (colds, influenza)

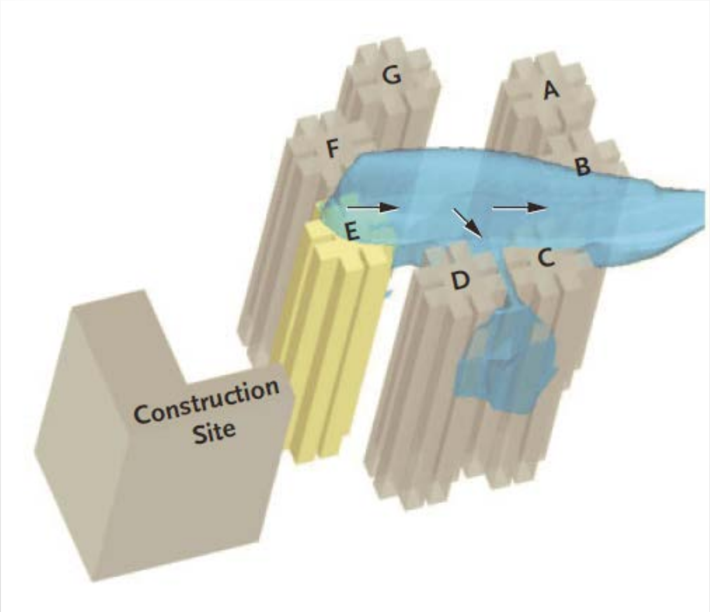
Background: Significance of Airborne Route

- Status uncertain for many diseases, but evidence of airborne transmission in multiple studies
  - Hospital influenza outbreak controlled by UVGI (McLean 1961)
  - Influenza transmission on aircraft (Moser, et al. 1979)
  - SARS transmission in Hong Kong apartments (Yum et al. 2004)
  - Incidence of colds vs. ventilation in Chinese dormitory (Sun, et al. 2011)

Background:
Amoy Gardens SARS Outbreak

Transmission via drain piping and wind





Yu, et al. 2004

Background:
Cold Incidence and Ventilation Rate

- Sun, et al.,2011
- Compared incidence of colds among dormitory residents with ventilation rate in winter

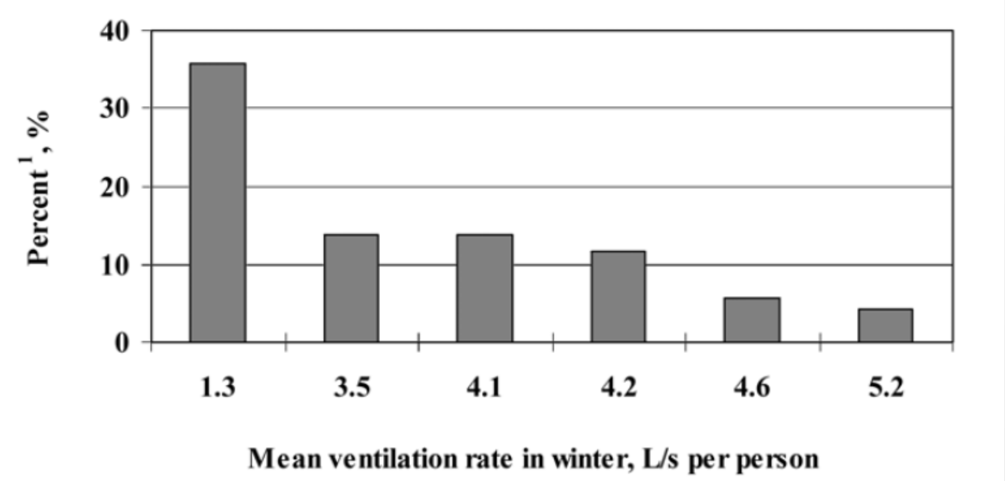


Figure 4. Associations between common cold infection rates and mean ventilation rate in winter in buildings constructed after year 1993. [1] Proportion of occupants with ≥6 common colds in the previous 12 months.

Practical Implications: General

- Practical limits to what HVAC – focused measures can accomplish
  - Need to consider multiple approaches
  - Collaborate to develop best overall strategies
    - Owners
    - Operators
    - Engineers
    - Infection control specialists

Practical Implications: Specific to Facility Type

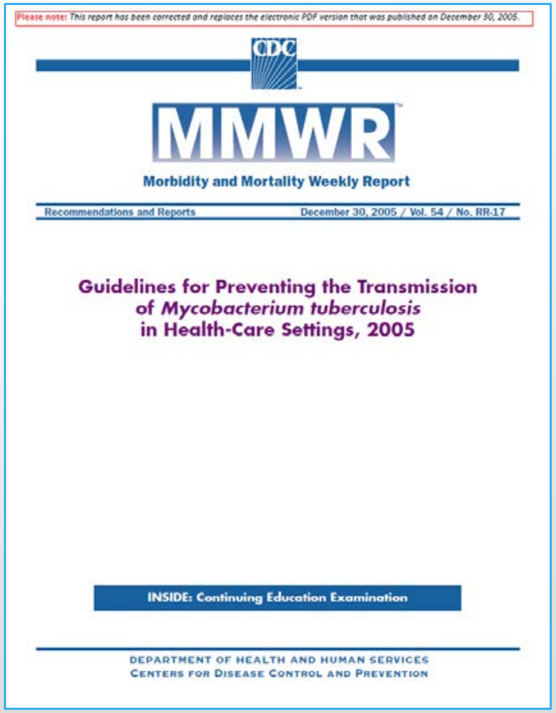
- Most infections transmitted in non-health care facilities
- Follow applicable standards and beyond-code guidance
- “Infection control bundles” for health care facilities
  - Administrative controls (rules and procedures)
  - Environmental controls (e.g., HVAC)
  - Personal protective equipment
- Proper installation, commissioning and maintenance!

Practical Implications: Guidance Documents

- Ventilation
  - ASHRAE Standards 62.1 and 62.2 for non-health care
  - ASHRAE Standard 170 for health care facilities
  - National Institutes of health guidelines for laboratories
- Beyond-code
  - CDC TB control guidelines
  - Facilities Guideline Institute criteria
  - ASHRAE IAQ Guide

US Centers for Disease Control Tuberculosis Guidelines

- Infection control program
- Risk assessment
- Training and education
- Environmental controls
- Respiratory protection
- Free download
  http://www.cdc.gov/mmwr/pdf/rr/rr5417.pdf


Please note: *This report has been corrected and replaces the electronic PDF version that was published on December 30, 2005.*

CDC

MMWR

Morbidity and Mortality Weekly Report

Recommendations and Reports December 30, 2005 / Vol. 54 / No. RR-17

Guidelines for Preventing the Transmission of *Mycobacterium tuberculosis* in Health-Care Settings, 2005

INSIDE: Continuing Education Examination

DEPARTMENT OF HEALTH AND HUMAN SERVICES
CENTERS FOR DISEASE CONTROL AND PREVENTION

ASHRAE Indoor Air Quality Guide –

Best Practices for Design, Construction, and Commissioning

- Eight objectives with detailed guidance
    1. Manage the design and construction process to achieve good IAQ
    2. Control moisture in building assemblies
    3. Limit entry of outdoor contaminants
    4. Control moisture and contaminants related to mechanical systems
    5. Limit contaminants from indoor sources
    6. Capture and exhaust contaminants from building equipment and activities
    7. Reduce contaminant concentrations through ventilation, filtration, and air-cleaning
    8. Apply more advanced ventilation approaches

Free download:
http://iaq.ashrae.org

Practical Implications: Ventilation and Air Cleaning

- Reduce exposure and, therefore, risk by reducing aerosol load of air
- Approaches
  - Supply clean air to susceptible occupants
  - Contain and exhaust contaminated air to outdoors
  - Dilute indoor air with cleaner outdoor or filtered air
  - Clean air in the space

Ventilation and Air-Cleaning Strategies

- Means shown to be effective
  - Ventilation (including pressurization)
  - Particulate filtration
  - Inactivation by ultraviolet germicidal irradiation (UVGI)
- Evidence in literature
  - Reduced aerosol loads/inactivation – Yes
  - Controlled interventions demonstrating clinical effectiveness – No
  - Some field studies indicating effectiveness

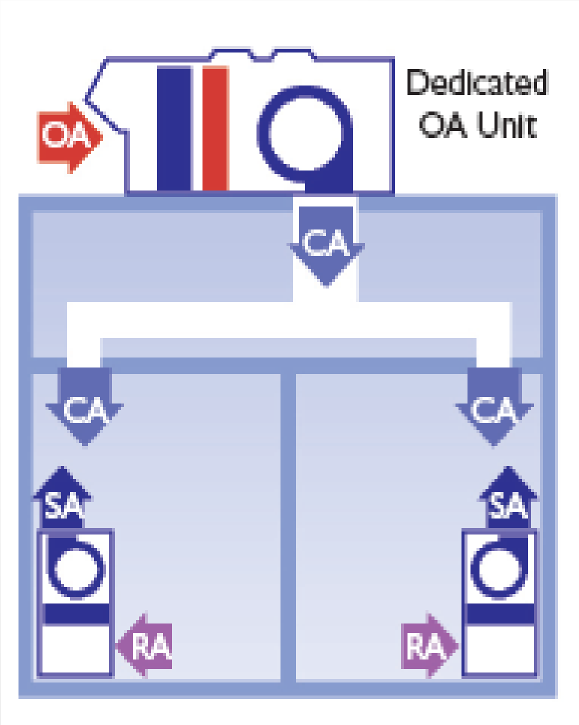
Ventilation and Pressurization

- Ventilation
  - Addresses all airborne contaminants
- Effective if
  - Outdoor air is low in contaminants or can be filtered to acceptable levels
  - Contaminants of concern are airborne and can be captured by ventilation
  - Cost of conditioning ventilation air is not prohibitive

- Pressurization
  - Addresses all airborne contaminants
- Effective if
  - Areas of concern can be isolated
  - Zones are reasonably airtight
  - HVAC design provides stable control

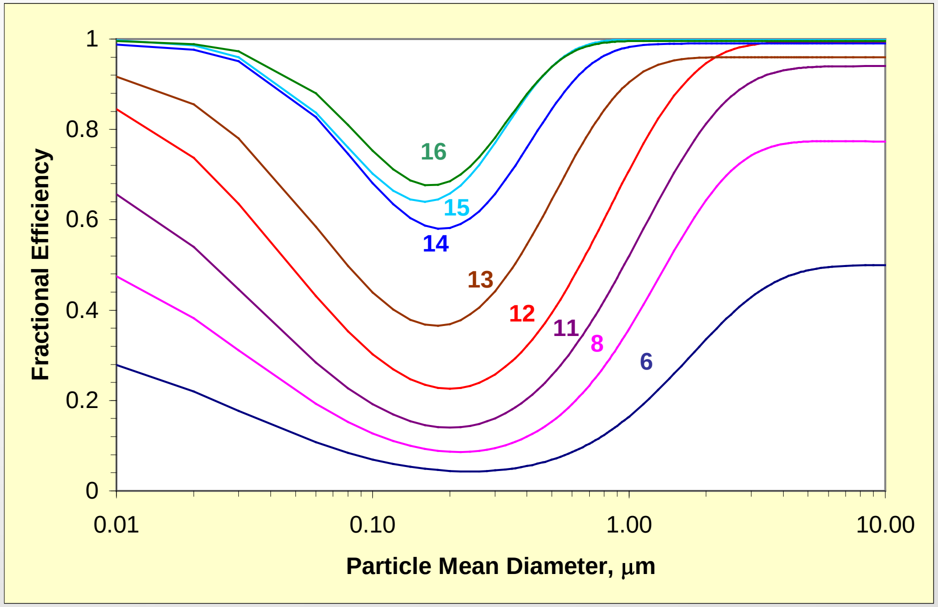
Ventilation and Pressurization

- System considerations
  - Dual path (dedicated outside air) systems can eliminate recirculation but preclude centralized filtration
  - Limiting area served by a single recirculating system helps to reduce risk of distributing contaminants
  - Variable air volume systems need attention to ensure desired ventilation is delivered consistently and that pressurization is maintained



Filtration

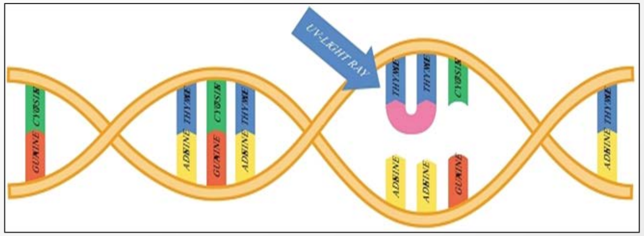
- Can remove any aerosol contaminant
- For indoor sources, requires recirculation in space or system
- Effective if
  - Contaminants of concern are airborne
  - Clean air delivery (efficiency + recirculation) is high enough

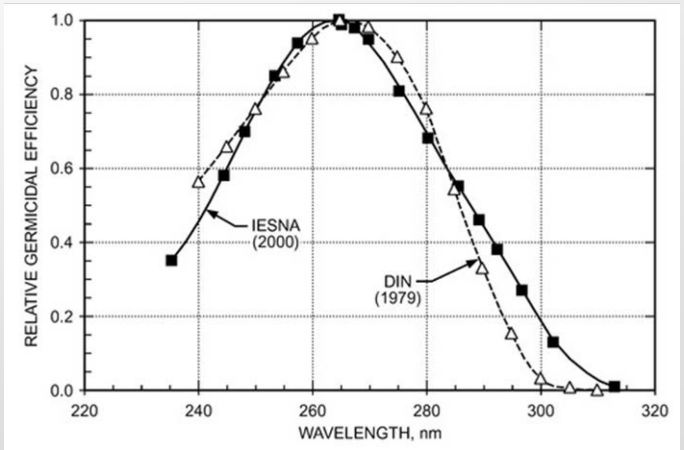


Representative MERV rated filter performance (Kowalski and Bahnfleth 2002)

Ultraviolet Germicidal Irradiation

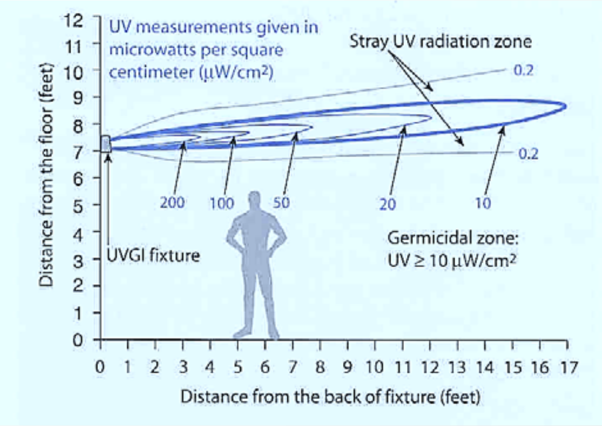
- Ultraviolet light in UVC band
- 265 nm ideal, 254 nm produced by low pressure Hg vapor lamps
- Disrupts microbial DNA/RNA, prevents reproduction
- Treats air in-room, in air-handling units, disinfects surfaces
- Effective if contaminant is airborne, viable, susceptible





Ultraviolet Germicidal Irradiation

Upper Air UVGI



In-Duct/Coil UVGI

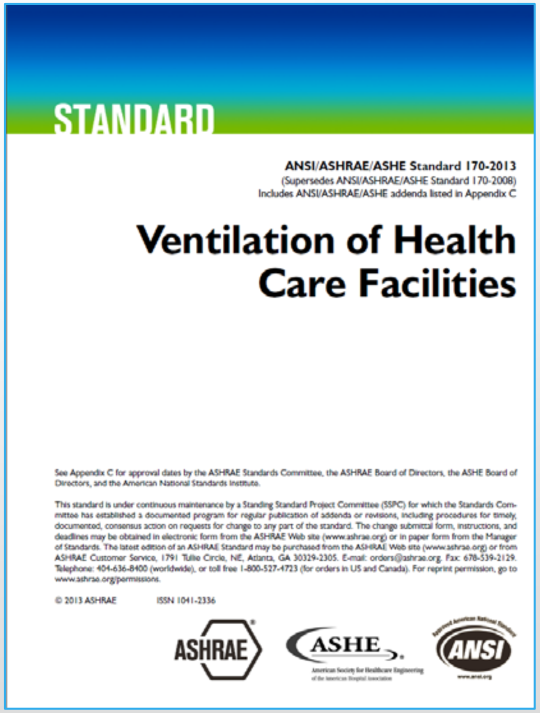
Portable Surface Treatment UVGI

Comparison

- All three approaches have strengths, some complementary
- All have limitations
- Some combinations are mutually exclusive, e.g. centralized filtration in once-through systems
- Best solution economically and in terms of performance may be a combination of the three

ASHRAE Standard 170
Ventilation of Health Care Facilities

- Planning
- Systems and Equipment
- Space Ventilation
- Construction and Start-up



ASHRAE Standard 170 Key Requirements

- Systems and Equipment
  - Protect outdoor air intakes Filtration from MERV 7 – HEPA
  - Cleanable air distribution devices
  - Requirements for cooling coils, cooling towers, humidifiers to prevent contamination
- Space Ventilation
  - Air moves clean → less clean
  - Limits on use of recirculation
  - Minimum air change requirements
  - Unidirectional flow and positive pressurization for operation rooms

Practical Implications: Temperature and Humidity

- Most published studies suggest that relative humidity control can reduce transmission
- Review of literature by Memarzadeh (2011) and Yang and Marr (2012) suggest possible mechanisms
  - Higher RH → slower droplet evaporation, more settling
  - Lower RH → desiccation of mucosa by dry air increases susceptibility
  - RH affects virulence of microorganism

Evaporation and Settling Time

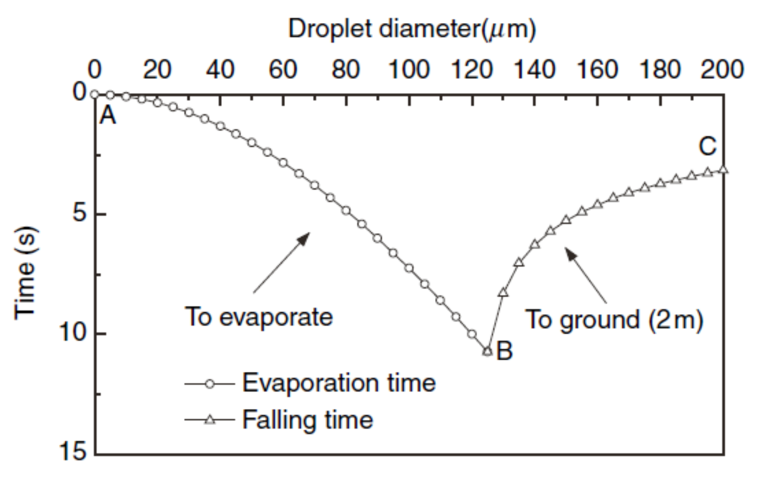


Fig. 5 Evaporation time and falling time of droplets of varying diameter ($T_{p0} = 33$ °C, $T_{\infty} = 18$ °C, RH = 0%)

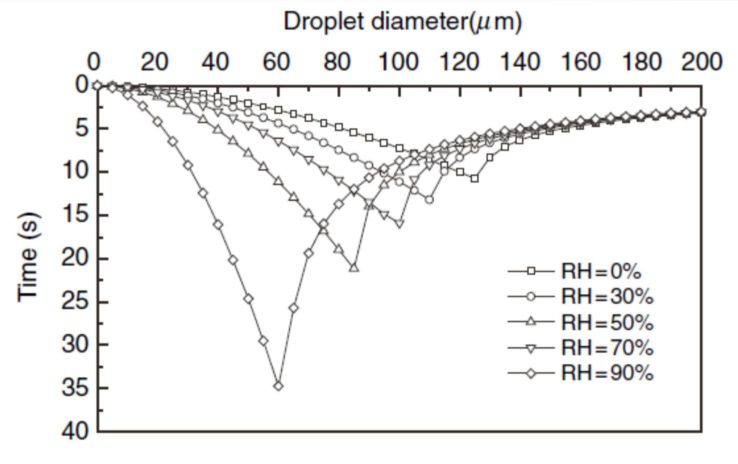


Fig. 6 Evaporation time and falling time of droplets of varying diameter under different atmospheric conditions ($T_{p0} = 33$ °C, $T_{\infty} = 18$ °C)

Xie, et al. 2007

Practical Implications: Temperature and Humidity

- Although isolated effect of higher RH may reduce disease transmission, higher RH
  - May reduce effectiveness of UVGI
  - May adversely affect comfort
  - Increases likelihood of condensation and related mold problems
- Current state of knowledge unsettled
- Based on lack of clear evidence, no position taken by ASHRAE

Practical Implications: Non-HVAC Strategies

- May be more effective than HVAC interventions
- Examples
  - Education and policy, e.g., encourage employees to stay home when sick
  - Administrative measures, e.g., take steps to identify individuals with influenza symptoms
  - Respiratory hygiene, i.e., best ways to cough, sneeze, dispose of contaminated tissues, etc.
  - Vaccination

Practical Implications: Emergency Planning

- Design, maintain, and operate buildings for effective performance during emergencies
- Examples
  - Ability to increase dilution ventilation
  - Ability to increase RH
  - UVGI in key areas – emergency room, waiting area, shelter, jail
- Understand building vulnerabilities and assets
  - Outside air intakes
  - Shelter in place locations
  - Control strategies

Recommendations

- Follow latest standards related to disease transmission
- Good commissioning, maintenance, operation
- HVAC systems with supplemental filtration, UVGI, possibly ventilation
- Incorporate ability to respond to pandemics in new healthcare facilities

Recommendations

- Bundle interventions for best effect
- Use multidisciplinary teams to find and implement best program
- Standard and guideline writes should consider
  - Enhanced particle filtration for central air-handlers
  - Upper room and other UVGI – or readiness to deploy rapidly
  - Ability to rapidly increase outside air flow rate
  - Avoiding energy saving measures that increase risk of disease transmission, e.g., demand controlled ventilation

Recommendations

- Research needs
  - Input on study design, methodology, execution from application focused experts (engineers, infection control, public health)
  - Controlled intervention studies needed to determine performance and cost-effectiveness
  - Quantify removal/inactivation rates of filtration, UVGI and validate effectiveness in real facilities
  - Better characterize particle size distributions from coughing

Recommendations: Application & Research Priorities

Strategy	Application Priority	Research Priority
Dilution ventilation	High	Medium
Temperature and humidity	Medium	High
Personalized ventilation	Medium	High
Local exhaust	Medium	Medium
Central system filtration	High	High
Local air filtration	Medium	High
Upper-room UVGI	High	Highest
Duct and air-handler UVGI	Medium	Highest
In-room flow regimes	High	High
Differential pressurization	High	High

Summary

- As an ASHRAE position document, *Airborne Infectious Diseases* supports advocacy efforts – policy development, allocation of research budgets
- Also provides peer-reviewed positions of broad value
  - What we know about airborne transmission and its relative importance
  - Factors affecting airborne transmission
  - Consequences for design, operation, and maintenance of HVAC systems
  - Identifies research priorities
- Good list of key current references
- Living document, periodically updated

References

- All citations in this presentation are taken from the references in the Airborne Infectious Diseases Position Document.

Questions?