Tuberculosis Infection Control

A PRACTICAL MANUAL FOR PREVENTING TB 2024 | 2ND EDITION

UCSF
University of California
San Francisco

CURRY
INTERNATIONAL
TUBERCULOSIS
CENTER

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Design: Edi Berton Design

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Acknowledgements

The following individuals are gratefully acknowledged for their invaluable participation and guidance on this project:

2nd Edition Contributors

Heidi Behm, RN, MPH
TB Controller/Nurse Consultant
Tuberculosis Program
Oregon Health Authority
Portland, Oregon

Robert Belknap, MD
Director, Denver Metro TB Program
Denver Health and Hospital Authority
Associate Professor, Division of Infectious Diseases, University of Colorado
Denver, Colorado

Gary Blackwelder, BArch (retired)
Architect
Division of Global HIV & TB
Centers for Disease Control and Prevention
Atlanta, Georgia

Karen Brudney, MD
Former Senior Expert Adviser on Tuberculosis to the CDC (2013-2019)
New York, New York

Kevin Fennelly, MD, MPH, ATSF
Senior Research Clinician
Pulmonary Branch
Division of Intramural Research
National Heart, Lung, and Blood Institute (NHLBI)
National Institutes of Health (NIH)
Bethesda, Maryland

Disclaimer: These are my views and recommendations alone, and do not represent official policy or recommendations from the NIH or other organizations.

Lauren Lambert, MPH
Epidemiologist
Surveillance, Epidemiology, and Outbreak Investigations Branch
Surveillance Team,
Division of Tuberculosis Elimination
Centers for Disease Control and Prevention
Atlanta, Georgia

Stephen Martin, Jr., PhD, PE
CAPT, U.S. Public Health Service
Senior Research Engineer
Field Studies Branch
Respiratory Health Division
National Institute for Occupational Safety and Health
Centers for Disease Control and Prevention
Morgantown, West Virginia

Isabel Milagros Ochoa Delgado, MPH
Architect, Urban Planner
Head, Infrastructure and Equipment Unit of the Health Services Management Institute (MINSA)
Peru

Michelle Pearson, MD (retired)
Medical Epidemiologist
Division of Global HIV & TB
Centers for Disease Control and Prevention
Atlanta, Georgia

Carrie Tudor, PhD, MPH, RN
Deputy Project Director, SMART4TB
Research Associate
Johns Hopkins University School of Nursing
Baltimore, Maryland

Richard Vincent, MSc, BSArch
Manager
Department of Medicine
Division of General Internal Medicine
Icahn School of Medicine at Mount Sinai
New York, New York

Editors

Paul Arthur Jensen, PhD, PE, CIH
Environmental/Mechanical Engineer
Cofounder and Independent Consultant
Final Approach Inc
Centers for Disease Control and Prevention (retired)
Port Orange, Florida

Dr. Jensen's 43-year career with the U.S. government included 33 years with the Centers for Disease Control and Prevention (CDC), where he served as the lead for Airborne Infection Prevention Control and Laboratory Biosafety. Dr. Jensen chaired the CDC working group that developed *CDC Guidelines for Preventing the Transmission of Mycobacterium tuberculosis in Health-Care Facilities* (2005) and was a member of the group that developed the *WHO Guidelines on Tuberculosis Infection Prevention and Control, 2019 Update*. Dr. Jensen serves as the Secretariat of the End TB Transmission Initiative of the Stop TB Partnership and is a subject matter expert for IES, IEC, ASHRAE, and AIHA guidance committees.

Lisa Chen, MD
Principal Investigator/Medical Director
Curry International Tuberculosis Center
Professor, Division of Pulmonary and Critical Care Medicine
University of California, San Francisco
San Francisco, California

Project Manager

Kelly Musoke, MPH
Deputy Director
Curry International Tuberculosis Center
University of California, San Francisco
San Francisco, California

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Kay Wallis, MPH*, and* **Amelia Alonis**
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Graphic Design

Edi Berton Design

Peer Reviewers

Lana Kay Dov, RN, MSN
Tuberculosis Nurse Consultant
Office of Communicable Disease Epidemiology
Division of Disease Control & Health Statistics
Washington State Department of Health
Shoreline, Washington

Susannah Graves, MD, MPH
Director, Tuberculosis Prevention and Control
San Francisco Department of Public Health
San Francisco, California

Irina Grigorov, RN, BSN
Clinical Nursing Supervisor
Multnomah County Health Department
Portland, Oregon

Julie Higashi, MD, PhD
Director
Tuberculosis Control Program
Los Angeles County Department of Public Health
Los Angeles, California

Abir "Abby" Hussein, MD, MPH
Associate Medical Director, Infection Prevention and Control
Clinical Assistant Professor,
Division of Allergy and Infectious Disease
University of Washington Medical Center
Seattle, Washington

Stephen B. Martin, Jr., PhD, PE
CAPT, U.S. Public Health Service
Senior Research Engineer
Field Studies Branch
Respiratory Health Division
National Institute for Occupational Safety and Health
Centers for Disease Control and Prevention
Morgantown, West Virginia

Kenneth Mead, PhD, PE
Chief
Engineering and Physical Hazards Branch
Division of Field Studies and Engineering
National Institute for Occupational Safety and Health
Centers for Disease Control and Prevention
Cincinnati, Ohio

Edward Nardell, MD
Professor of Medicine
Brigham and Women's Hospital
Division of Global Health Equity
Harvard School of Public Health
Department of Environmental Health; and
Department of Immunology and Infectious Diseases
Boston, Massachusetts

Masahiro Narita, MD
TB Control Officer
Public Health — Seattle & King County
Professor, Division of Pulmonary, Critical Care, and Sleep Medicine
University of Washington
Seattle, Washington

Cynthia Nancy O'Connor, MBA, BSN, RN, CIC
System Director of Infection Prevention and Employee Health
Cayuga Health System
Ithaca, New York

Nicholas Pavelchak
Chief-Industrial Hygiene and Intervention Services (retired)
NYS Department of Health
Albany, New York

Shameer Poonja, MPH
Public Health Advisor/Project Officer
Field Services Branch
Division of Tuberculosis Elimination
Centers for Disease Control and Prevention
Atlanta, Georgia

Trista Reglein, RN, BSN, CIC
Director of Outpatient Clinic
Infection Control Nurse
Texas Center for Infectious Disease
San Antonio, Texas

Grigory Volchenkov, MD
Vladimir Regional TB Control Center
End TB Transmission Initiative (ETTi)
Vladimir, Russia

Kristen Wendorf, MD, MS
Public Health Medical Officer
Tuberculosis Control Branch
California Department of Public Health
Richmond, California

Christine Wu, MD, MPH
Deputy Health Officer
Chief, Communicable Diseases Bureau
Solano County Public Health & Medical Services
Fairfield, California

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Introduction

Tuberculosis Infection Control: A Practical Manual for Preventing TB, 2nd edition (2024) is a publication of the Curry International Tuberculosis Center (CITC). This manual is a practical guide to infection prevention and control (IPC) principles and serves as a technical bridge between clinical and administrative staff and engineering consultants working to reduce the risk of tuberculosis (TB) transmission in health and community care settings.

This second edition is comprised of six chapters:

1. **Administrative Controls**
2. **Environmental Controls: Part 1 – Ventilation; Part 2 – UVC**
3. **Personal Protective Equipment**
4. **Airborne Infection Isolation Rooms**
5. **Clinics**
6. **Homeless Shelters**

The contents feature more detailed explanations to help non-engineers understand some of the technical requirements, alongside practical guidance and examples relevant to TB IPC. The 2024 update organizes the material into new, dedicated chapters reflecting the IPC hierarchy of interventions: administrative controls, environmental controls, and personal protective equipment. This material includes expanded information on ventilation principles and interventions, with a new section dedicated to use of ultraviolet-C (UVC) germicidal irradiation. The practical, site-specific content included in the first edition of this manual that addresses the specific needs of clinics and homeless shelters has been updated and retained.

A group of 13 contributors and 16 reviewers representing experts from public health, academia, governmental agencies, and the field of industrial engineering provided content, guidance, and peer review commentary to the 2024 release.

The first edition of the manual, released by CITC in 2007, was a compilation of five separate CITC products that focused on TB infection prevention and control concerns specific to the following settings: clinics, sputum induction areas, isolation rooms, emergency departments, and homeless shelters.

Tuberculosis Infection Control: A Practical Manual for Preventing TB is designed for:

- TB/IPC program managers in public health departments
- Directors and facility managers in community and public health clinics and homeless shelters
- Public health and community healthcare providers
- Architects, engineers, and others who design healthcare facilities or shelters
- Others who work in or may provide services to healthcare facilities or shelters

This manual complements introductory materials currently available from the Centers for Disease Control and Prevention (CDC), such as the *Core Curriculum on Tuberculosis, Chapter 6: Tuberculosis Infection Control.*

About TB

Tuberculosis is transmitted from person to person through the air, primarily from an individual who has active TB disease in the lungs, larynx, or respiratory tract. When a person sick with TB disease coughs, sneezes, speaks, or breathes, the TB germs (also referred to as microbes, bacilli, or organisms) can become airborne within tiny droplets (droplet nuclei*). Airborne TB can then be inhaled and infect others. When first learning about TB and its transmission, it is important to recognize the difference between two TB-related conditions: inactive (or "latent") TB infection and active TB disease.

- Inactive, or latent TB infection (LTBI), is a condition that occurs when a person has been infected with TB germs, but the germs have not multiplied enough to cause an illness. The person's immune system keeps the infection in check, and the individual does not feel sick or have symptoms. Most importantly, **a person with LTBI cannot spread TB to others.**
- Active TB disease occurs when the TB germs grow and multiply enough to cause illness in a person, with symptoms related to the parts of the body involved (most often the lungs). **Persons with TB disease can transmit the germs to others.**

Appropriate treatment can cure active TB disease and prevent persons with LTBI from potentially progressing to illness.

Where to learn more about TB

This manual focuses on methods to reduce the risk of TB transmission in healthcare and community care settings and does not include more basic information about TB disease and LTBI. Readers can learn more about TB online at the CDC's "tuberculosis" website portal.

The CDC materials are organized by target audience:

- **For the general public:** Basic overview of TB, signs and symptoms, risk factors, transmission, prevention, testing, and treatment. Includes fact sheets and other educational resources.
- **For healthcare providers:** Clinical overviews and information on LTBI, TB disease, drug-resistant TB, TB testing and diagnosis, guidelines, and links to TB 101, self-study, and core curriculum materials.
- **For public health professionals:** Information on TB case reporting, CDC announcements and guidelines, TB laboratory testing and toolkits, and TB programs.

*Airborne particles 1-5 µm in size that contain TB bacteria and can be suspended for several hours in the air; also referred to as "airborne infectious particles" within this manual.

A few key organizations

Various organizations and agencies define, study, and/or regulate infection control principles and engineering standards. Among the entities mentioned in this manual are the following organizations:

American National Standards Institute (ANSI), a private nonprofit organization that oversees the development of voluntary consensus standards for products, services, processes, systems, and personnel in the U.S.

American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc. (ASHRAE), a professional association seeking to advance heating, ventilation, air conditioning and refrigeration systems design and construction.

Association of Home Appliance Manufacturers (AHAM), a leadership and advocacy group for the home appliance industry, informing public policy, standards, and business decisions.

Centers for Disease Control and Prevention (CDC), the U.S. federal public health agency, located within the U.S. Department of Health and Human Services, and dedicated to the protection of public health and safety through the control and prevention of disease, injury, and disability in the U.S. and worldwide.

Facility Guidelines Institute (FGI), an independent, not-for-profit organization dedicated to developing guidance for the planning, design, and construction of hospitals, outpatient facilities, and residential health, care, and support facilities.

National Institute for Occupational Safety and Health (NIOSH), the U.S. federal institute, located within CDC, responsible for conducting research and making recommendations for the prevention of work-related injury and illness.

Occupational Safety and Health Administration (OSHA), the U.S. federal agency, located within the U.S. Department of Labor, responsible for assuring workers have safe and healthful working conditions by setting and enforcing standards; providing and supporting training, outreach, education, and assistance; and ensuring state OSHA programs are at least as effective as federal OSHA.

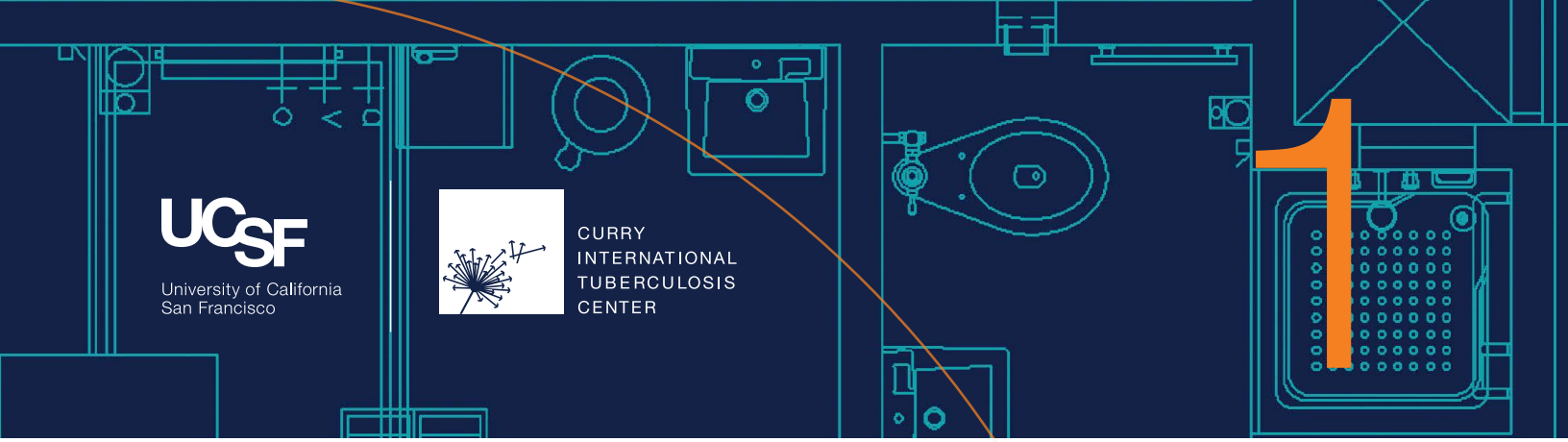
Acronyms and Abbreviations

Organizations

ACGIH	American Conference of Governmental Industrial Hygienists
AHAM	Association of Home Appliance Manufacturers
AIA	American Institute of Architects
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc.
Cal/OSHA	California Division of Occupational Safety and Health
CDC	Centers for Disease Control and Prevention
CIE	International Commission on Illumination
CITC	Curry International Tuberculosis Center
EPA	U.S. Environmental Protection Agency
FDA	U.S. Food and Drug Administration
FGI	Facility Guidelines Institute
HUD	U.S. Department of Housing and Urban Development
IES	Illuminating Engineering Society
ISO	International Organization for Standardization
NIOSH	National Institute for Occupational Safety and Health
NTCA	National Tuberculosis Coalition of America
OSHA	Occupational Safety and Health Administration
TBCTA	Tuberculosis Coalition for Technical Assistance
USAID	United States Agency for International Development
WHO	World Health Organization

Terms

ACH	air changes per hour
AIIR	airborne infection isolation room
APF	assigned protection factor
BMS	building management system
BSC	biological safety cabinet
CADR	clean air delivery rate
CAPR	controlled air-purifying respirator
CFM	cubic feet per minute
CFR	Code of Federal Regulations
dBA	decibel
DOT	directly observed therapy
DST	drug susceptibility test
FFR	filtering facepiece respirator
FPM	feet per minute
GUV	germicidal ultraviolet
HCP	healthcare personnel
HE	high efficiency
HEPA	high efficiency particulate air
HMIS	Homeless Management Information Systems
HVAC	heating, ventilating, and air conditioning
IGRA	interferon gamma release assay
IPC	infection prevention and control
µJ/cm²	microjoules per square centimeter
LED	light-emitting diodes
LEED	Leadership in Energy and Environmental Design
LEV	local exhaust ventilation
LTBI	latent tuberculosis infection
MDR	multidrug-resistant
MERV	minimum efficiency rating value
M³/hr	cubic meters per hour
MMWR	*Morbidity and Mortality Weekly Report*
m/s	meters per second
M. tuberculosis	*Mycobacterium tuberculosis*
mW	manufacturer UVC_{254} output
Pa	pascal
PAPR	powered air-purifying respirator
PPD	purified protein derivative
PPE	personal protective equipment
QFT-G	QuantiFERON®-TB Gold blood test
RAC	room air cleaner
REL	recommended exposure limit
TB COE	Tuberculosis Centers of Excellence
TLV®	threshold limit value
TST	tuberculin skin test
TWA	time weighted average
UR	upper room
UV	ultraviolet
UVC	ultraviolet C-band
UVGI	ultraviolet germicidal irradiation
VAV	variable air volume
µW/cm²	microwatts per square centimeter
"w.g.	inches of water gauge



Administrative Controls

Overview

The field of airborne infection prevention and control (IPC) requires a comprehensive approach with multiple interventions to prevent transmission of disease.

IPC measures for healthcare and congregate facilities are designed to prevent or minimize transmission of airborne microbes from a person with infectious disease to patients, clients, visitors, or staff. Persons infected by airborne microbes may develop diseases such as tuberculosis (TB), COVID-19, measles, chickenpox, common cold, and influenza. This manual focuses on airborne *Mycobacterium (M.) tuberculosis*, and will use the term TB IPC.

The setting can be a healthcare facility, such as an outpatient clinic or emergency room where people come for medical attention with acute symptoms such as fever, cough, vomiting, or diarrhea, or an inpatient setting where patients with these symptoms or other healthcare issues have been admitted. Other congregate settings, such as homeless shelters, long-term care facilities (e.g., skilled nursing facilities, and board and care facilities), or correctional facilities are also sites at inherent risk for spread of communicable airborne microbes. The development and implementation of measures to prevent or minimize transmission of any of these microbes have become increasingly complex, but also more effective, as knowledge about microbes and their transmissibility has increased.

To enable understanding and practical implementation, IPC measures have been divided into separate categories of control interventions.

The Centers for Disease Control and Prevention (CDC) uses three such categories[1]:

- **Administrative controls**
- **Environmental controls**
- **Personal protective equipment** (respirators and surgical/procedure masks)

Administrative controls for TB IPC are interventions through institutional policies, protocols, education, and oversight to reduce or prevent both exposure and transmission of TB within a facility.

Administrative control activities include:

- Assigning responsibility for TB IPC to a specific person within the facility
- Conducting a TB IPC facility risk assessment
- Developing a written TB IPC plan
- Baseline and periodic TB screening and evaluation of employees and volunteers, based on risk of TB exposure
- Educating patients, clients, and visitors
- Using appropriate signage and support for respiratory hygiene throughout the facility
- Applying triage and airborne precaution protocols using epidemiologic principles
  - Including criteria for isolation initiation and discontinuation of isolation for all patients with presumptive and infectious TB
  - Ensuring safe and feasible separation of patients, visitors, and staff
- Ensuring proper cleaning, sterilization, or disinfection of equipment
- Collaborating with clinical and laboratory services
  - Ensuring access to rapid molecular testing for TB
  - Promoting prompt initiation of effective treatment based on drug susceptibility testing (DST)
- Collaborating with local and/or state health departments to ensure all TB cases are reported and appropriate actions are taken

Adapted from CDC *Guidelines for Preventing the Transmission of Mycobacterium tuberculosis in Health-Care Settings*, 2005.[1]

Assigning responsibility for TB IPC

Administrative controls are the most important, least expensive, and often the most difficult measures to implement. Success requires institutional support for a designated IPC program leader with the authority, budget, and human resources to administer an appropriate IPC program (if IPC is assumed to be "everyone's job," it often becomes no one's job). This includes the support and authority to conduct a TB risk assessment for facilities or for individuals, implement and enforce TB infection control policies, and ensure the recommended screening, training, and education of healthcare personnel and other staff are done.

- A healthcare worker who is employed full time, such as a nurse, must be relieved of a portion or all of their clinical work, depending on the size of the institution, so that adequate time is available for TB IPC. In a small clinic one person may be sufficient for IPC, while in a large hospital several people will likely be needed.
- The person(s) responsible for TB IPC should have clinical experience in order to understand the nature of TB transmission and infectivity, but this may not always be possible. If an individual without any clinical background is appointed to oversee TB IPC, they must be trained in basic TB IPC (including the mechanics of airborne transmission) and be knowledgeable regarding populations most at risk for TB infection in the facility's service area. The IPC person(s) should recognize vulnerable populations for TB disease progression, including children and people with immunocompromising conditions (HIV or cancer). Medications such as steroids, chemotherapy, and immunosuppressive drugs (e.g., infliximab) also impact the immune system. It is ideal to have a certified infection preventionist lead the TB program or consult to develop and train the individual who will oversee the program.
- In addition to designating an IPC program leader, facilities such as hospitals and outpatient clinics serving large populations may create multidisciplinary IPC committees bringing together key staff members. The committee in a large facility or hospital should include representatives from facility management, facility maintenance, microbiology laboratory, occupational health, engineering, and multiple clinical disciplines (including medicine, nursing, surgery, and pediatrics) to advise on policy and protocols and to assist with implementation. The key to an effective IPC program is to motivate staff, clients, and visitors to follow airborne IPC procedures and policies.

Conducting a TB IPC facility risk assessment

Once a specific individual (or a group of individuals in a large hospital) has been assigned the job of TB IPC, that person must ensure and perform risk assessments of the facility. The ongoing evaluation of the risk assessment will help identify areas of the IPC program that may benefit from changes and/or enhancements.

- TB IPC risk assessments should be reviewed at least annually (if possible).[1]
- Additional risk assessment may be warranted under the following circumstances:
  - Construction or renovation
  - Creation of new patient areas
  - Seasonal increases in patient flow and respiratory illnesses
  - Implementation of new TB diagnostic and treatment regimens
  - Staffing shortages
  - Suspicion for TB transmission within the facility
- This process includes updated assessments of community TB incidence, details of facility spaces and utilization (including patient, client, visitor, and staff flow), and types of environmental and personal respiratory protections required of specific persons in specific areas.

The ongoing evaluation of the risk assessment will help identify areas of the IPC program that may benefit from changes and/or enhancements.

Routine risk assessment throughout the year is an important IPC monitoring and evaluation process for the facility. It should include the following:

- Assessment of patient flow at various times of day, taking note of areas of patient crowding
- Routine checks on the control measures of the TB clinic within the facility including location and scheduling (e.g., is it immediately adjacent to the HIV clinic or oncology clinic with potential overflow of waiting patients?)
- Routine checks on the control measures for high-risk procedures such as sputum induction (performed in a negative pressure room); non-induced sputum collection must be performed away from all other patients in a well-ventilated area

CDC provides a **TB risk assessment worksheet** for healthcare and nontraditional facility-based settings in Appendix B of the *Guidelines for Preventing the Transmission of Mycobacterium tuberculosis in Health-care Settings, 2005 MMWR* (see full CDC document for more details).[1]

A comprehensive facility risk assessment includes the following key information, as outlined in the CDC worksheet, to inform IPC policy and practice:

1. Local incidence of TB
2. Risk assessment based on utilization of specific areas within facility (e.g., inpatient vs outpatient vs. non-healthcare setting)
3. Screening, testing, and follow-up processes for staff and volunteers*
4. TB IPC plan
5. Implementation status of TB IPC plan
6. Laboratory processing of TB-related specimens
7. Environmental controls
8. Respiratory protection program
9. Reassessment of facility TB risk

*Important healthcare worker screening guidance updated in 2019 is not reflected in CDC 2005 worksheet. Refer to *Tuberculosis Screening, Testing, and Treatment of U.S. Health Care Personnel: Recommendations from the National Tuberculosis Controllers Association and CDC, 2019 MMWR* for updated information. See *Resources*.

Note: While the 2019 NTCA/CDC document updates recommendations for healthcare personnel screening strategies (testing, treatment, and education), the 2019 guidance specifically states that recommendations for "continuing facility risk assessments for guiding infection control policies and procedures" remain unchanged from the 2005 CDC guidelines.

The facility risk assessment should be done by or with the assistance of knowledgeable facility staff and healthcare providers who work in the institution and are familiar with flow and functional issues such as: patient crowding at certain times of day; windows that do not open easily; or problematic heating, ventilation, air-conditioning (HVAC) systems, Ultraviolet-C (UVC) fixtures, and room air cleaners.

- The details of the risk assessment should be documented in a **facility TB IPC risk assessment report** and shared with the IPC committee for review.
- A TB IPC risk assessment report should indicate the date of review, IPC staff who performed the review, and what level of transmission risk is associated with the setting (high, medium, or low).
- The risk assessment should include an evaluation of the effectiveness of and level of implementation of the IPC plan as well as recommendations for change.
- These reports should be filed in an accessible location for both staff and regulatory authorities, whether paper or electronic.

Developing a TB IPC plan

Once a risk assessment has been completed, a TB IPC plan should be written or updated to reflect issues identified. The plan should receive input from the IPC committee, facility staff, and management to ensure appropriate personnel support and financial resources for implementation. It should include remediation steps and assign accountability for completion.

- It may be useful to categorize short-term, medium-term, and long-term plans as well as cost assessments for each remedy recommended.
- If structural changes are required, such as new construction to decrease crowding or improvements to the HVAC system, an engineer will be needed to develop these sections of the TB IPC plan.

In general, the TB IPC plan should include:

Basic information

- Contact information of TB IPC responsible person(s) and facility management
- Location, basic information of setting
- Service(s) provided
- Updated TB epidemiology (facility, state/local, people in the community served who are at increased risk for TB, and staff)

Administrative controls

- Assignment of TB IPC responsibility
- Annual TB IPC facility risk assessment plan/procedures
- Training and education plan for employees
- Education plan for patients, clients, and visitors
- TB screening and evaluation of employees
- Signage and support for respiratory hygiene
- Triage and airborne precaution protocols as needed
- Policies and protocols ensuring proper cleaning of medical equipment
- Policies and protocols ensuring appropriate communication and collaboration with local or state health departments
- Policies and protocols ensuring appropriate communication and collaboration with clinical and laboratory services

Environmental controls

- Evaluation and maintenance plans for environmental controls
  - Mechanical and natural ventilation
  - Upper-room UVC (also referred to as ultraviolet germicidal irradiation [UVGI] and germicidal ultraviolet [GUV] systems, including air mixing)
  - Room air cleaners (or various other air-cleaning technologies)

Personal protective equipment

- Personal respiratory protection program (respirators) for at-risk employees
  - Training and education
  - Medical clearance
  - Fit testing for N-95 respirators
  - Powered air-purifying respirator (PAPR) or controlled air-purifying respirator (CAPR)
  - Adequate supply
- Surgical/procedure masks (primarily used for source control, for potential and confirmed TB patients, clients, and visitors); some IPC plans will include this under "administrative controls"
  - Education
  - Adequate supply

Sustainable TB IPC implementation plan and lifecycle

- Identification of human resources and appropriate linkages to public health program
- Access to funding for IPC program
- Continuous quality improvement cycle: plan implementation -> monitoring and evaluation -> plan revision -> implementation of revisions
- For general guidance on developing TB implementation plans, see *Resources*

Many examples and templates of TB IPC plans can be found online. See *Resources* for links to two examples that vary based on setting and extent of detail:

- Comprehensive medical center version: University of Nebraska Medical Center
- Two simplified examples shared in the TBCTA, CDC, USAID guide: IMPLEMENTING the WHO Policy on TB Infection Control in Health-Care Facilities, Congregate Settings and Households: *A framework to plan, implement and scale-up TB infection control activities at country, facility and community level*, 2009: pages 111-114

Baseline TB screening and evaluation of employees

It is essential that all healthcare personnel are **screened for TB infection and TB disease** prior to employment and after any exposure. Baseline evaluation includes screening for *M. tuberculosis* infection (with either interferon gamma release assay [IGRA] test or tuberculin skin test [TST]), an individual risk assessment, and TB symptom evaluation. Annual TB screening is no longer recommended for U.S. healthcare personnel with the exception of certain groups at increased occupational risk or if ongoing transmission risk exists.[2] For more detailed information on 2019 guidance on healthcare personnel screening, see Chapter 5, *Clinics*, section, *TB screening program*.

Facilities must maintain a registry of employee screening and results, maintaining appropriate security of private health information (electronic or hardcopy).

Training and educating employees

Education is a key element of TB IPC administrative controls. All healthcare and facility personnel, whether clinical, laboratory, maintenance, custodial, dietary, office, or other staff (including volunteers) who routinely work in the facility, should have annual TB IPC training and education.[2]

The education should be short and simple—less is more—and include the following topics:

- The TB bacillus and how it causes both latent TB infection (LTBI) and TB disease, including a clear explanation of the difference between infection vs. disease (see *Resources* for links to CDC resources in English and Spanish)
- Airborne transmission of TB (e.g., through coughing, sneezing, speaking, etc.)
- Infectiousness of TB as compared with other pathogens (e.g., COVID or flu)
- Signs and symptoms of TB disease
- How crowding or environmental factors can influence transmission
- Basic information on how environmental controls work to support safety
- How and when to use appropriate respiratory PPE

Remember to explain to all personnel the availability and effectiveness of TB treatment for both LTBI and TB disease. Share information about LTBI regimen options that are shorter in duration with improved safety profiles.

In a large institution, it may be appropriate to educate staff separately by job category, to allow open dialogue and the ability to ask questions freely (as some may be less comfortable asking questions in the same setting with clinical or physician staff).

CDC provides basic TB online modules (TB 101 for Healthcare Workers) or visit CDC Centers of Excellence for additional materials. See *Resources*.

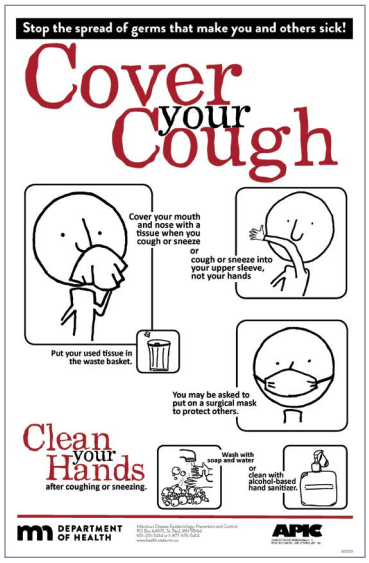
Educating patients, clients, and visitors

Simplified, user-friendly educational material that is appropriate for the setting should be made available to patients, clients, and visitors. This could be through language-appropriate signage or brochures, videos shared in waiting areas, or individual or group educational sessions offered by staff.

- TB educational material developed for patients and the general public can be found online from CDC (see *Resources*).

Using appropriate signage and support for respiratory hygiene

Signage is a crucial tool for education and reinforcement for patients, clients, visitors, and staff.



- All waiting areas in a facility should display simple posters in appropriate languages. Posters illustrating cough etiquette (with drawings of coughing patients wearing masks and coughing into their elbows rather than their hands) are available from CDC and many other sites in multiple languages (see *Resources*).

Respiratory hygiene in crowded, high-risk areas can include giving tissues or surgical masks to patients, clients, and visitors to cover their mouths until TB has been excluded. Staff should wear N95 respirators or more protective respirators (e.g., powered air-purifying respirator) when working with a person with potential or confirmed TB to prevent infection.[1]

- Administrative control policies should include ensuring that there is a smooth process for procurement and distribution of masks and a person whose responsibility it is to maintain supply and re-order when the stock of masks is low.
- Within specific clinical areas, such as TB or HIV clinics, a trained staff member should educate patients in more detail about potential TB transmission and good respiratory hygiene including IPC practices for use in the home.

Applying triage and airborne precaution protocols

To minimize TB transmission within any healthcare facility, **effective work practices** must be maintained for managing patients who are identified as having potential or confirmed TB disease.

- Implement **triage and airborne precaution protocols** to quickly identify and separate from others those who are identified as having potential or confirmed TB disease.[1] In a medical facility, this requires clinical assessment at facility entry to identify coughing patients. They should be separated from other patients immediately, and if TB or other communicable respiratory illness risk factors are identified, fast-tracked for medical evaluation and diagnostic testing with proper airborne precautions. It is important that healthcare personnel, including providers, have a relatively high level of suspicion for TB based on their knowledge of risk factors, symptoms, community rates, etc.
- Isolate patients with potential infectious TB as rapidly as possible. In a medical facility, if the patient is to be admitted, this requires support from bed control services or other staff if airborne infection isolation rooms (AIIRs) are scarce. Inpatients occupying an AIIR who do not have TB or any other airborne infection should be moved.
- Require all medical staff caring for potential TB patients to wear N95 or more protective respirators until it has been proven that the patient is no longer infectious. A discussion of recommendations for release from isolation for healthcare settings is beyond the scope of this manual and may vary by state or local jurisdictions. See *Resources* for links to state/local TB program contact information and to updated 2024 TB isolation recommendations by the National Tuberculosis Coalition of America (NTCA).[3]
- Instruct healthcare personnel on how to educate family members about TB transmission within the hospital as well as the home if patients are discharged before becoming noninfectious. Care should be taken to reduce potential stigma for the patient, particularly from family or community members.

Ensuring proper cleaning of equipment

Administrative controls must ensure that there is a protocol for **cleaning and sterilization or disinfection** of equipment (e.g., endoscopes, bronchoscopes) and protocols for the **safe disposal** of sputum cups or other potentially contaminated equipment.[1,4]

- Protocols must be written and readily available to staff.
- Person(s) responsible for implementing the protocol should be clearly specified, with routine monitoring and documentation of compliance readily available for review.

Collaborating with clinical and laboratory services

Because timely diagnosis and appropriate, early treatment initiation are among the most effective means to reduce transmission, TB IPC administrative control responsibilities must include coordination with clinical and laboratory personnel.

Example areas for IPC administrative support include, but are not limited to[1]:

- **Ensure timely availability of recommended laboratory processing, testing, and reporting of results to the ordering clinician and the infection control team.**
- Provide use of, or prompt access to, rapid diagnostic methods. This includes:
  - Rapid molecular testing for *M. tuberculosis* and DST included in TB diagnostic algorithms.
  - Rapid DST should at a minimum include testing for rifampin, but ideally should have access to additional molecular testing that includes isoniazid and fluoroquinolones.
- Regular inventory monitoring to ensure that all laboratory supplies are well stocked and re-ordered and replenished when in low supply.
- Ensure tools needed to effectively manage patients with potential or confirmed TB disease are in place, including proper supplies of diagnostic and specimen collection materials (e.g., sputum cups).
- Support coordination of services for timely and expedient access to TB care, such as strong linkages to care or integrated services for people with HIV and those who are at increased risk for infections.

As TB disease is most often diagnosed through sputum examination, IPC administrative controls must address all aspects of **sputum collection and processing** (with similar attention to non-sputum specimens).

- This includes sputum collection within an AIIR and/or a ventilated, negative pressure sputum collection booth (or collection outdoors if a booth is not available within a facility).
- Monitoring of sputum processing time is important and includes tracking the course of the sputum container from collection of sputum to arrival and processing in the laboratory.
- If patients or clients collect sputum at home and bring it to the facility themselves, administrative controls include ensuring they know how to properly collect a sputum sample at home and appropriate signage and instructions to patients and clients as to where in the facility they should drop off their sputum.
- In a small facility, a TB nurse or laboratory technician can be delegated this responsibility, but the TB IPC administration must ensure an assignment is made and activities completed.

Collaborating with local or state health departments

Collaborate with the local or state health department to develop administrative controls consistent with health department policies on management of patients with presumptive or confirmed TB disease (including plan for triage or possibly transfer for those with TB symptoms), health department notification, facility TB risk assessments, healthcare personnel screening, and education policies and priorities.[1]

Prompt and ongoing communication of TB diagnoses with local and state health departments includes:

- For clinical sites, reporting includes positive test results of smears or nucleic acid amplification tests, such as the Xpert® MTB/RIF (often referred to as Xpert or Gene-Xpert) or other rapid TB diagnostic tests. Positive pathology and culture results must always be reported as well, noting that rapid tests may not have been performed on biopsy specimens.
  - This is often the responsibility of the facility's laboratory, but as part of IPC administrative controls, the responsibility for reporting to the health department must be clearly assigned and monitored monthly in communities with high TB incidence, or quarterly where TB is less frequent.
  - Reporting rules may differ between states and/or local jurisdictions and the IPC guidance should reflect local requirements.
- Routine monitoring will enable tracking of TB incidence within an institution to identify nosocomial transmission (spread within the facility) as well as any increase in TB within a community. The investigation of unexpected positive test results may uncover possible gaps in IPC practice or procedures or laboratory equipment malfunction that resulted in transmission within a facility.

While interventions are presented as separate categories, keep in mind that there are crucial overlapping features. The entire "package" of interventions should be considered as one integrated and coordinated IPC strategy.

Resources

General resources

- *Cover Your Cough* signage in multiple languages – Centers for Disease Control and Prevention (CDC)
  https://www.cdc.gov/flu/prevent/actions-prevent-flu.htm
- State and local regulations – Occupational Safety and Health Administration (OSHA) offices by state
  https://www.osha.gov/html/RAmap.html
- List of state, big city, and territory TB program contacts – National TB Coalition of America (NTCA)
  https://www.tbcontrollers.org/community/statecityterritory/
- TB data and statistics – CDC
  https://www.cdc.gov/tb/statistics/default.htm
- Guidelines and resources for infection preventionists – Association for Professionals in Infection Control and Epidemiology (APIC), Sierra Chapter
  https://community.apic.org/sierra/resources/overview
- Infection prevention and control resources – The Joint Commission
  https://www.jointcommission.org/resources/patient-safety-topics/infection-prevention-and-control/
- TB training, education, and medical consultation – CDC-supported TB Centers of Excellence
  https://www.cdc.gov/tb-programs/php/about/tb-coe.html

TB education for healthcare staff and patients/general public (CDC)

- The TB bacillus and how it causes both latent TB infection (LTBI) and TB disease, explaining the difference between infection vs. disease (English, Ukrainian, and Spanish)
  https://www.cdc.gov/tb/communication-resources/tuberculosis-fact-sheet.html
- TB 101 for Health Care Workers (online modules)
  https://www.cdc.gov/tb/webcourses/tb101/
- TB educational material developed for patients and the general public
  https://www.cdc.gov/tb/communication-resources/index.html

TB facility risk assessment and classification

- Comprehensive resource for conducting a TB risk assessment – CDC *Guidelines for Preventing the Transmission of Mycobacterium tuberculosis in Health-Care Settings, 2005*
  https://www.cdc.gov/mmwr/preview/mmwrhtml/rr5417a1.htm
  - TB risk assessment worksheet for healthcare and non-traditional facility-based settings (Appendix B)
    https://www.cdc.gov/tb-healthcare-settings/hcp/facility-risk-assessment/
  - Updates to CDC 2005 Appendix B based on CDC/NTCA 2019 TB screening, testing, and treatment recommendations provided in 2020 companion document, Appendix 1, from the American College of Occupational and Environmental Medicine and NTCA
    http://links.lww.com/JOM/A780

TB screening, evaluation, infectiousness, and isolation

- General: TB in healthcare settings resource page – CDC
  https://www.cdc.gov/tb-healthcare-settings/index.html
- Concise coverage of principles of infectiousness, detection and diagnosis of TB disease, and discontinuation of airborne isolation within overview of TB IPC – CDC, *Core Curriculum on Tuberculosis: What the Clinician Should Know, 7th edition,* 2021, *Chapter 6: Tuberculosis Infection Control*
  https://www.cdc.gov/tb/hcp/education/core-curriculum-on-tuberculosis-continuing-education.html
- TB screening and testing of healthcare personnel – CDC
  https://www.cdc.gov/tb-healthcare-settings/hcp/screening-testing/index.html
- *Tuberculosis Screening, Testing, and Treatment of U.S. Health Care Personnel: Recommendations from the National Tuberculosis Controllers Association and CDC, 2019*
  https://www.cdc.gov/mmwr/volumes/68/wr/pdfs/mm6819a3-H.pdf
  - Companion implementation document: *Tuberculosis Screening, Testing, and Treatment of US Health Care Personnel: ACOEM and NTCA Joint Task Force on Implementation of the 2019 MMWR Recommendations* – American College of Occupational and Environmental Medicine, July 2020
    https://acoem.org/acoem/media/PDF-Library/Publications/Tuberculosis_Screening,_Testing,_and_Treatment.pdf
- Basic review of estimating the infectiousness of a person with TB and use of TST within the context of guidelines for TB IPC – CDC *Guidelines for Preventing the Transmission of Mycobacterium tuberculosis in Health-Care Settings, 2005.*
  https://www.cdc.gov/mmwr/preview/mmwrhtml/rr5417a1.htm
- Updates on isolation policy guidance – NTCA
  https://academic.oup.com/cid/advance-article/doi/10.1093/cid/ciae199/7649400

Creating a sustainable TB IPC implementation plan and lifecycle

- Field Guide for Assessing Readiness to Implement Evidence-Based Cancer Screening Interventions (CDC Colorectal Cancer Control Program); Phase 4: Develop an Implementation Plan
  https://www.cdc.gov/colorectal-cancer-control/php/field-guide/phase-4.html
- Program Sustainability Assessment Tool and Clinical Sustainability Assessment Tool (Washington University in St. Louis)
  https://www.sustaintool.org/
- Example template of a comprehensive medical center version: University of Nebraska Medical Center
  https://www.unmc.edu/ehs/safety/TB_Exposure_Plan.pdf
- Two simplified example templates shared in the TBCTA, CDC, USAID guide: IMPLEMENTING the WHO Policy on TB Infection Control in Health-Care Facilities, Congregate Settings and Households: *A framework to plan, implement and scale-up TB infection control activities at country, facility and community level*, 2009: pages 111-114
  https://stoptb.org/wg/tb_hiv/assets/documents/tbicimplementation framework1288971813.pdf

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4. Rutala WA, Weber DJ; Healthcare Infection Control Practices Advisory Committee. Guideline for Disinfection and Sterilization in Healthcare Facilities. Centers for Disease Control and Prevention; 2019. https://www.cdc.gov/infection-control/media/pdfs/Guideline-Disinfection-H.pdf

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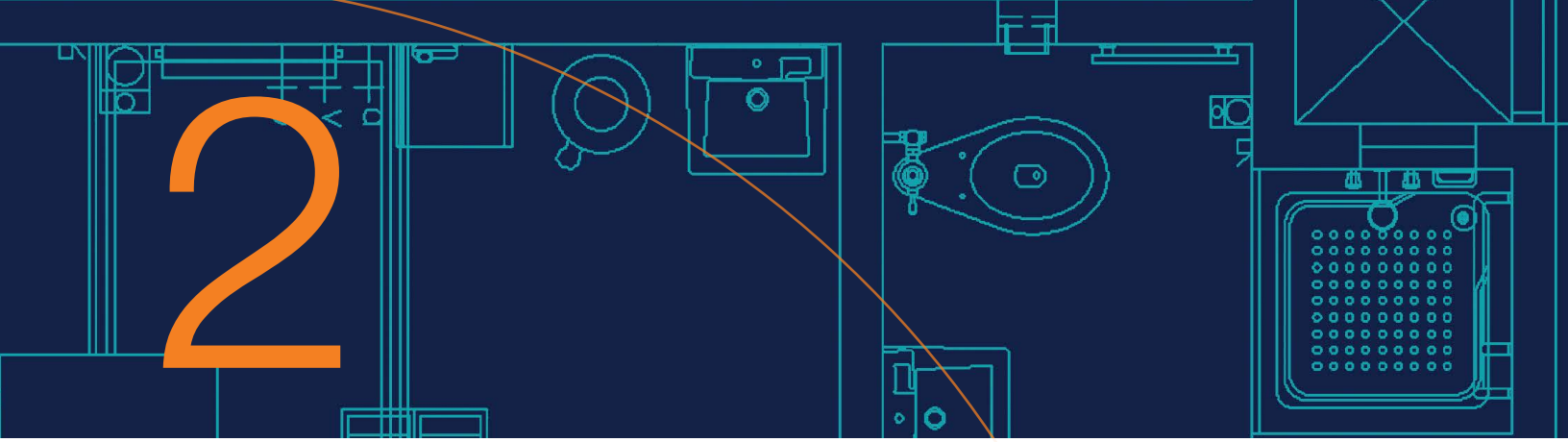
2

Environmental Controls



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PART 2 UVC

Overview: Environmental Controls

In this manual, the term “environmental controls” refers to the use of engineering and architectural technologies to help prevent the spread of infectious diseases, specifically focusing on reducing the transmission of airborne infectious disease.

Due to limited funding and other restrictions, care facilities such as public health clinics, community health clinics, and homeless shelters frequently make use of locations that were not originally designed for such use. Within hospitals and large healthcare institutions, areas may also be repurposed from other services. As a result, if a location has an existing “office” or “residential” ventilation system, it may not have sufficient safeguards to prevent the spread of TB or other airborne microorganisms. In worst case scenarios, ventilation systems may not be operational or may not be present at all.

Environmental controls are the second line of defense in the TB infection prevention and control program, after basic administrative controls.

Additional risks faced by care facilities are deficiencies in environmental controls for airborne infection prevention and control (IPC). When deficiencies occur, persons with potential or known TB are sometimes placed in airborne infection isolation rooms (AIIRs) that have inadequate environmental controls. Poorly designed and/or incorrectly operating AIIRs can place healthcare personnel (HCP), visitors, and patients at risk for TB infection and disease. This chapter outlines the design, implementation, and maintenance of environmental controls at both a facility level and at an AIIR level.

After basic administrative controls, environmental controls are the second line of defense in the TB infection prevention and control program. Effective administrative controls are necessary to ensure the proper operation and maintenance of environmental controls. Environmental controls help to prevent the spread and reduce the concentration of airborne infectious particles (e.g., TB-containing droplet nuclei). A summary of environmental controls and their use in prevention of transmission of *Mycobacterium (M.) tuberculosis* is provided in this chapter's two sections: Part 1: *Ventilation* and Part 2: *Ultraviolet C-Band (UVC)*.

ENVIRONMENTAL CONTROLS FOR TB INCLUDE:

Ventilation		Ultraviolet C-Band (UVC)

MECHANICAL & NATURAL VENTILATION
Mechanical ventilation: heating, ventilating, air-conditioning (HVAC) systems
• Dilution ventilation
• Unidirectional ventilation
• Single-pass ventilation
• Recirculating ventilation
  • No filtration
  • Filtration: low, medium, or high; high efficiency particulate air (HEPA)
  • In-duct UVC (UVGI)
Mixed-mode ventilation
Natural ventilation
	ROOM AIR CLEANERS (RACs)
	• HEPA filtration
	• Minimum efficiency reporting value (MERV) 11-14 filtration
	• UVC
		• Upper-room UVC
		• Whole-room UVC
		• In-duct UVC
		• RACs with UVC

What does "commissioning" mean?

Any project to build or renovate a facility's environmental control systems will involve commissioning. Commissioning (of a building or system [e.g., HVAC, UVC, RAC]) is a process, not a specific task. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) describes commissioning as a series of procedures, methods, and documentation requirements that confirms a building "performs" as desired.[1]

Major stages in the commissioning process

1. **Pre-design stage** ensures the building owner's/operator's needs, requirements, and objectives are well defined.
2. **Design stage** ensures the design meets the owner's/operator's needs, requirements, and objectives. This stage involves not just designers, but also the owner/operator and peers to review and comment on the design.
3. **Construction stage** ensures that the work conforms with the construction design plans.

4. **Occupancy and operation stage** ensures the end product meets the owner's/operator's needs, requirements, and objectives; and staff and management have the necessary skills and/or funds to operate the product.

    - During this stage, the contractor provides operation and maintenance manuals to the owner/operator and necessary training to staff. Whether operation and maintenance activities will be contracted out or handled within the owner's/operator's organization, forward all maintenance and operations information to the applicable person(s).
    - At the end of the construction stage or the beginning of the occupancy and operation stage, conduct **performance testing** and repeat periodically throughout the operation of the equipment and/or space. Also called **final acceptance testing,** this testing step confirms the equipment meets the design requirements under various conditions, e.g., can the HVAC system provide the design airflow rates with both clean and with loaded (dirty) filters?

What to do

- If the project is small (e.g., installing a RAC or minor modifications to the ventilation system), a person knowledgeable in the technology can oversee the commissioning process.
- Larger projects may require an independent **commissioning agent,** professional engineer, or certified industrial hygienist (someone familiar with the required activities) to "witness" the final acceptance testing. A commissioning agent can make sure the entire commissioning process is executed completely and correctly.

PART 1

Ventilation

Using ventilation to reduce TB transmission

What is ventilation and why do we need it?

Ventilation is the movement of air within a building and replacement of inside air with air from the outside, preferably in a controlled manner. Two general types of ventilation include:

- **Mechanical ventilation,** which usually refers to the use of mechanical equipment that circulates air in a building and may also involve heating and/or cooling. Mechanical ventilation systems may or may not bring in air from the outside.
- **Natural ventilation,** which relies on unrestricted movement of air (doors, windows, ducts/channels, design of building, etc.) to bring in air from the outside. Fans may also assist in this process and distribute the air (mixed-mode ventilation).

Ventilation is needed to:

- Dilute and/or remove infectious aerosols
- Contain and/or prevent the spread of infectious particles to other areas within the facility
- Provide a comfortable environment (temperature, relative humidity, low noise, and no drafts)

How ventilation helps reduce TB transmission

Ventilation can reduce the risk of airborne disease transmission through dilution, removal, and containment.

Dilution (general) ventilation: When clean or outdoor air enters a room, by either natural or mechanical means, and is mixed well with the existing air, the concentration of small airborne infectious particles in room air is reduced. An example of using dilution ventilation would be the opening of doors and windows to bring in clean outdoor air to dilute objectionable odors, reduce carbon dioxide (CO_2), and reduce airborne contaminants. Dilution reduces the likelihood that a person in the room will breathe air that may contain infectious particles.[1]

Removal and containment: Further interventions to remove and direct the air with the infectious particles safely away from others in the facility (containment) help to prevent airborne transmission.

Infectious particles are removed when potentially contaminated room air is:

- Exhausted outdoors to a safe place (i.e., away from persons, ventilation intakes, building openings) and replaced with outdoor air, or
- Filtered or irradiated to trap or inactivate infectious particles containing *M. tuberculosis* and then recirculated into the facility, or
- A combination of these methods.

In any ventilated space, air is constantly entering (being supplied) and leaving (being exhausted). When air is introduced into a space, it may mix to a certain extent with the air already in the room. Effective **air mixing** will dilute any airborne pollutants (vapors, odors, infectious particles).

- The more effective the mixing of air, the better the dilution of infectious particles.
- The more efficient the airflow patterns in a room, the better the removal of infectious particles.

Ventilation systems are designed to balance these two properties.

Airflow rate and air changes per hour (ACH)

- **Mechanical airflow rate or volumetric airflow rate** (cubic feet per minute [CFM] or cubic meters per hour [m^3/h]) is the volume of air which passes per unit time. In terms of characterizing a room or space, it might be the air into or out of a room or space through a grille or diffuser, under a door, and through various "openings" in the envelope or boundary of the space.[2]
- **Clean air delivery rate (CADR)** (CFM or m^3/h) is the volume of "clean air" which passes per unit time. For the purpose of this document, "clean air" is defined as the sum of the airflow rate of outdoor air and treated air (particle-free and/or air in which microbes have been inactivated). Treatment of air may include filtration and/or UVC.[3,4]
- **Air changes per hour (ACH)** or air exchange rate is a function of the **CADR** and the efficiency of room air mixing. The ACH is the amount of clean air added to or existing air removed from a room or space, divided by the volume of the space. If the air in the room or space is perfectly mixed, ACH is a measure of how many times the air within a defined space is replaced with clean air in one hour.[2,5]

For many facilities, indoor air is often recirculated with minimal cleaning and with no addition of outdoor air (approaching zero ACH), or only a small or variable proportion of outdoor air (very little ACH). Some facilities add environmental controls to clean recirculated air using special filters or disinfect with germicidal ultraviolet-C light (UVC, also referred to as Ultraviolet Germicidal Irradiation, UVGI). These controls can be described in terms of relative equivalence of air exchange rate (**equivalent air changes per hour, eACH**) as compared to strictly ACH.[6,7] Note: if $ACH_{OUTDOOR\ AIR}$ equals zero, the space may not meet the minimum ventilation requirements for control of CO_2 and other environmental contaminants.

- Four methods to produce ACH (may be used in combination and presumes perfect air mixing) include:
  - $ACH_{OUTDOOR\ AIR}$ is based on the clean outdoor air flowing into a space.
  - $eACH_{CLEAN}$ is the clean air returning to the space (recirculated air) that has been cleaned using filtration or disinfected using UVC. Note that the air returned to the space may not be 100% clean if the filtration/disinfection is not 100% efficient.
  - $eACH_{RAC}$ is the clean air returning to the space using a RAC. Note that the air from the RAC returning to the space may not be 100% clean if the filtration/disinfection is not 100% efficient.
  - $eACH_{UR\ UVC}$ is the clean air circulated in the space, disinfected with upper-room UVC.
  - For any combination of methods, the total equivalent air exchange rate ($eACH_{TOTAL}$) is:

    $$\mathbf{eACH_{TOTAL} = ACH_{OUTDOOR\ AIR} + eACH_{CLEAN} + eACH_{RAC} + eACH_{UR\ UVC}}$$

Room clearance

Room clearance (%) is the percentage of initial number or concentration of infectious particles removed after a specified unit of time. Room clearance may be expressed in terms of percent reduction in infectious particles in one hour or in terms of time to achieve a defined clearance rate at a specified ACH.

- If we assume perfect mixing in a room or space with 6 ACH and **no further generation of particles,** 99.75% of the initial particles will have been removed from the room or space in one hour (see Table 1). If the same room or space was ventilated at a rate of 12 ACH, 99.999% of the initial particles will have been removed in one hour.
- If we assume perfect mixing in a room or space with 6 ACH and **no further generation of particles,** it will take 46 minutes to reduce the initial particles by 99% and it would take 69 minutes to reduce the initial particles by 99.9%. In a room or space with 12 ACH, it would take 23 minutes to reduce the initial particles by 99%, and it would take 35 minutes to reduce the initial particles by 99.9% (see Table 2).
- In reality, most rooms have less than ideal air mixing, therefore the reduction in particles and times shown in Tables 1 and 2 represent best case scenarios.

Note: Increasing the number of ACH beyond 12 ACH will have diminishing returns and will be of very little benefit at a significant cost for most spaces (Table 1). Exceptions could include small spaces, such as a sputum collection booth, where an ACH or eACH >12 can be achieved at a reasonable cost for the added removal and/or inactivation rate.

TABLE 1. **Air-changes per hour (ACH) and infectious particle removal:** ACH and percent of infectious particles remaining and removed after one hour, assuming no patients/clients or procedures are generating infectious particles and there is "perfect" air mixing.[8]

ACH	Remaining (%)	Removed (%)
1	36.8	63.2
2	13.5	86.5
4	1.8	98.2
6	0.25	99.75
9	0.01	99.99
12	0.001	99.999
18	0.000002	99.999998
24	0.000000004	99.999999996

Source: P.A. Jensen

TABLE 2. **Air-changes per hour (ACH) and clearance times:** ACH and time required for removal efficiencies of 99% and 99.9% of airborne contaminants, assuming there is "perfect" air mixing.[5]

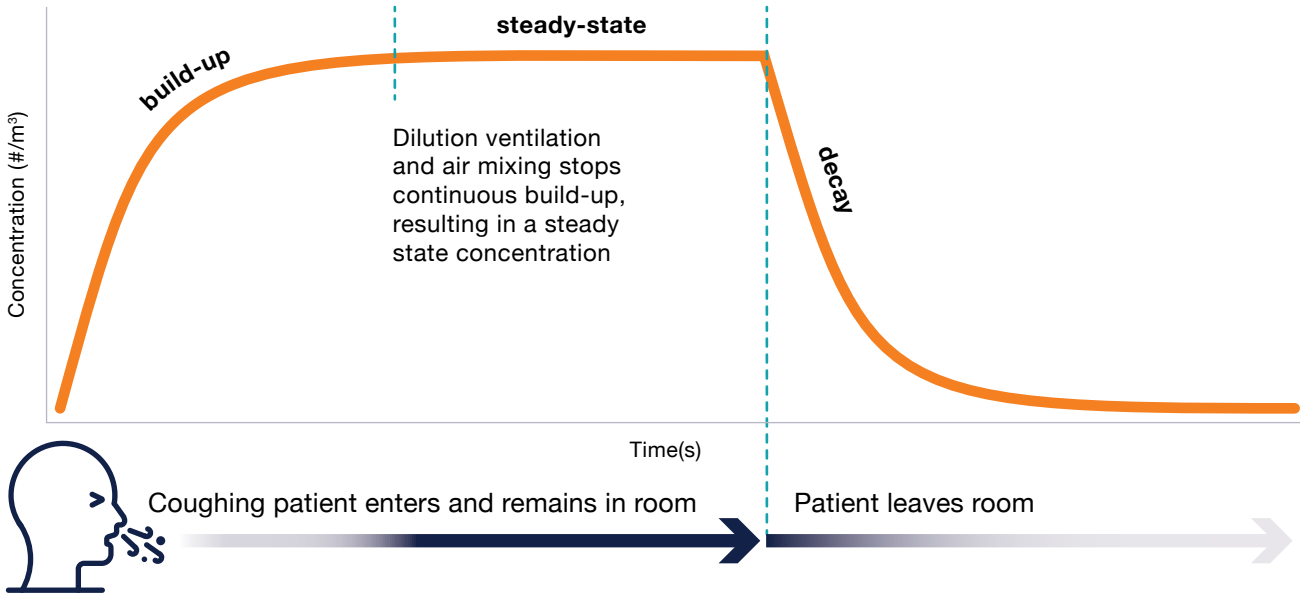
	Minutes required for removal efficiency*	
ACH	99%	99.9%
2	138	207
4	69	104
6	46	69
12	23	35
15	18	28
20	14	21
50	6	8
400	<1	1

*Time in minutes to reduce airborne concentration by 99% then 99.9%

Source: CDC *Guidelines for Preventing the Transmission of Mycobacterium tuberculosis in Healthcare Settings*, 2005[5]

Note: **If there is ongoing production of infectious particles in a room** (e.g., an untreated, coughing patient with pulmonary TB), a well-designed ventilation system can dilute and reduce the concentration of infectious particles, but the number of infectious particles in the room will eventually reach a steady state between production and removal (Figure 1). The number of infectious particles in the room will not reduce to zero until the source is removed. Increasing the number of ACH can reduce the steady-state concentration of infectious particles in a room. Similar to the infectious particle decay when there is no source of infectious particles, increasing ACH beyond 12 ACH will have diminishing returns. Once the person who is producing the infectious particles leaves the room, continued air exchange can then clear the air within the room completely as seen in the concentration decay curve in Figure 1.[8]

FIGURE 1. **Infectious particle production and clearance:** Schematic of steady-state concentration of infectious particles using dilution ventilation with perfect air mixing then clearance (decay curve) when source of infectious particles is removed.



Source: P.A. Jensen/CITC

For step-by-step instructions on how to calculate the ACH and room clearance time, see Appendix A, *Room Clearance Time Calculation (and ACH) Worksheet*.

Using directional airflow to reduce TB transmission

What is directional airflow?

Ventilation can also help reduce the concentration of infectious particles in specific locations within a room. By directing where clean air enters a space and knowing where potentially infected air is removed from a space, the location of people and activities can be matched to the **directional airflow** to optimize the protective benefits of ventilation.

Simply stated:

- Locate the people you are trying to protect from TB exposure closer to the clean air supply
- Locate people who may be infectious closer to the place where air is removed from the space

Directional airflow is also referred to as "airflow currents" in some guidelines and recommendations.

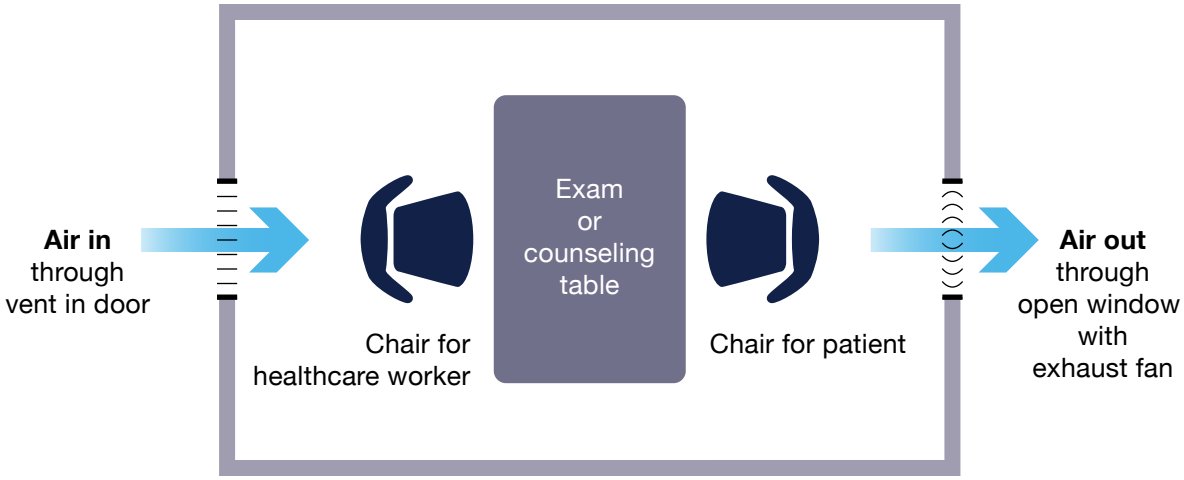
How directional airflow helps reduce TB transmission

Directional airflow principles apply to either mechanical or natural ventilation systems.

Unidirectional airflow (horizontal): If applied appropriately, the strategic use of directional airflow can help protect staff from an unidentified TB patient.[5] For example, horizontal directional airflow can help reduce the chance that TB will spread from a patient/client to a staff member doing intake interviews.

- If the airflow direction is always the same (e.g., a room with a reliable exhaust-only window fan), the staff member should sit near the outdoor (clean) air supply, and the patients/clients should sit near the exhaust location as shown in Figure 2A.

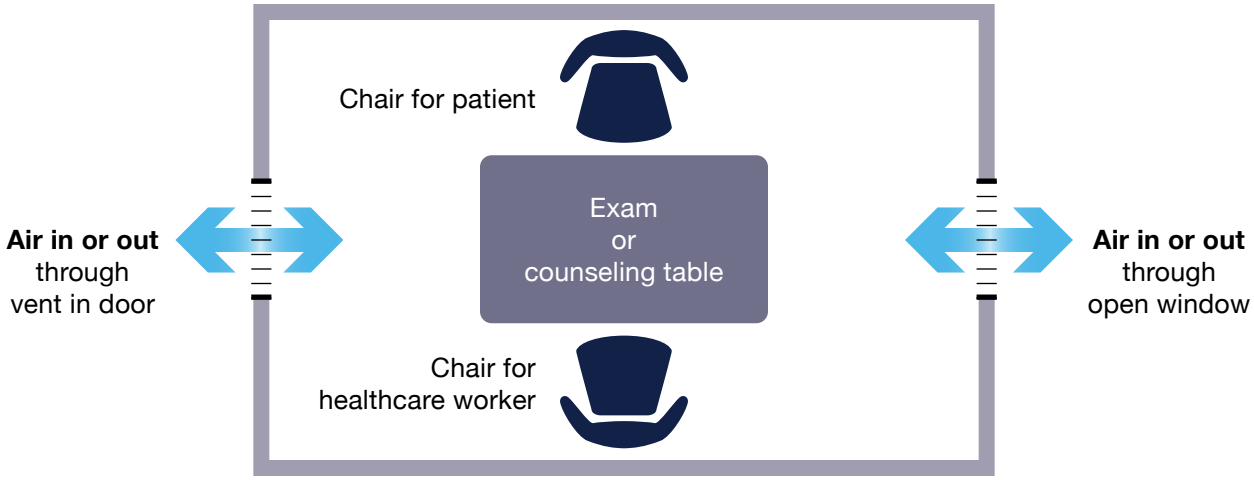
FIGURE 2A. **Room layout with unidirectional airflow:** Example layout in a room with unidirectional airflow using an exhaust-only window fan (TB exam or counseling room)



Adapted from CDC *Core Curriculum on Tuberculosis: What the Clinician Should Know*, Chapter 6: Tuberculosis Infection Control, 2021[9]

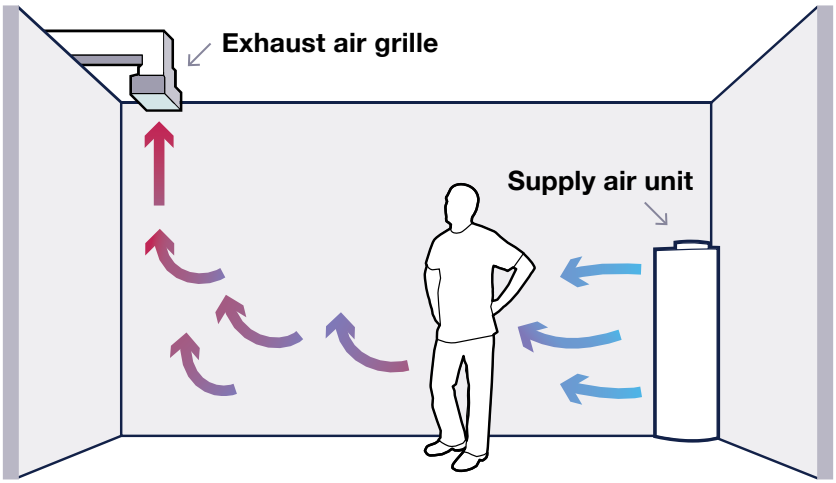
In a naturally ventilated room where the direction of airflow may be less predictable, as shown in Figure 2B, the table is rotated 90 degrees to make the desk orientation optimal for airflow to be in either direction. Note: When an exhaust-only window fan is relatively weak and outside prevailing winds are strong, the unidirectional airflow may not work as intended and this second layout may be preferred.

FIGURE 2B. **Room layout with variable airflow:** Example layout of a room with airflow that may be in either direction, generally a naturally ventilated room (TB exam or counseling room)



Displacement ventilation (vertical): This is a vertical, unidirectional air distribution system that introduces cool air (conditioned "clean" air) at low velocity, usually from air supply diffusers located near the floor and exhausted above the occupied zone, usually in the ceiling (see Figure 3). Occupants and equipment in a space will warm the air, and the warmer air will rise (referred to as "buoyancy forces"). Buoyancy forces ensure that this cooler clean air supply pools near the floor level. As the air warms, any infectious particles being produced by an occupant with TB will be carried up in the thermal plumes that are formed and are exhausted at or near the ceiling. Detailed information on use of displacement ventilation can be found in the 2016 *Price Engineering Guide Displacement Ventilation*.[10]

FIGURE 3. **Example of room with displacement ventilation**

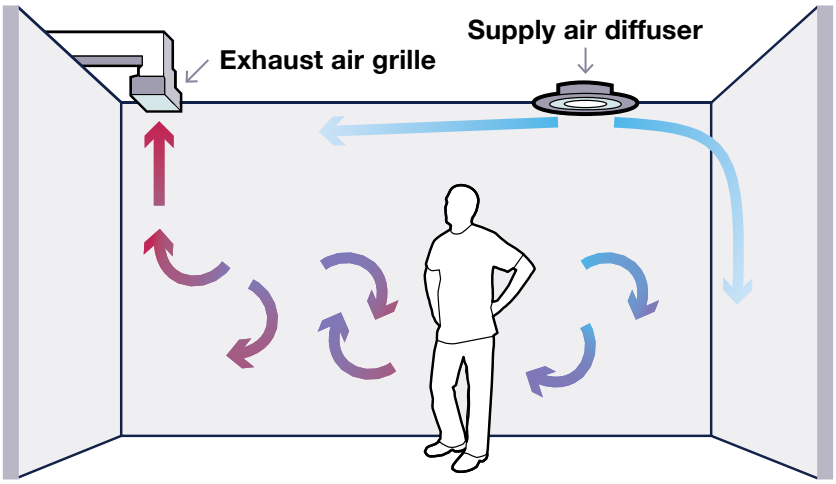


Using directional airflow vs. dilution ventilation methods for congregate settings

In a room in which large numbers of people may congregate, such as a dormitory or a waiting room, anyone could be a source of TB that could spread to others in the room. In general, the direction of air movement to protect one primary location in the space is less critical. A potential exception would be a congregate setting with an adjacent designated staff or healthcare personnel (HCP) area (e.g., receptionist or nursing workstation). In this case, directional airflow from a clean air source going from the staff/HCP area to the congregate patient or client area would be best.

- A dilution-based strategy to provide clean air that is mixed well to dilute the concentration of any infectious particles and then distributes the air throughout the space reduces the average transmission risk for other occupants regardless of where the source may be located (see Figure 4).
- Installing upper-room UVC to disinfect air with a good air mixing system is another example of using a dilution system for a crowded space.[7,11] See *Environmental Controls: UVC*, section, *Upper-room UVC*.
- A displacement ventilation method that supplies cooler, clean air near the floor throughout the space could also work in a crowded situation in which the potential source of infectious particles is not known.

FIGURE 4. **Example of dilution ventilation.** Note round, louvered supply air diffuser positioned at a distance from the exhaust grille in the ceiling



Checking directional airflow and airflow patterns

People can usually feel or "smell" the presence or absence of air movement in a space. A ventilated space may have a slight draft; however, this is more a function of the diffuser (the air supply inlet) design and not an indication of the effectiveness of the ventilation system. In the absence of adequate ventilation, air may feel stuffy and stale, and odors will linger.

Checklist to assess ventilation in your facility:

- ☐ Check that all occupied rooms have a source of natural or mechanical ventilation (both air supply and air exhaust). When directionality is desired, validate that the airflow moves in the desired direction (e.g., from the supply and through the room to the exhaust, or from the corridor into the room). Air may move to adjacent spaces via open doors or grilles in doors.
- ☐ Check that windows, doors, vents, ductwork, etc., are easy to open and to keep open, that all supply diffusers and air exhaust grilles (exhaust outlets) are open and airflow is unimpeded. Note that most mechanical ventilation systems will not operate properly when combined with natural ventilation (windows and doors open to outdoors).
- ☐ Check air mixing and determine directional air movement in all parts of occupied rooms. A preferred method is to use non-irritating "smoke tubes" or "smoke/fog generators" designed for checking airflow. Acetic acid smoke tubes may be preferred over sulfuric acid tubes due to safety concerns.[12] Inexpensive ways to visualize air movement are to use a thin strip of tissue paper or incense sticks (two lit together may be needed to produce enough visual smoke).

CONTINUED

Checklist to assess ventilation in your facility:

CONTINUED

☐ The following is a general description of the procedure:

1. Activate smoke tubes per manufacturer instructions (or hold two incense sticks together and light them, allow to start to burn, then blow out flame, cup one hand over the smoke to allow it to cool and become neutrally buoyant).
2. Observe the direction of the smoke movement. Repeat in various areas of the space (including the opening under the closed room entry door) and record.

   Observe how quickly the smoke dissipates. This is a subjective test that may require some practice. It does not give a definite result but is useful for qualitatively comparing rooms to each other. For example, it may take one minute for smoke to dissipate in one room but 10 minutes in another. Repeat smoke tests for various common conditions at your facility. For example, if doors are kept open during the day but closed at night, the tests should be done under both conditions. If smoke does not move or dissipate over approximately 5 minutes, technically evaluate airflow with an environmental engineer and consider remediation.

For further information on methods for checking airflow (e.g., smoke or tissues tests, use of manometer), see Chapter 4, *Airborne Infection Isolation Rooms*, section, *Monitoring AIIR environmental controls*.

Mechanical ventilation

Mechanical ventilation systems use dilutional strategies, remove contaminated air, and control airflow patterns in a room or setting through mechanical means. This includes a building's heating, ventilation, and air-conditioning (HVAC) system but may also entail specialized systems for a room or workstation. An engineer or other professional with expertise in ventilation (preferably within hospital, healthcare facility, laboratory, and/or protected environments) should be included as part of the staff of the healthcare setting. Otherwise, a consultant with expertise in ventilation engineering specific to healthcare settings should be hired for design, installation, or maintenance issues. Ventilation systems should be designed to meet all applicable federal, state, and local requirements.

- Mechanical ventilation systems may be designed to apply directional airflow methods to supply clean air to specific locations within a space (e.g., unidirectional airflow of clean air towards staff, and removing contaminated air near an infectious source).
- A mechanical system may be designed to use vertical, displacement ventilation methods, where cool air is supplied near the floor and the warm air removed near the ceiling as a primary means of removing airborne infectious particles. A displacement strategy may be a more efficient method than dilution ventilation at removing airborne infectious particles for some settings, particularly in large, congregate settings, and more uniformly reduces the risk of exposure to all occupants in the space.

This section will cover details of mechanical ventilation systems as they apply to infection control for:

- Negative and positive pressure systems
- HVAC systems

More guidance on mechanical ventilation principles and implementation:

- For general TB infection prevention and control (IPC) guidance and specific use of negative or positive pressure: Centers for Disease Control and Prevention (CDC) 2005 *Guidelines for preventing the transmission of Mycobacterium tuberculosis in health-care settings.*[5]
- For airborne infection isolation rooms (AIIRs): CDC 2019 update: *Guidelines for Environmental Infection Control in Health-Care Facilities, Recommendations of CDC and the Healthcare Infection Control Practices Advisory Committee (HICPAC)*.[13]
- Guidelines by the Facilities Guideline Institute on the design and construction of hospitals and outpatient facilities, and residential, care, and support facilities.[14,15,16]

Airflow differentials and pressure differentials

To better understand mechanical ventilation strategies and systems, it is useful to understand the concepts of airflow differentials and pressure differentials:

- **Airflow differential** (CFM or m^3/h) is the difference between the total supply airflow rate and the total exhaust airflow rate. If this number is negative and the room or space does not have excessive openings or leakage, the room or space would be depressurized or "negative" pressure relative to the surrounding spaces. If this number is positive and the room or space does not have excessive openings or leakage, the room or space would be pressurized or "positive" relative to the surrounding spaces.
- **Pressure differential** (inch water gauge, "wg; or Pa) is the pressure inside the room or space relative to the pressure outside of the room or space. If the pressure inside is less than the pressure outside, the room or space would be depressurized or "negative" pressure relative to the surrounding rooms or spaces. If the pressure inside is greater than the pressure outside, the room or space would be pressurized or "positive" relative to the surrounding rooms or spaces.

Using specialized equipment (e.g., negative pressure laboratory hood or sputum induction booth) or the facility HVAC system, supply and exhaust airflow rates can be mechanically adjusted to produce the desired negative or positive pressurized spaces relative to the surroundings. Air movement is driven by this pressure differential, i.e., air is always moving from the more "positive" space towards the "negative" space.

How negative pressure helps reduce the risk of TB transmission

Negative pressure is created by setting (or balancing) a ventilation system so that more air is mechanically exhausted from a room than is mechanically supplied, until the pressure differential is >0.01 "wg (2.5 Pa). This creates a ventilation imbalance, called airflow differential, and the room will have a negative pressure relative to surrounding areas, including the corridor. If the room is sufficiently sealed, the room makes up the airflow differential by continually drawing in air from outside the room.

- Infectious particles that are generated within a room will be contained there by a continuous flow of air being pulled into the room from under the door or through openings in the walls, ceilings, or floors. Therefore, when a negative pressure room is used as designed, infectious particles cannot escape to the corridor or other areas of the facility.

The most common examples of negative pressure are residential bathrooms. Often a bathroom will have an exhaust fan but no mechanical air supply. The most common application within healthcare facilities is the use of negative pressure to create AIIRs or localized negative pressure use in laboratory safety hoods.

Room pressurization should be monitored in accordance with an IPC plan. Even if the AIIRs are equipped with electronic pressure monitors, the Centers for Disease Control and Prevention (CDC) recommends AIIRs be checked for negative pressure by using smoke tubes or other visual checks before occupancy. In addition, these rooms should be checked daily when occupied by a patient with presumptive or confirmed TB disease. See Appendix B, *Airborne Infection Isolation Room Pressure Monitor Checklist* as a template for recording verification results. For further information on methods for checking airflow (e.g., smoke or tissues tests, use of manometer), see Chapter 4, *Airborne Infection Isolation Rooms,* section, *Monitoring AIIR environmental controls*.

Negative pressure is created by exhausting more air from a room than is supplied to the room by the HVAC system.

Infectious particles are contained within a room by a continuous air current being pulled into the room under the door or through openings in the walls, ceilings, or floors.

Negative pressure: Airborne infection isolation rooms (AIIRs)

AIIRs use dilution ventilation principles to reduce the concentration of airborne infectious particles within them, but also use mechanical containment methods to keep contaminated air in the room from potentially moving into shared corridors or other adjacent indoor spaces. To achieve this, a negative pressure differential is created relative to adjacent spaces by exhausting more air from the room than the amount supplied, as described in the preceding section. These are sometimes referred to as “negative pressure” rooms.

CDC 2005 recommendations specify:[5]

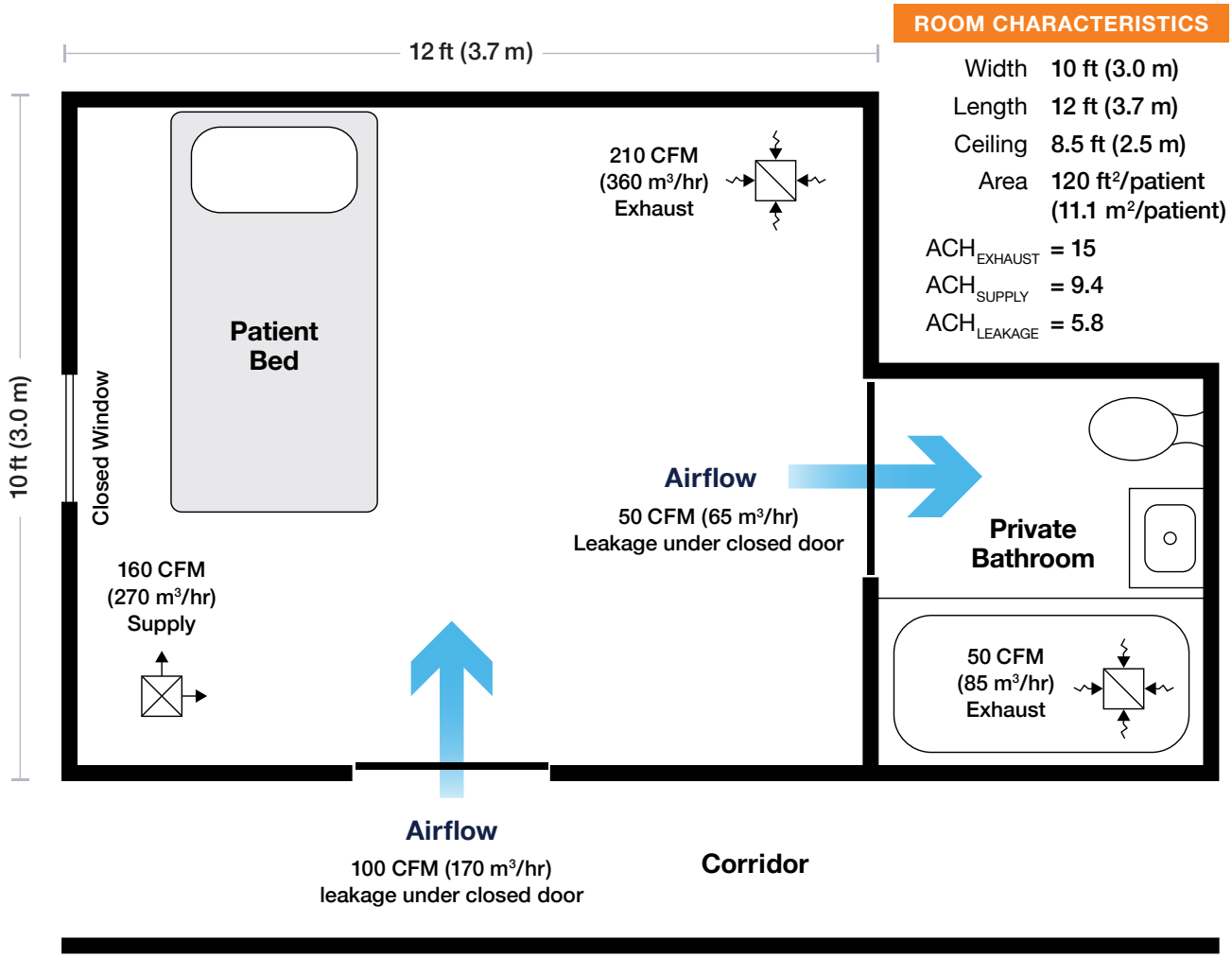
- To dilute airborne TB or microorganisms, AIIRs should have a **minimum of 12 ACH.**
- To contain airborne TB or microorganisms, AIIRs should have a **minimum pressure differential, relative to surrounding areas, of at least 0.01 "wg (2.5 Pa)** such that air flows into the AIIR. AIIRs are generally set for a minimum of 0.05 "wg (12.5 Pa) to maintain containment during small fluctuations in the HVAC system airflow rates.
- To maintain a negative pressure differential relative to surrounding areas, the **exhaust airflow rate should be ≥10% or ≥100 CFM (≥170 m^3/h), whichever is greater, than supply airflow rate.** This is called airflow differential or differential airflow.
- Variable air volume (VAV) systems that are often used to adjust "zones" of temperature should not be used for AIIRs. The primary purpose of VAV systems is to vary the airflow rate based on room temperature and they may not reliably meet the requirements for contaminant control.

Note that higher pressure differentials of up to 0.1 "wg (25 Pa) have been used; however, this is difficult to maintain and requires more powerful ventilation equipment, stronger ductwork, and a tightly sealed room.

For more in-depth information on AIIRs, including considerations for upgrading or converting an existing room into an AIIR, see Chapter 4, *Airborne Infection Isolation Rooms*.

An example of an AIIR is illustrated in Figure 5.

FIGURE 5. **Sample ventilation scheme for an AIIR used for a TB patient**



Source: Adapted from *CDC Core Curriculum*, Chapter 6[9]

- The mechanical exhaust airflow rate of 210 CFM in the AIIR is set higher than the room's HVAC air supply rate of 160 CFM. The mechanical exhaust airflow rate in the bathroom is 50 CFM. The total airflow differential of 100 CFM meets the recommendations of CDC. In addition, the ACH of 15 exceeds the recommendation of CDC for an AIIR. Assuming this AIIR does not have a large opening to the surrounding areas (except slot under the door), the pressure of this room should be at least 0.01 "wg (2.5 Pa) lower than the corridor and adjacent areas.
- The pressure differential will cause additional air to flow into the room, mainly from the more positive pressure space of the corridor through the space under the entry door into the room (100 CFM). The continuous flow of air inward prevents the spread of any infectious particles generated by an individual within the room from spreading through the corridors to other areas of the facility.
- Note the positioning of the clean air supply is at a distance from the exhaust grille. This avoids "short-circuiting" of clean air so that it is not inadvertently pulled immediately out through the exhaust system without having a chance to mix and dilute the concentration of any infectious particles in the room.

- The exhaust grille is located closer to the patient (potential source of infectious particles). Exhaust air should be released outdoors away from other windows or areas of air entry into the building and away from where people may congregate outside.

AIIR leakage and sealing

The magnitude of the required airflow differential to achieve a pressure differential of ≥0.01 "wg (2.5 Pa) is a function of the leakage area and the airflow differential of a room. Poorly sealed rooms are susceptible to losing their intended pressure differential and allowing contaminated air to flow into adjacent spaces. One might think that the only leakage area is the slot under a door. There may be additional leakage around windows and doors as well as through holes in surfaces for electrical outlets or other utilities, false ceilings, and other openings in walls, ceiling, or floor.

- Sealing a room may be required to make it as airtight as possible to prevent air from being pulled in through cracks and other gaps and preserve the desired degree of negative pressure.
- If the leaks allow in a greater amount of air than the negative pressure offset, this excess air will flow out of the room under the door and through any other openings. This can cause a room to operate under positive pressure even though the mechanical system is designed to create negative pressure.
- If the envelope (i.e., all outdoor-facing aspects: exterior walls, foundation, roof, windows, and doors) of a building is not sealed, wind can adversely affect room pressurization.
- False ceilings (i.e., a ceiling with 2'x2' or 2'x4' “tiles”) are major areas of air infiltration and a huge airflow differential may be needed to maintain an adequate pressure differential.[13-15] The Facility Guidelines Institute (FGI) recommends ceilings in AIIRs be solid, with no seams, to provide a pressure barrier (additional technical details may be found in references).[14-16]

As the opening under the door gets smaller, the velocity of the air entering the room will increase and the pressure differential will increase.

- As a general rule of thumb, the velocity of air under the door should be at least 100 fpm (0.5 m/s).

Whenever the door is open, directional air movement at the doorway is uncertain. Although more air is being drawn into the room than is leaving because of the airflow differential, the large door opening results in a free exchange of air occurring at the door. Air is coming into the room, but air is also leaving. Negative pressure spaces may be designed with an anteroom to reduce the counterproductive effects used by entry and exit into the room.[17]

The greater the offset and the tighter the room is sealed, the better the containment of infectious particles.

Positive pressure: Protective environment

At times, it is desirable to reinforce the safety of an area (e.g., a nursing station next to a crowded ward). This can be accomplished by creating a positive pressure environment, **supplying higher amounts of clean air to a space relative to the adjacent surrounding areas.** This works to discourage flow of potentially contaminated air from the adjacent areas into the protected areas.

- To create a protective environment, the recommendation for air exchange rate remains 12 ACH and the differential pressure remains the same (≥0.01 "wg, 2.5 Pa); however, air should flow out of the room. This is sometimes called "positive pressure."
- To achieve a positive pressure relative to surrounding areas, the supply airflow rate should be ≥10% or 100 CFM (170 m^3/h), whichever is greater, than the exhaust airflow rate.
- The principles for designing and maintaining a protective environment are similar to those discussed for AIIRs, with the primary exception being that the driving force behind the airflow and pressure differentials is the higher supply of clean air relative to exhaust or return air creating a positive pressure space. Operating rooms, bone-marrow transplant rooms, and burn-patient rooms are other examples of protective environments.

In specialized circumstances, a combination of positive and negative pressure strategies for adjacent spaces or combination AIIR and protective environment rooms may be desired. An example for application would be a special care unit for highly immunocompromised persons being treated for a transmissible airborne infectious disease.

Local ventilation methods: Booths, tents, hoods

Local ventilation is a ventilation method in which airborne contaminants (e.g., infectious droplet nuclei or other infectious particles) are collected and/or removed before they are dispersed into the general environment.

- **Enclosing devices contain the source of aerosolization as well as remove the aerosolized infectious particles.**
- The most common examples of local ventilation methods include sputum collection booths, isolation tents, enclosing hoods, and biological safety cabinets (BSCs).
- Enclosing booths or tents, such as those used for sputum collection/induction or isolation of an infectious patient, are available in many different designs.
- Ventilated external exhaust hoods are generally not very efficient unless they have a high capture velocity and are placed very close to the point of aerosol generation. Use caution and properly vet the hoods with an environmental engineer or contractor if considering for use during high-risk aerosol generating procedures such as sputum induction (generally not recommended for this use).
- Ventilated workstations and BSCs are used in clinical, microbiological, and research laboratories. These two technologies will not be discussed further in this manual. For a useful CDC-collaborative resource, see *Ventilated Workstation Manual for AFB Smear Microscopy* (Angra, 2011).[18]

Sputum booths

A sputum collection booth is an enclosing device functioning as a mini AIIR. The aerosol-generating procedure is conducted within the booth (the patient is inside the booth and the HCP outside the booth). See Figure 6.

- In general, the sputum booth should be located within a room that meets the ventilation requirements of an AIIR. This is recommended so that the HCP is protected if the exhaust high efficiency particulate air (HEPA) filter and/or exhaust UVC lamp(s) are not working properly.
- The sputum booth should be at a lower pressure than the surrounding area to prevent contamination of the room.
- Generally, sputum booths should be operated at 20-24 ACH or greater and a pressure differential of at least 0.1 "wg (25 Pa).
- Some units have HEPA filters that recirculate air back into the same room or duct air outside, while others simply duct all air outdoors, away from people, open windows, and ventilation air intakes.

FIGURE 6.

Sputum booth
(installed within an AIIR)

Source: CITC/San Francisco Department of Public Health, TB Prevention and Control Clinic

Isolation tents

"Tents" may come in different configurations. Figure 7 depicts a tent that encloses the patient as well as all necessary medical equipment.

- Tents may provide temporary isolation when no AIIRs are available.
- A negative pressure environment may be created inside the tent to reduce transmission risks from an infectious source to HCP within a "normal" neutral pressure room.
- A negative pressure environment inside a tent may also be located within a positive pressure environment (outside the tent) for a combination AIIR and protective environment solution.
- Tents should provide both inward airflow as well as a minimum of 12 ACH and a pressure differential of at least 0.01 "wg (2.5 Pa).
- The air may be recirculated if HEPA filters are properly maintained and tested; otherwise, the air should be safely exhausted to the outdoors.

FIGURE 7.

Example of a tent isolation room

Source: UCSF/Barbara Ries

HVAC systems

Facilities that do not already have an HVAC system (central ventilation system) can improve air circulation and reduce TB transmission risk by adding one. Facilities that have existing HVAC systems should make any necessary improvements to make sure the systems have adequate components in place and meet the applicable regulatory requirements. In all cases, environmental controls must be in place and followed to prevent the spread of contaminants.

This section describes HVAC systems and methods to assess and improve a system. It should be useful to those responsible for an existing facility served by a mechanical system and to those considering the design of an HVAC system for a new or an existing building.

About mechanical ventilation systems

HVAC systems, also called forced-air systems, are mechanical ventilation systems that circulate air in a building. By providing a combination of outdoor air and clean air (filtration and/or UVC disinfected) to support dilution, a mechanical ventilation system can help prevent the spread of TB.[19]

However, the same system can inadvertently spread particles containing *M. tuberculosis* beyond the room occupied by the TB patient because it recirculates air throughout a building. **Recirculating ventilation systems have been responsible for TB transmission** among people who were never in the same room but shared air through a ventilation system.[20]

Using a mechanical system to improve TB IPC

There are four general ways in which an HVAC system can help interrupt the path of TB transmission:

- It can introduce outdoor air to dilute and replace room air.
- It can use filters to remove infectious particles from recirculated air.
- It can use UVC lamps to disinfect recirculated air.
- It can be designed to support the pressure differentials for AIIR and protective environments.

These features can be incorporated into the design of a new system or can be added to some existing systems.

HVAC configurations

HVAC systems come in many different configurations. A ventilation unit can be in a utility room, a rooftop, an attic, a basement, or a closet, or it can be suspended from the ceiling in the room itself. The basic components of the system are usually the same and may include some or all of the following:

- Filters to remove particles from outdoor air
- Filters to remove particles from recirculated air
- In-duct UVC lights to inactivate microbes

- A fan to move the air through the unit
- A section for heating
- A section for cooling and/or dehumidifying

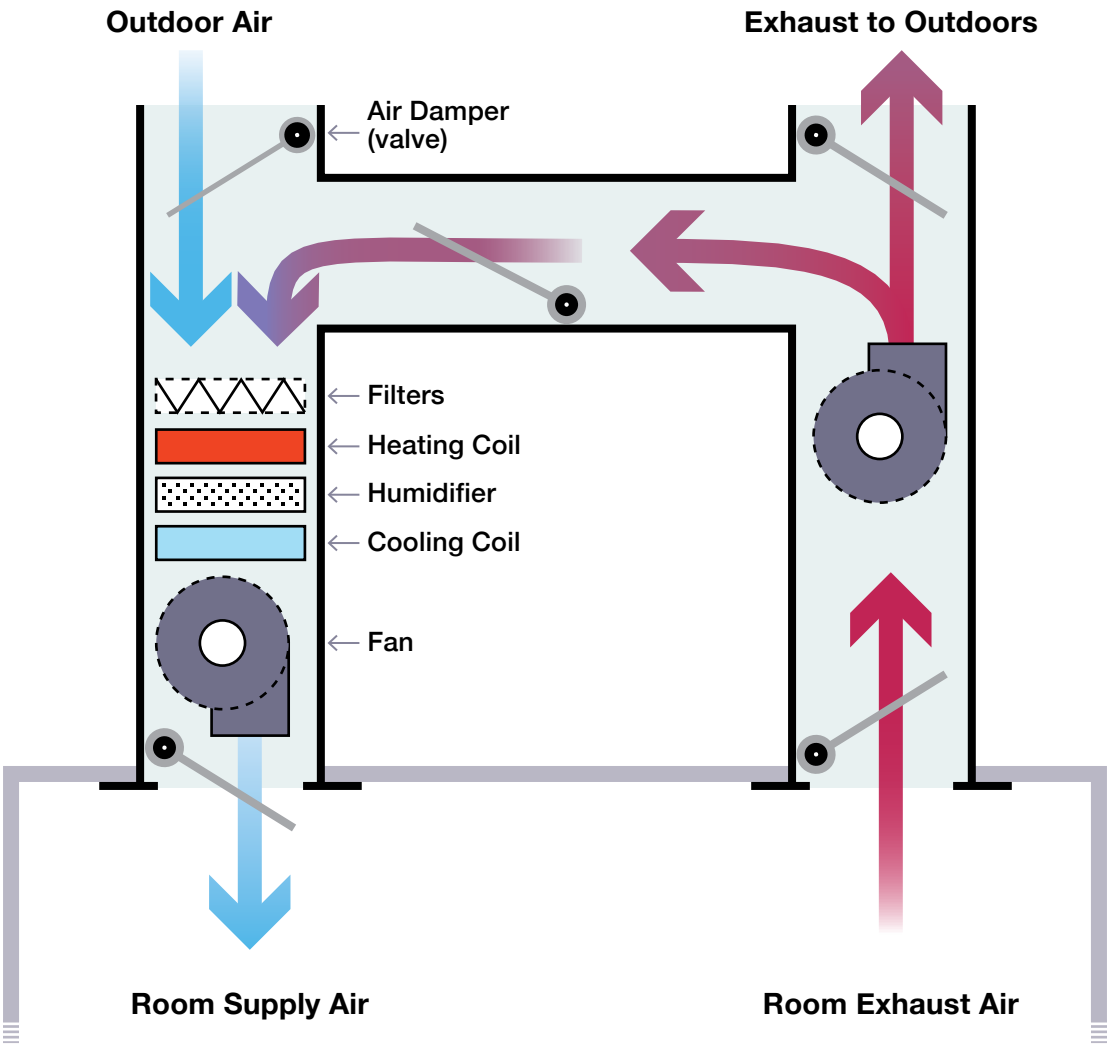
These components can be installed in a single unit or can be housed in separate sections. A system may also include other parts, such as:

- A thermostat and controls
- Ductwork, diffusers, and/or grilles to distribute and collect air

Figure 8 shows an example of a recirculating HVAC configuration.

A more detailed introduction to engineering HVAC principles can be found in the Price Industries *Engineer's HVAC Handbook* (2011).[21]

FIGURE 8. **Example HVAC recirculating system (partial outdoor air intake)**



Recirculating HVAC systems

Some buildings have an HVAC system that recirculates all air returned to the system, i.e., 100% recirculation and 0% outdoor air.

In a 100% recirculating HVAC system, air is supplied to a room to provide ventilation and/or heating or air conditioning. This air mixes with room air and then is drawn back (returned) to the HVAC system, where it is filtered and/or irradiated as well as heated and/or cooled before being sent back to the room.

Even in a building with a recirculating HVAC system, some rooms will exhaust rather than return air. Typically, bathrooms, shower rooms, institutional kitchens, and similar spaces will have a separate fan to exhaust air directly outdoors. Care must be taken so that exhaust air to outdoors does not inadvertently re-enter the facility through leakage points around nearby doors, windows and even ceilings, walls, or outdoor air intakes.

For TB control, the best type of HVAC system is one without recirculation—that is, a 100% outdoor air (single-pass or once-through) arrangement. In this case, all supply air is outdoor air, which is filtered and then heated or cooled before it is supplied to the AIIR. All potentially contaminated room air is exhausted directly outside the building.

However, once-through HVAC systems are uncommon in smaller healthcare settings because it is expensive to continuously heat or cool air from outside to a comfortable room temperature and relative humidity. For example, if it is 40 degrees Fahrenheit (°F) outdoors and 70°F indoors, recirculating 70°F air is cheaper than heating outdoor air from 40° to 70°F. To maintain comfort and minimize mold growth, relative humidity should range from 40-60%.

Most commercial HVAC systems, such as those that serve office buildings, are a compromise between 100% recirculation and 100% outdoor air. They recirculate most, but not all, of the air returned by the system. The portion of outdoor air is usually somewhere between 10 to 30% of the total quantity of supply air. If not properly treated, recirculated air may increase risk of infection. Many larger HVAC systems also have some kind of energy recovery. See ASHRAE COVID Recommendations[22] as well as the *ASHRAE Handbook: HVAC Systems and Equipment*, 2020.[23]

Air supply and exhaust

A ventilation system introduces and removes air by means of air diffusers and grilles. In most healthcare applications, diffusers and grilles are usually mounted on a ceiling or on a wall.

- Supply air inlets are called **diffusers**. Exhaust air outlets (or return) outlets are generally called **grilles** or registers.
- The neck of the inlet or outlet is the point at which the outlet connects to the air duct. The neck size is selected to match the desired airflow rate and air velocity.

- The pattern or style of an inlet or outlet is the physical configuration of its face as seen from the room. For example, many supply air diffusers (inlets) can have a louvered pattern while many exhaust air grilles have a perforated metal pattern

Air provided to a room is called *supply* air. Air removed from a room, however, is either *return* air or *exhaust* air, depending on the path it takes after it leaves the room.

- **Return air** is "returned" to the HVAC unit for up to 100% recirculation
- **Exhaust air** is discharged outdoors for up to 100% exhaust (no recirculation)

The effectiveness of any given ventilation rate in clearing a space of air contaminants depends on how well the air is mixed. In turn, air mixing depends largely on how and where air enters and leaves the space. Consequences of poor air mixing are stagnation, temperature stratification, and short-circuiting. Avoid these situations because they reduce the benefits of dilution ventilation.

- **Stagnation** occurs when part of the room does not benefit from the clean supply air. It also occurs in a room that does not have any ventilation, or has poorly designed diffusers and/or poor installation. People in a stagnant location would probably feel that the air is stuffy. Infectious particles in a stagnant area can remain concentrated and will dissipate slowly.
- **Stratification** occurs when there is an increase in temperature from the lower level of the room to the ceiling. A poorly designed room, with incorrect supply air diffusers at or near the ceiling, may provide warm, clean air during the heating season that unfortunately remains in the upper portion of the room without significantly mixing, diluting, or warming the air in the occupied lower part of the room.
- **Short-circuiting** occurs when clean air is removed before it has mixed well with room air, such as when the exhaust air grille is located right next to the supply of incoming air. A room must not only have a satisfactory amount of clean air supplied to it, but this air must also mix with the air already in the room.

Proper selection and location of the supply air diffusers and exhaust air grilles will help avoid stagnation, temperature stratification, and short-circuiting.

More detailed engineering considerations for HVAC principles and mixing ventilation can be found in the Price Industries *Engineer's HVAC Handbook* (2011).[21,24]

HVAC components

Diffusers and grilles

Supply air diffusers provide tempered air for comfort (temperature and relative humidity) as well as outdoor and/or clean recirculated air to reduce the airborne concentration of CO_2, odors, chemical vapors, and infectious particles. Clean supply air also reduces the concentration of infectious particles in a room.

- For example, an HVAC system provides heating to two separate dormitory rooms in a homeless shelter. Each dormitory room has three small supply-air diffusers in the ceiling, directing air into the occupied space, to ensure that the heated air reaches everyone in both rooms. A single large grille in the hallway

returns air to the HVAC system. In this building, the general direction of air will be from the dormitory rooms to the hallway, then the air is returned to the HVAC system. In this case, 90% of the air is recirculated back to the dormitories and 10% is replaced with outside air. With proper diffuser design, the air will be well-mixed in the dormitories.

Choosing a proper type of diffuser and its placement can impact how well the supply air moves and mixes in a space to reach all areas, avoiding stagnation, and how well heated or cooled air is mixed and distributed to avoid counterproductive temperature stratification. The design of a diffuser can determine the direction and influence the velocity of entering air.

Placement of **exhaust grilles** in relationship to supply diffusers is also important. Short-circuiting, as described in the previous section, may occur if the source of supplied air is located too close to the exhaust grille and does not allow the desired mixing and dilution of air in the room. Hence, a ceiling exhaust grille is generally placed far from the supply air diffuser.

An HVAC specialist can assist in the proper selection and placement of supply air diffusers and exhaust grilles.

Figure 9A shows the ideal (but rarely applied) supply air diffuser and exhaust air grille locations. Note that this is similar to an industrial "clean room" and is generally not feasible in most healthcare settings. Figure 9B shows alternate placement of diffusers and grilles as a compromise to the ideal locations. This is seen in a large number of operating theaters and in a few AIIRs.

FIGURE 9A.

Example of HVAC design where air moves from one wall to the opposite wall (most efficient design)

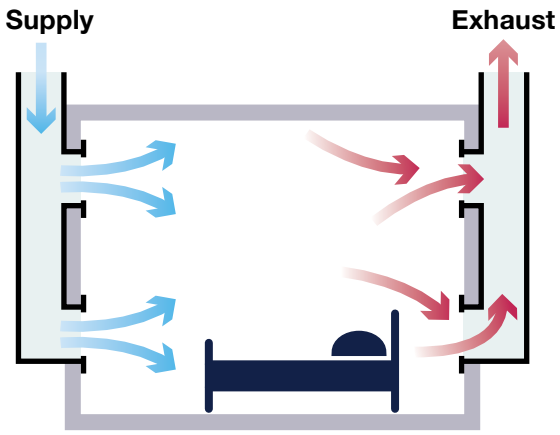
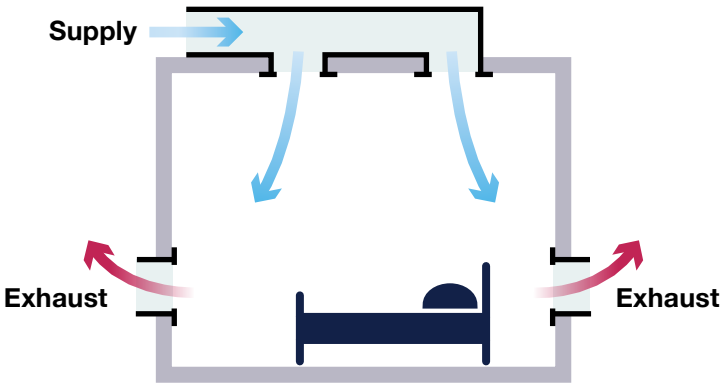


FIGURE 9B.

Example of HVAC design with air supplied from ceiling and exhausted lower in room through walls



Source: Figures 9A and 9B. Adapted from CDC: *Guidelines for Preventing the Transmission of Mycobacterium tuberculosis in Healthcare Settings, 2005*[5]

Figure 10A depicts another reasonable example of diffuser and grille placement. Here, the desired airflow is pushed from a diffuser across the ceiling then down the walls to mix in the occupied space. The exhaust is in the corridor so the airflow patterns (i.e., air mixing) is acceptable. This HVAC setup could be used to support a protective environment.

FIGURE 10A.

Supply air source in room with exhaust in corridor: A louvered supply air diffuser in the ceiling with the exhaust grille located outside of the room

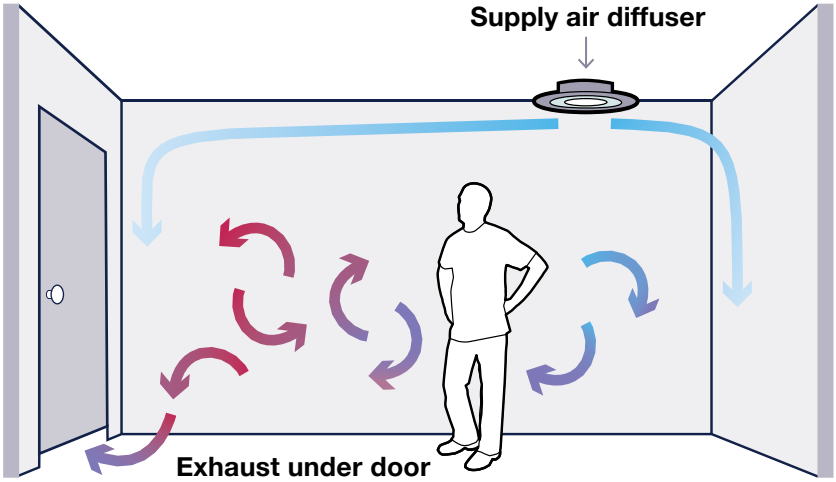


Figure 10B depicts the problem of short-circuiting due to the close proximity of the supply air diffuser and the exhaust air grille. Short-circuiting occurs when a portion of the supply air is quickly exhausted, limiting the desired air dilution and mixing.

- With both air supply and exhaust located in the ceiling, short-circuiting may increase when heating systems are in use, since warm air rises (buoyancy factors). Proper mixing to adequately move the warm supply air downward can reduce short-circuiting.

FIGURE 10B.

Short-circuiting: A louvered supply air diffuser in the ceiling with an exhaust grille located nearby (too close together)

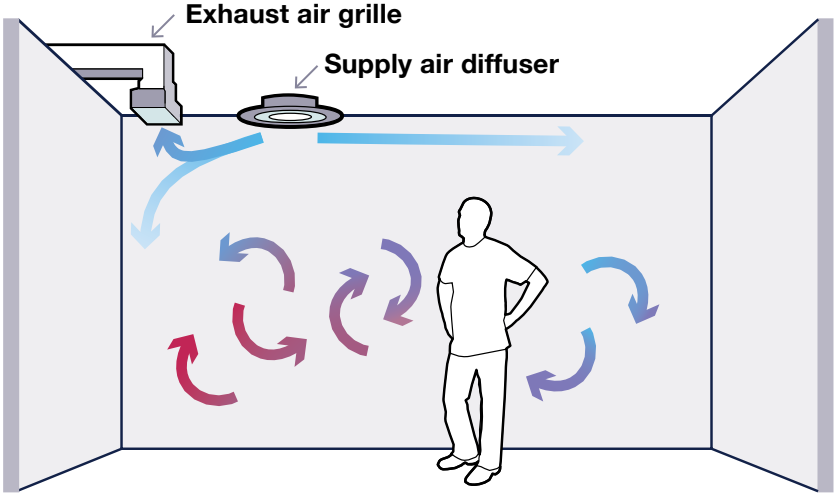
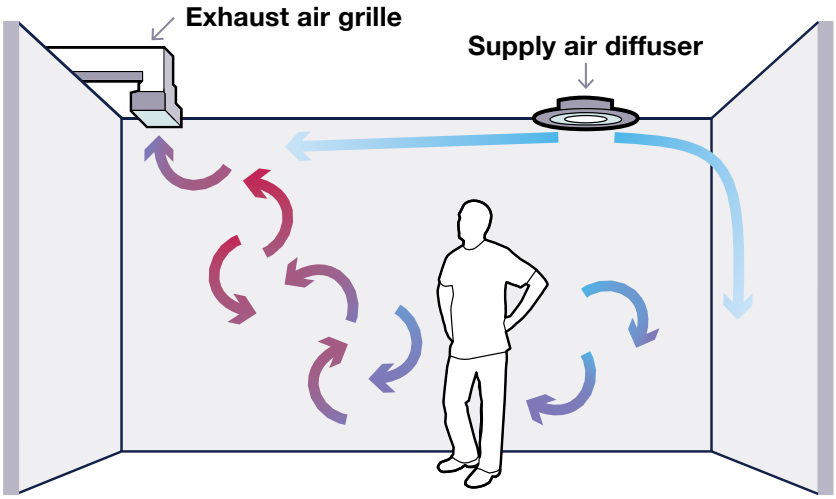


Figure 10C depicts the best compromise when both the supply air diffuser and the exhaust air grille are located in the ceiling. In addition, some vertical air movement is created as air is warmed from the presence of occupants in a room. Therefore, the diffuser design should take into account not only the geometry of the room, but also the equipment, activities, and occupants in the room.

FIGURE 10C.

Supply air source separated from exhaust within the same room:
A louvered supply air diffuser in the ceiling with an exhaust grille located as far from the supply air diffuser as possible



For images of different types of supply air diffusers and exhaust grilles, see section, *Design of new HVAC systems, Air distribution*, and Figure 11.

Outdoor air intake

The **outdoor air intake** is where outdoor air enters the HVAC system on the roof or an outside wall. It can be a duct opening or part of the unit, and it usually includes an adjustable damper. A damper is a device that can be adjusted to increase or decrease the amount of outdoor air drawn into the unit.

If possible, existing 100% recirculating HVAC systems should be modified to include an outdoor air intake. A facility engineer or a mechanical contractor should do this work.

As air is drawn in, dirt and debris, such as bird feathers, pollen, mold, and dust may accumulate around the opening. For this reason, intakes are usually easy to find. A wire mesh screen and low-efficiency filters (minimum emission reporting value [MERV] 1-7) are often used to trap dirt and debris. Note that some filters are "loose fitting" while others are "tight fitting." Loose-fitting filters are generally lower efficiency and may have significant leakage around the filter. Tight-fitting filters generally have a neoprene or synthetic gasket to seal the filter onto the HVAC system, thus preventing leakage of particles around the filter.

When feasible, outdoor air intakes should be kept fully open and routinely cleaned to allow in as much outdoor air as possible.

Air filters

Filters are used to clean air. They are rated based on their efficiency to remove particles from air that is passed through them, assuming a secure seal of the filter to the HVAC system. ASHRAE MERV rates the filtering efficiency of an air filter on a scale of 1 to 16. The higher the MERV rating, the more efficient a filter is. In general, as filter efficiency increases, the resistance (pressure drop) of the sealed filter increases. Physical/non-electrostatic filters rely on physical filtration properties to remove airborne particles. The pressure drop across a non-electrostatic filter will increase with loading and potentially lead to a decrease in the actual airflow rate.[25]

An electrostatic filter relies on a "permanent charge" to increase its filtration efficiency. As the electric charge is lost or shielded, the filter may become less efficient. In general, an electrostatic filter will have a lesser pressure drop than a physical filter of the same reported filtration efficiency. The pressure drop across an electrostatic filter and the actual filtration efficiency may decrease as the electrostatic charge is dissipated and/or masked by airborne particles. Therefore, depending on the type of filter used, the pressure drop may or may not be the most useful indicator of ongoing filter efficiency or when the filter should be changed. In addition to ASHRAE, other trade or standardization organizations offer rating systems for filters that may be listed under specifications, including the International Organization for Standardization (ISO).

- Appendix C contains a table of MERV filter efficiencies for three different particle size ranges (0.3-1.0 µm, 1.0-3.0 µm, and 3.0-10.0 µm).
- HEPA filters are specialized filters that remove 99.97% of particles 0.3 µm in size (U.S. Department of Energy standards). HEPA filters are rated separately from MERV filters.

Infectious particles (droplet nuclei) generated by TB patients are believed to have a broad size distribution. These droplets may contain one or more bacilli. Because only **1–5 µm sized infectious particles** can reach deep into the lung and infect a susceptible host, systems should target filtration for particles of this size.

Filters are a standard component within recirculated air systems as well as individual room air cleaners. Ventilation systems may have just one filter, or they may have two or more. More than one filter is referred to as a filter bank.

What type of filter should be used?

The most suitable type of filter for many recirculating air systems is a pleated filter, named because the filter inside the filter frame is folded into pleats. Lint filters are commonly flat.

Table 3 compares three different rated filters:

- **Coarse or lint filter (MERV 4):** A common lint filter will remove few particles in the size range of infectious particles containing *M. tuberculosis* (note: MERV 1-7 filters are only tested with 3.0-10 µm to determine their rating).
- **Pleated filter (MERV 13):** Pleated filters can remove more than 85% of all particles in the size range of infectious particles containing *M. tuberculosis*. Pleated filters are most commonly supplied as "box/frame"-style filters. "Bag/pocket"-style filters may have similar (or greater) filter surface area and similar performance as compared to pleated filters.
- **HEPA filter:** A HEPA filter will remove virtually all particles in the size range of infectious particles containing *M. tuberculosis*. Note that a HEPA filter is a densely pleated, specialized device that will not fit in most standard HVAC systems.

Lint or coarse filters (MERV 1-4) as well as pleated filters (MERV 5-13) are generally available from hardware stores in sizes that fit most small HVAC systems.

Pleated filters are slightly more expensive than lint filters. They also cause more of an obstruction, which may reduce airflow.

More detailed engineering considerations for use of filters within HVAC systems for healthcare settings can be found in the Price Industries *Engineer's HVAC Handbook* (2011).[21,26,27]

TABLE 3. **Examples of selected ventilation filters and their filtration efficiencies**

Coarse or Lint Filter	Pleated Filter	HEPA Filter
MERV 4	**MERV 13**	**HEPA**
		
Particle Size Efficiency / **Filtration** 0.3-1.0 µm — Not evaluated 1.0-3.0 µm — Not evaluated 3.0-10.0 µm — <20%	**Particle Size Efficiency** / **Filtration** 0.3-1.0 µm — ≥50% 1.0-3.0 µm — ≥85% 3.0-10.0 µm — <90%	**Particle Size Efficiency** / **Filtration** 0.3 µm — ≥99.97%
A MERV 4 filter will not remove small infectious particles containing *M. tuberculosis*. They will remove very large, visible particles such as some pollens, molds, and lint. There is very little initial resistance across a filter such as this upon initial installation. Generally, these filters are changed on a monthly or quarterly basis. They are designed to extend the life of more expensive, more efficient filters.	A MERV 13 filter will remove at least 85% of small infectious particles containing *M. tuberculosis*. An N95 respirator filter is more efficient at small particle removal than a MERV 13 filter. There is moderate initial resistance across a filter such as this upon initial installation. Generally, these filters are changed on a quarterly, semi-annual, or annual basis. They are designed to extend the life of very expensive, more efficient, HEPA filters.	A HEPA filter will remove nearly 100% of small infectious particles containing *M. tuberculosis*. An N100 respirator filter is of equivalent filtration efficiency. There is a significant initial resistance across a filter such as this upon initial installation. Generally, these filters are changed based on a combination of resistance (pressure drop across the filter) and system airflow rate.
Reference: ASHRAE 52.2-2017[25]	**Reference:** ASHRAE 52.2-2017[25]	**References:** ASHRAE Handbook: HVAC Systems and Equipment, Chapter 29;[28] and IEST RP-CC 001.7[29]

Sources: CITC, Adobe/Sakuramos, Adobe/Vchaulup

How often should filters be changed?

In the absence of a pressure gauge to measure the pressure drop across a filter, **there should be a set schedule to change filters. In addition, filters should be checked visually every month** and replaced if a decrease in airflow is noticed or per manufacturer's instructions, whichever is more frequent.[30]

It is important to replace filters before they obstruct or reduce the airflow rate below the minimum acceptable airflow rate. As mentioned in Table 3, there are often two or three filters in a system. When used in combination, the lint or course filter helps

extend the life of a pleated filter, and a pleated filter helps extend the life of a higher MERV or HEPA filter. **In general, lint or course filters are changed monthly or quarterly. Pleated filters, if protected by a lint or coarse filter are changed quarterly or annually.** HEPA filters, if protected by both a lint or coarse filter and a pleated filter, and based on acceptable pressure drop, may be changed every few years. The amount of time it takes for a filter bank to load up depends on:

- How many particles there are in the air (the dustier the room air, the quicker the filter will load up); and
- How often the ventilation system is operated (the more frequently the ventilation system is used, the quicker the filters will become dirty).

Fan energy is used to push or pull air through filters. This is because filters cause an obstruction in the air's path. Over time, as dust accumulates, the obstruction increases. Consequently, the amount of air that the fan can move through the filter may decrease. Less airflow means less removal of infectious particles and less clean air supplied back to a space to support dilution.

Pressure drop and filter gauge

The relative amount of obstruction caused by filters is called the **pressure drop or resistance.** It is measured in inches of water gauge ("wg).

A pressure gauge installed across a filter bank shows the pressure drop across the filter. This is the most effective way to monitor filter loading and to determine when it is time to change the filter.

A filter gauge assembly consists of:

- The gauge
- Two measurement ports that are installed inside the duct, one on each side of the filter
- Copper or rubber air tubing

Generally, tubing connects each sampling port to a pressure gauge or manometer. The gauge reads the pressure difference between the front (upstream) and the back (downstream) of the filter.

The observed pressure drop when new filters are installed is called the **clean pressure drop.** For pleated filters, this is usually about 0.25 "wg (62 Pa). As the filter loads up, the pressure drop will increase. The filter is usually replaced when the pressure drop increases by roughly 0.20 "wg to 0.45 "wg (50-110 Pa). This is called the **changeout pressure drop.** HEPA filters start with a clean pressure drop of approximately 1"wg (250 Pa). Follow filter, HVAC system, and RAC manufacturer's instructions for actual changeout pressure drop recommendations. This is critical as airflow generally decreases with an increase in pressure drop.[30]

Some filter banks in HVAC systems (and most RACs) do not include a filter gauge, and many smaller ventilation systems are not constructed to accommodate one; e.g., most residential-type recirculating HVAC systems do not have an obvious

location for a filter pressure gauge. As a rule of thumb, consider installing a filter pressure gauge if the system has a filter bank, as opposed to just a single filter. A facility engineer or mechanical contractor can assist with the system evaluation and installation.

Replacing existing filters with higher-efficiency filters

On occasion, a **low-cost improvement to an existing HVAC system can be done by upgrading the existing filter with a replacement filter that has a higher filtration efficiency.** General issues to consider include:

- Potential added airflow resistance of a higher efficiency filter
- Increased load on the fan/motor combination with a new filter (as well as effect of loaded filter)
- Possible shortening of the life of the fan/motor combination
- Increased cost due to increased frequency of changing/replacing the filter
- Reduction in airflow rate and reduction in ACH of room or setting

If higher efficiency filtration is deemed important based on the facility risk assessment, consider consulting with a facility engineer to ensure the system can support replacement with an upgraded filter.

- A standard residential or small office system is generally a recirculating system. Often, they are fitted with a MERV-5 (1"- or 4"-thick) filter.
- Do **not** jump immediately from a MERV-5 to a MERV-13 filter (often recommended for COVID-19 prevention and for clean air to obtain Leadership in Energy and Environmental Design [LEED®] certification). The best solution is to test by slowly increasing the filtration efficiency (MERV rating) until a significant reduction in airflow rate is detected.
    - A simple, qualitative way to test for a drop in airflow involves taping a thin strip of tissue paper to the supply air diffusers in several rooms to see if they flutter the same using the higher efficiency filter compared to the airflow (strip flutter) using the original MERV-5 filter.
    - Once you observe a change, remember this change is with a clean filter (rather than the performance expected over the filter life). Install a filter two MERV ratings lower than the one that showed a significant reduction in airflow.
- Follow the manufacturer's recommendations with respect to when and how to change a filter. Before changing the filter, look at the flutter strip on the supply air grilles.
    - Is there an observed reduction in the flutter observed and/or extension of the strip after the filter change?
        - **If yes,** see if the filter manufacturer makes a different model filter (at the same desired rating) which has a lower resistance (pressure drop across the filter). If not, you should use a new/replacement filter with a lower MERV rating.
        - **If no,** was there a significant increase in airflow as indicated by the flutter strip? If yes, continue to use this MERV-rated filter.

- Note: **Filters with the same MERV rating may have different resistances (pressure drops) between different brands and models.** Do not jump from one filter manufacturer to another without following the steps previously mentioned.
- Aim to have sufficient airflow when the filter is loaded (dirty), not just when it is clean. As such, the filter may need to be changed more frequently than the manufacturer's recommended interval.
- While not intuitive, a thicker filter assembly, such as a 4", has greater filter surface area which results in a lower resistance relative to a standard 1" filter with the same MERV rating. Some HVAC systems may be retrofitted to handle 4" filters. Follow the same routine previously described to check airflow.

Thermostats

In small HVAC systems, similar to residential or small clinic systems, thermostats are usually mounted on a wall near a return air grille. In larger HVAC systems, there may be a network of temperature and relative humidity sensors throughout the systems and a computerized HVAC control system (building management system [BMS]) may serve to control temperature and humidity for the areas served by the HVAC system.

Many different types of thermostats are available for small HVAC systems, ranging from the very simple to programmable units with many functions. Most designs include three basic components:

- A switch that allows the thermostat to control the unit (on/off, fan on/cycle with heating or cooling)
- A thermometer that measures and displays room temperature and often relative humidity
- An adjustable set point that allows the user to input the desired room temperature and often relative humidity

More expensive thermostats allow the user to program the fan, heating, and air conditioning parameters by zone and to have different set points for weekdays and weekends.

The simplest type of thermostat, as used in small HVAC systems, is a three-position switch that operates in response to room temperature. The two positions are **OFF**, **ON**, and **AUTO**.

- When set to **OFF**, the unit will not run, no matter how cold or hot the room becomes.
- When set to **AUTO**, the thermostat will turn on the fan and the heating/cooling component when the room temperature, as measured by the thermostat, drops below the heating set point or rises above the cooling set point.
- When set to **ON**, the fan will operate continuously and the thermostat will turn on the heating/cooling component when the room temperature, as measured by the thermostat, drops below the heating set point or rises above the cooling set point. There are many benefits to leaving the thermostat in the **ON** position:

- The supply air will provide dilution with "clean air" (some portion will be filtered and/or irradiated and some portion may be outdoor air).
- Continuous airflow allows for better airflow patterns and mixing as required for upper-room UVC systems.

For TB control, central control of the HVAC system is recommended.

Checking an HVAC system

To improve TB control and general indoor air quality, make regular checks of all ventilation systems serving the facility. An N95 respirator may need to be worn in the area in the AIIR, within the HVAC system, and where AIIR air is exhausted (in case the air filtration system is not operating properly). Choose a staff person to be the in-house monitor for the ventilation system and follow standard operating procedures for personal protection approved by IPC professionals.

- Develop and maintain a list of basic information for all HVAC systems in the building as a useful IPC tool. The list should include information such as HVAC system location, rooms (including room function) served by the unit, the thermostat location, and the number and size of filters. See Appendix D, *Summary of HVAC Systems Worksheet* for a sample checklist.

If engineering drawings are unavailable, it may be necessary to have a facility engineer or contractor "trace" the HVAC systems to see where all the ducts lead and document the details of the HVAC system. For this task, the facility engineer or contractor will need a rough floor plan of the facility to map and draw the HVAC system. Ducts removing air from AIIRs should be noted and specifically labeled.

Labeling

Maintenance personnel and contractors often re-route ducts to accommodate new services, change-out filters, or perform other maintenance that may require turning off exhaust fans. To help protect these workers, exhaust ducts, fans, and filter housings should be permanently labeled clearly with the words "Caution – TB Contaminated Air," or "TB-Contaminated Air – Contact Infection Control Coordinator before turning off fan or performing maintenance," or other similar warnings. The labels should be attached, at most, 20 ft (6.1 m) apart, and at all floor and wall penetrations. Additional signage located on the fans and filters should include the telephone number of the infection control coordinator and the room number(s) of the AIIR(s) exhausted by the fan or through the filter.[5]

Performing checks of HVAC unit

Check operational status of unit:

- Does the unit have the proper filters? Are the filters clean? In a recirculating HVAC system, the lowest efficiency filter is often located at the return grille in the return ductwork (remove grille to check and replace the filters). Larger systems will have the filter bank located immediately before the HVAC unit.

- Check whether an outdoor air intake is provided at or near the HVAC unit. If yes, check that the damper is set to the fully open position and that the intake grille and ductwork are clean. While not necessary in all situations, ensuring the damper is set to the fully open position allows for maximizing outdoor air and reducing the dependency on filtration/disinfection systems for recirculated air.
    - Note: "Fully open" does not mean 100% outdoor air. If there is an outdoor air intake on a larger HVAC system, it will generally be on the roof or an outside wall. For small systems (i.e., individual room HVAC systems), the damper is generally located in the back of the unit. If there is no damper, then the air is 100% recirculated back into the areas served by the HVAC unit.

Performing checks of AIIRs

- Check that each HVAC system is working by turning on the fan at the thermostat or BMS and observing airflow at all supply diffusers and return grilles. Hold a tissue or generate visible smoke/fog against each outlet to check the direction and "strength" of airflow.
    - At the supply diffuser, the tissue or smoke/fog will be blown away from the diffuser and into the room.
    - At the exhaust or return-air grille, the tissue or smoke/fog will be drawn into the grille and out of the room. Note that dirty or blocked diffusers may impede both airflow rate and airflow patterns.
- CDC (2005) states: "All rooms should be checked for negative pressure by using smoke tubes or other **visual checks before occupancy,** and these rooms should be **checked daily when occupied by a patient** with suspected or confirmed TB disease."[5] This policy statement was originally developed because of the poor performance of physical and electronic pressure monitors.

  At the gap under the door:
    - The tissue or smoke/fog will be drawn into the room for an AIIR.
    - The tissue or smoke/fog will be pushed out of the room for a protective environment.
    - If the tissue or smoke/fog does not move in the proper direction, the cause should be investigated, and the problem remedied before using the room as an AIIR.
    - See Appendix B, *Airborne Infection Isolation Room Pressure Monitor Checklist* for a template to record results.

  Note: Generally, a facilities engineer or trained personnel should also verify the accuracy of the AIIR electronic pressure monitors monthly with a micromanometer (handheld tool to measure pressure).
- Check that the thermostat has a FAN ON or similar setting that allows continuous operation of the fan.
- Check that the HVAC system serves all occupied rooms.
- Check air mixing and determine directional air movement in all parts of occupied rooms.

    - An inexpensive and reliable way to perform these tests is to use incense sticks to visualize air movement. Smoke tubes or simple smoke generators are other options.
- Check that all diffusers and grilles are clean.
- Check that all exhaust fans in bathrooms and shower rooms are operating properly.

Additional guidance on the evaluation of AIIRs can be found in a review article by Int-Hout (2015).[31]

For further information on methods for checking airflow (e.g., smoke or tissues tests, use of manometer), see Chapter 4, *Airborne Infection Isolation Rooms*, section, *Monitoring AIIR environmental controls*.

Optimizing existing HVAC systems

- Use highest MERV filter that allows adequate airflow rate and ACH
- Maximize exhaust airflow rate
- Maximize outdoor air (adjustment of outdoor air dampers) and treatment air (filtration and/or UVC)
- Use thermostats and BMS that allow continuous fan operation
- Run HVAC systems continuously whenever the building is occupied
- Install, if one doesn't already exist, a pressure gauge in HVAC units to monitor filter loading
- Provide natural ventilation to occupied rooms not served by ventilation systems and to all occupied spaces at times when ventilation systems are broken or otherwise not operating
- Consider the use of in-duct UVC as a supplement to filtration and outdoor air dilution (see Chapter 2: *Environmental Controls, Part 2: UVC*)

Routine upkeep of existing HVAC systems

- Check filters per standard operating procedures and replace when required (see section, *Air filters,* for additional details).
    - Ensure filters are installed correctly in the filter track (not jammed into position).
    - When a new set of filters is installed, write the replacement date on the frame of the filter and/or affix a label to the outside of the filter housing (so the filter change information may be checked without opening the filter housing). Tracking the average life of the filters will help in planning maintenance.
- Clean diffusers, grilles, and in-duct UVC lamps every month.
- Check ventilation units and thermostats every year. Make sure that thermostats operate as designed.

If in-duct UVC is used:

- Check that lamps are operating (ideally, monitor with a calibrated UVC meter)
- Clean lamps every month
- Replace lamps at least once a year or as recommended by the manufacturer
- Dispose of used lamps per local or state regulations or per the manufacturer's recommendations (similar to the disposal of fluorescent lamps)
- Keep records of all routine maintenance activities and dates as well as all episodic maintenance events

Design of new HVAC systems

Architects, engineers, and others designing mechanical systems for new or renovated facilities should consider the following recommendations:

Ventilation rate

- Provide sufficient **airflow rate within the range of 6-12 total ACH** based on the function of the room and the TB risk of those using the room (2 ACH may be appropriate for rooms not used by HCP, patients, or clients). Note that ASHRAE[1,32] and CDC 2019[13] define ACH as CADR divided by room volume. ACH is a measure of how many times the air within a defined space is replaced with clean air in one hour.
- Because loading of filters may result in a decreased airflow rate, the designers should select fans that can still provide an airflow rate in the target range even if the filter is fully loaded.
- Dilution ventilation is an effective environmental control against TB transmission. When installing a new ventilation system, it is generally worth the investment to increase ventilation capacity; the incremental cost is insignificant compared to the total cost of the installation's design and construction.
- If the HVAC system will be supporting an AIIR or protective environment designs, other considerations will need to be included (see sections, *Negative pressure: AIIRs* and *Positive pressure: Protective environments*, or see Chapter 4, *Airborne Infection Isolation Rooms*.

Supply air: Minimum required from outdoor source

- If a recirculating system is used, a fixed minimum proportion of the supply air should be outdoor air. This value is usually called the **minimum outdoor air set point.**
  - **CDC 2005 guidelines recommend a minimum outdoor air supply rate of 25 CFM per person for homeless shelters.**[5]
  - **ASHRAE** (Standard 170-2021) **recommends a minimum 2 outdoor ACH (out of a total of 12 ACH) in AIIRs and emergency departments, with 100% of the air exhausted to the outdoors.** With 100% of the air being exhausted, the supply must either be: 1) partially recirculated air and/or disinfected air (via filtration or UVC) from other areas of the facility, or 2) 100% outdoor air.[1]
  - Appendix E contains ACH and other ventilation recommendations for selected settings within a healthcare facility.

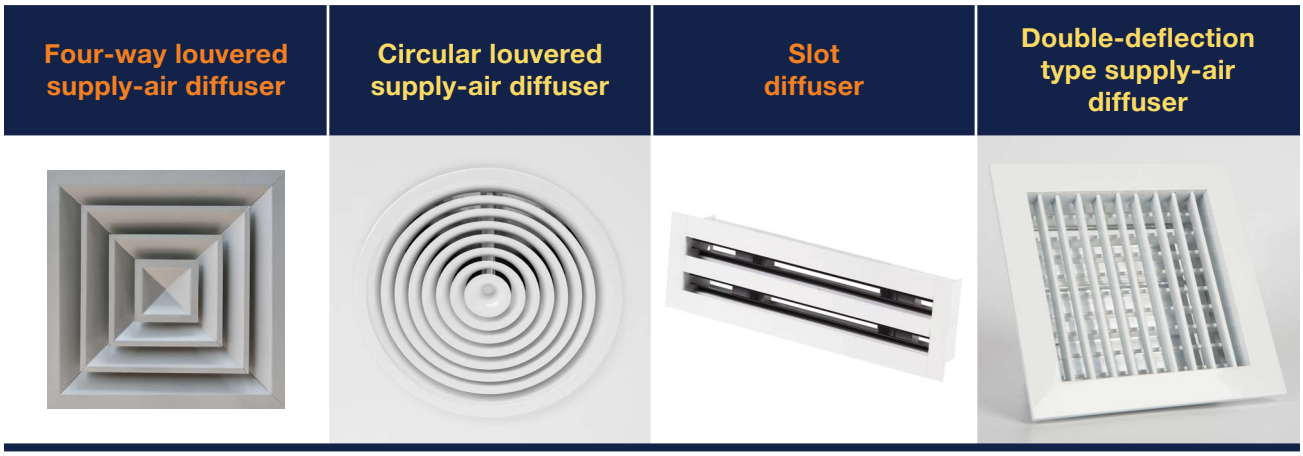
Once-through system or variable recirculating system

- Consider using a single-pass or once-through ventilation system for TB control. This type of system exhausts all air to the outdoors, rather than recirculating a portion of the air.
- If the operation of this type of system would be too expensive, consider providing a recirculating ventilation system that allows adjustment of the amount of outdoor air mixed with the recirculated air. Such systems automatically adjust the amount of return air to be recirculated depending on the temperature outdoors. If it is temperate outdoors (e.g., 65°F, 18°C), outdoor air will be continuously brought in to provide what is often referred to as "free cooling," effectively serving as a single-pass system (with all exhaust air directed to the outdoors).

Air distribution

- **Whenever possible, provide supply air and exhaust locations in each room, rather than collecting exhaust air from several rooms at a single location.** This will reduce the possibility of air currents carrying infectious particles to other areas.
  - Return-air grilles should be located in the same room and as far away as possible from supply-air diffusers so that supply air can fully mix with room air.
- Select the supply air diffusers and exhaust air grilles of the HVAC system to ensure good air mixing. Adequate air supply, air exhaust, and air mixing will greatly reduce the risk of TB transmission by diluting and removing infectious particles. Select diffuser characteristics, such as size and air diffusion pattern, to suit the room characteristics and the individual diffuser location within the room.
  - If the system includes ceiling diffusers, air mixing can be enhanced by using the louvered face type or slot diffusers, rather than the perforated face type of diffusers. Perforated designs are better suited to be used as exhaust grilles. See Figures 11 and 12.

FIGURE 11. **Examples of diffusers**



Sources: Adobe/AliaksandroBS, Adobe/Evannovostro, Adobe/29612992, Adobe/Grispb

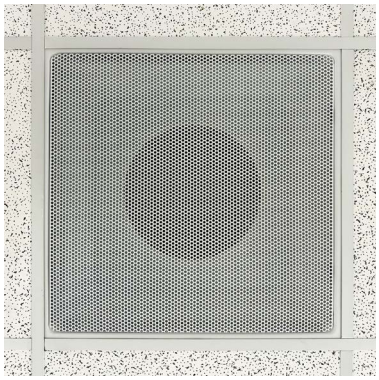
- If sidewall air supply diffusers are used, the diffusers should be the double deflection type, with two sets of air deflection blades. The front set of blades is vertical; the second set behind these is horizontal. The louvers should be adjusted to provide even air-flow patterns in each room.

In-duct UVC in HVAC systems

- In-duct (or return-duct) UVC may be used in an HVAC system to disinfect air removed from a group setting before recirculation. In-duct UVC is discussed in more detail, see Chapter 2: *Environmental Controls, Part 2: UVC, section, Irradiation of air in an HVAC system (in-duct UVC)*

FIGURE 12.

Exhaust grille (perforated)



Source: CITC

Advantages and disadvantages of HVAC systems

ADVANTAGES	DISADVANTAGES
Can be effective 24 hours a day, year-round	Expensive to plan, install, operate, and maintain
Controllable, adjustable, and predictable	May be drafty and/or noisy if poorly designed and/or installed
Help prevent transmission of airborne infectious diseases, including TB	Like all environmental controls, maintenance required
Help control temperature, relative humidity, odor, and indoor air pollutants	

HVAC system

CASE STUDY

Dan has been running an inner-city homeless shelter called *You're Welcome Here* for the last 4 years. The shelter is in the converted basement of a church. When he started working there, Dan noticed that it felt stuffy most of the time.

The public health department recently issued a notice alerting shelters of an increase in TB cases among the community's marginally housed population. The shelter screens clients for TB symptoms at intake. The notice prompted Dan to implement some environmental control improvements, something he had been thinking about since his first day on the job. He decided to start by looking at the ventilation system.

Dan made the following assessments and improvements in a few hours, without having to call in the service company, and equipped only with incense sticks, a screwdriver, and a tape measure.

- The existing forced-air HVAC system consisted of a furnace in a janitor's closet, a single return-air grille on the wall outside the closet, six supply-air diffusers in the ceiling of the basement, and a thermostat.
- The return-air grille and duct were extremely dusty. Dan removed the grille and cleaned out the dust with a vacuum cleaner.
- He opened the filter section. The filter was a flat lint-type (MERV-3). It was also extremely dusty and was incorrectly installed in the filter track. Dan measured the lint filter (20" x 25" x 1") and discarded it. He bought three replacement pleated filters (MERV-11) of the same size from a nearby hardware store. They cost about $15 each. He wrote the date on one of the filters, placed it in the furnace, and saved the other two as spares.
- The thermostat had an adjustable temperature setting and three fan settings: OFF, FAN AUTO, and FAN ON. It was set to AUTO so the fan would come on only when the temperature dropped below 68°F. Dan set the controls to FAN ON, and the fan in the unit came on immediately. The improvement in ventilation was obvious (more air moving into room) and less dust was observed on surfaces over time.
- The furnace had no outdoor air intake and there was no obvious way to connect one because the unit was not close to an outside wall. To let in natural ventilation, Dan decided to keep at least two windows partially open whenever the building was occupied.
- Dan used some incense sticks to evaluate air movement. In addition, he noticed the tissue paper strips taped to the supply-air diffusers fluttered the same as with the lower-efficiency filter. He was happy to see that air movement was visible throughout the shelter. He also confirmed the direction of airflow at each diffuser and at the grille.

ASK:

What steps should Dan take to ensure that routine maintenance is done for the HVAC system?

Include annual budget for maintenance and set-up routine checks as part of the IPC plan (see Chapter 1, *Administrative Controls*).

Natural ventilation

Natural ventilation refers to outdoor dilution air that enters and leaves a building through openings such as windows, doors, rooftop "whirlybirds", vertical ducting, and skylights. Natural ventilation is the use of natural forces to introduce and distribute outdoor air into or out of a building. These natural forces can be wind (horizontal) or buoyancy generated by the density difference (vertical, warm air rising over cooler air) between indoor and outdoor air.

While natural ventilation may be appropriate in some healthcare settings, it is not an option in many settings where airborne infectious particles need to be controlled. In buildings without operational mechanical ventilation systems, natural ventilation may be used to provide outdoor air to all occupied rooms in the building. However, this may not be practical in extremely hot or cold climates.

Note: Use of natural ventilation methods may not apply to certain settings, such as AIIRs where well-defined airflow rates and pressure differentials are required. Natural ventilation should be implemented only when in compliance with applicable local, state, and industry regulations for your facility.

Wind-driven, buoyancy-driven, and mixed-mode natural ventilation

Wind-driven natural ventilation is sometimes called *horizontal natural ventilation* because winds are generally in a horizontal direction. To optimize wind-driven natural ventilation, good cross-ventilation is needed. To achieve this, one needs openings on opposing sides of a room such that the air may freely flow through the room or space. There is much more to this than simply opening windows. Openings on each opposing side should be approximately 10% of the area of the room (ft^2 or m^2). Ideally, the building should be aligned perpendicular to the prevailing winds.

FIGURE 13. **Wind-driven ventilation**

Source: Adobe/Fokke Baarssen

Next to wind speed and direction, the area of the smallest opening is the limiting factor in maximizing air exchange.

Buoyancy-driven natural ventilation is sometimes called vertical natural ventilation or temperature-driven natural ventilation. In this case, if there are vertical stacks (or ducts) from a room or space to the outdoors, and the air temperature in the room is greater than the air outdoors, air will flow from the room or space to the outdoors. In addition, people and equipment generate heat which enhances the movement of air vertically.

Mixed-mode or hybrid natural ventilation is natural ventilation that is "combined" with some type of mechanical ventilation system. Because the effectiveness of wind-driven natural ventilation alone may wane to near zero levels when the wind is minimal or non-existent, a mechanical means of ensuring a minimum air exchange rate is needed. In this case, you may supplement the natural ventilation with a well-designed exhaust-only or dilution mechanical ventilation system. One must ensure good air-mixing or movement across the room.

FIGURE 14. **Buoyancy-driven ventilation**

Source: Adobe/James

FIGURE 15. **Whirlybird**

Source: Shutterstock

Clinics or shelters that do not have a central heating and/or air conditioning system often have **exhaust fans** serving certain areas. Two common examples of exhaust-only mechanical ventilation are bathroom exhaust fans and range hoods used over kitchen stoves. These fans increase ventilation by directly exhausting room air to the outdoors. The "make-up air" or air entering the room is generally leaked in from the outside. There is a wide variety of exhaust fan systems. A system can be as simple as a propeller fan installed in the wall, or it could include a ceiling grille, with a fan and a duct, discharging air through an outside wall or the roof. Over time, dust and lint accumulate on all fans. The fans will become less efficient, and less air is exhausted. For this reason, these systems should be cleaned regularly.

"Whirlybirds," or wind turbines, provide a means to convert wind energy into an exhaust fan by causing the spherical top of a duct to rotate and cause suction; hence, exhausting air from a room. If there is no wind but the temperature inside the room is warmer than the outdoor temperature, air will move vertically and exhaust to the outside. See Figure 15.

In general, natural ventilation strategies can range from very simple to very complex designs. See WHO *Natural Ventilation for Infection Control in Health-Care Settings*, 2009.[33] for a more detailed discussion for natural ventilation applications.

Using fans with natural ventilation

Propeller fans

Propeller fans can be an inexpensive way to **increase the movement and mixing of air in a room;** however, unless they are sealed and pulling air directly from a window or other opening and pushing it inwards, they provide very little air exchange. They are often added to support both natural and mechanical ventilation systems and induce airflow patterns and air mixing.

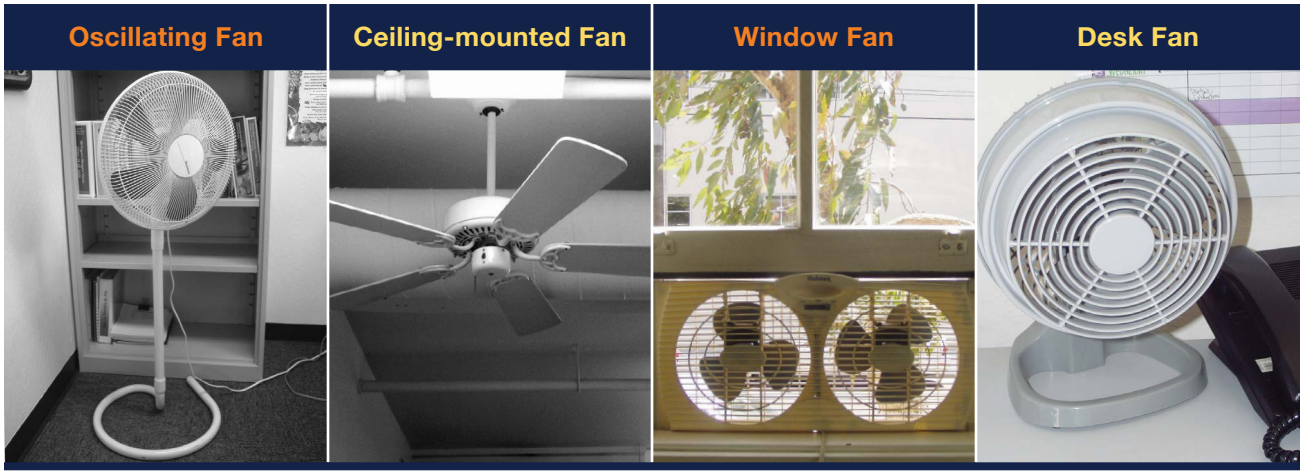
Types of propeller fans

Ceiling fans are propeller fans that are suspended from the ceiling and move air vertically. They circulate air throughout a room but do not remove or inactivate microorganisms. In general, vertical air movement is more efficient at air mixing compared to horizontal air movement only. **Wall and oscillating fans** move air both horizontally and vertically. **Stationary propeller fans** move air mostly horizontally in a room and are less efficient at air mixing than ceiling or oscillating fans.

Types of propeller fans include:

- Fixed fans that pedestal (stand) on the floor
- Ceiling-mounted fans
- Window fans
- Small fans that sit on a desk or other surface

FIGURE 16. **Examples of propeller fans**



Source: CITC

Considerations for natural ventilation

As previously noted, natural ventilation with horizonal airflow using cross-ventilation may work well in some settings. A room with good cross-ventilation (open windows and/or doors with a mixing fan; good mixing, dilution, and removal) will have less TB-transmission risk than a room that may have a mixing fan but openings only on one side with only modest exchange of air in and out (good mixing, modest dilution and removal). The highest TB-transmission risk would be an enclosed room with windows only on one side and no fan and/or no mechanical ventilation (poor mixing, dilution, and removal).

When relying on natural ventilation (with or without fans), consider the following:

- **Natural ventilation can be unpredictable** and may not be practical in very cold or very hot climates. If this is the case, you should consider adding an HVAC system. See section, *HVAC systems*.
- Check that doors, windows, and skylights are easy to open and that any screens or grilles are clear of obstructions. **Keep them open as often as possible** to provide outdoor air to all occupied rooms (especially if there is no HVAC system).
- Provide extra blankets to occupants who complain of drafts so that ventilation can be used when the space is occupied.
- If fans cause objectionable noise or drafts and cannot be used when the space is occupied, look first for simple solutions that preserve ventilation.
  - Clean the fan blades
  - Adjust direction and/or speed of air movement
  - Replace fan with quieter equipment
- If appropriate for the space and how it is utilized, **consider increasing ventilation at times when the space is unoccupied.** For example, many settings (e.g., shelters) are closed during part of the day, providing an opportunity to open windows and doors while running fans at high speed to "air out" the space.
- If natural ventilation or addition of an HVAC system is not feasible, consider the use of room air cleaners or upper-air UVC to provide clean air on a room-by-room basis. See sections, *Upper-air UVC* and *Room air cleaners*.

Supply and exhaust fans

- A **supply fan** in a window or other opening may be added to augment airflow into the facility. Use the manufacturer's stated airflow rates to select the proper size fan to obtain desired ACH. Window screens or other objects overlying the unit will result in airflow rates lower than those stated by the manufacturer and must be considered.
- When possible, room fans should be placed in locations where they will add to horizontal natural ventilation currents.
  - **Place staff near outdoor air sources.**
  - It is always easier and more efficient to blow/push air than to suck/pull air (e.g., it is easier and more efficient to blow out a candle than to suck in air near a candle to extinguish the flame). Therefore, **a well-placed supply fan may be a more efficient way to bring in outdoor air for air exchange than using an exhaust fan.**

- Place exhaust fans so that air flows from clean to less clean areas. Fan selection criteria are the same as those stated for supply fans.

Mixing fans

- **Add ceiling or wall fans to increase air mixing.**
- Air mixing can be verified using a simple smoke test to ensure all areas of the room have appropriate air movement. Adequate air movement for mixing is technically at least ≥ 20 ft/min (0.1 m/sec) which visually would be a slow drift during the smoke test of ≥ 4 in/sec.
- Keep fans running as much as possible when the space is occupied.

Routine upkeep for natural ventilation and exhaust fans

- Ensure all windows, doors (and grilles in doors), and other openings are clean and airflow is unimpeded by furniture, curtains, equipment, or other items.
- **Clean exhaust fan outlets and fans about once a month.** Use a damp cloth or vacuum cleaner to remove dust and lint from fans and grilles. Do not perform this task when patients or clients are in the room.
- The effectiveness of natural ventilation will vary. **Check the appropriateness of natural ventilation in different seasons, times of day, and environmental conditions.** This will give the building management an understanding of whether supplemental mechanical ventilation might be needed due to lack of airflow or unacceptable environmental conditions for natural ventilation.
- **Keep records** of all routine upkeep activities and dates.

Advantages and disadvantages of natural ventilation and fans

ADVANTAGES	DISADVANTAGES
Natural ventilation can be implemented easily by opening doors and any operable windows and skylights. Unfortunately, not all modern buildings are suited for natural ventilation.	Natural ventilation can be uncontrollable and unpredictable depending on wind conditions and other microenvironmental factors. For example, people may close windows and doors, or the wind direction outside may change.
Bringing outdoor air into a space reduces the risk of TB transmission and may improve overall indoor air quality. Unwanted indoor pollutants and odors are reduced.	Air that is introduced directly from the outdoors, without the benefit of filters or other air-cleaning devices, may bring in unwanted elements, such as traffic exhaust and noise, rain, dust, odors, pollen, and insects.
Exhaust fans are generally inexpensive.	Keeping windows and doors open may adversely affect security, comfort (temperature and humidity), and privacy. This is especially true at night and in the winter.
Good natural ventilation can be easily added to a building in the design stage.	It is difficult to modify a building originally designed with an HVAC system to ensure adequate natural ventilation.
	If a building has an operable HVAC system, opening windows may adversely affect room pressurization as well as result in damage to both the HVAC system and building if not properly implemented.

Natural ventilation and exhaust fans

Lynn is the director of *Welcome Home*, a homeless shelter that serves approximately 100 people each night.

The building is a converted warehouse with a high ceiling. It is divided into men's and women's dormitories, each with a shower and toilet room, and a small office area.

CASE STUDY

Lynn is concerned about the spread of TB because of the high incidence of TB among the urban homeless population. Her facility does not screen clients for TB. Because it operates on a first-come, first-served basis, it generally houses a different group of clients each night, thereby possibly increasing the risk of TB transmission. While her facility has not had a TB outbreak, Lynn knows it could happen at any time.

There is no HVAC system. Each shower and toilet room has an exhaust fan.

Check ventilation

After adding a TB screening program for her clients, staff, and volunteers, Lynn wanted to improve ventilation in her building. Her first step was to check the existing ventilation.

Using incense, she noted that air mixing seemed satisfactory near doors and open windows as smoke seemed to disperse quickly. In the corners, away from doors and open windows, however, air movement seemed slow or nonexistent.

To match nighttime conditions, Lynn closed the doors and windows and repeated the tests. Air movement was slow or nonexistent throughout the facility.

Lynn looked at the two exhaust fans in the shower and toilet rooms. Both had a considerable buildup of lint and dust. She turned them on and held a piece of paper against each grille. In the men's room the paper was pulled against the grille. But in the women's room there was no pulling effect, and Lynn noticed that she could not hear the fan running.

Based on these simple checks, Lynn now had a good idea of the ventilation in her building:

- **During the day, when doors and windows were kept open, air movement was good except in the corners of the rooms.**
- **At night, when doors and most windows were closed, air movement was slow to non-existent.**
- **Both exhaust fans needed cleaning.**
- **The exhaust fan in the women's room was not operating.**

ASK:

How could Lynn improve the situation with her limited budget?

With a vacuum cleaner, she thoroughly cleaned the two exhaust grilles. She noticed an immediate improvement in airflow at the grille in the men's room, but the fan in the women's room still was not working.

CONTINUED ON NEXT PAGE

CASE STUDY

CONTINUED FROM PREVIOUS PAGE

Improvements

The very first step taken by Lynn was to ensure there was some minimal opening at the top of **all** windows, including windows above any doors. Near the corners on the back wall were two blocked-up windows. It occurred to Lynn that if she were to install an exhaust fan in each of these windows, it should produce an air current throughout the stagnant area near each fan, regardless of whether the doors and windows were open. Air would be drawn from the "permanent" openings added by Lynn. When additional funds are available, Lynn will purchase and install a few ceiling fans to increase air mixing in the room.

The very first step taken by Lynn was to ensure there was some minimal opening at the top of all windows

She measured the window openings and the room volume. She then bought through-the-wall fans at her local hardware store for each window to improve the ACH. Commercially available kitchen and bathroom fans generally come in different sizes and airflow rates (50-200 CFM). Staff from an affiliated job-training program installed the fans in the windows as part of a training exercise. Lynn made sure that the window fans exhausted air out the back of the building.

While the crew was at her building, Lynn asked them to look at the exhaust fan in the women's room. They found the problem, a loose connection, and repaired it.

The results

Lynn did some final incense tests that night, with the fans on and the doors closed. Air movement was greatly improved throughout the facility. However, some clients complained about a slight draft and were provided with extra blankets.

She repeated the tests the next morning with the windows and doors open and was pleased to see that airflow was now satisfactory, even in the corners.

Feeling very proud of herself, Lynn wrote and posted a one-page policy summarizing her environmental control efforts:

- **Keep doors and windows open during the day.**
- **Always keep all fans (toilet exhaust and through-the-wall exhaust fans) ON.**
- **Clean fans on the first of every month.**

The next month, Lynn was happy to share her experience and her policies with her peers at a meeting of the local homeless shelter directors' organization. The members agreed that, while TB transmission at *Welcome Home* could still occur, the risk had been reduced. Furthermore, the increased outdoor air had improved the indoor environment for her staff and clients.

ASK:

What else could be done to prevent the transmission of TB in homeless shelters?

See Chapter 1, *Administrative Controls*, and Chapter 6, *Homeless Shelters*, for more ideas.

Using fans within a room with an HVAC system

Propeller fans may be used in conjunction with some HVAC systems:

- When using upper-room UVC fixtures, air mixing (from the occupied space to and from the upper portion of the room) is critical. Propeller fans and ventilation diffusers will enhance the effectiveness of this application.

Adequate **air mixing** is also an important component for dilution ventilation strategies. Propeller fans may be useful **to minimize stagnation, temperature stratification, and short-circuiting.**

If placed in or near a wall opening, fans can also be used to encourage air movement into and out of a room; however, a **facility engineer should be consulted** to determine if such an intervention will adversely affect the performance of the existing mechanical ventilation system. For example, if someone opens a window and blows warm air into an air-conditioned space, three things may happen:

- At or near the supply air diffusers, water will condense. This will cause water to "drip" into the space as well as wet the ceiling, creating an environment perfect for mold growth.
- Because the air-conditioning system was not designed to cool the additional heat load of the warm outdoor air, it will run much longer to reach a set temperature, possibly running continuously. The air conditioning system may not be able to maintain the desired temperature and humidity.
- The life of the air conditioning system will be shortened

Windows and doors should not be left open in AIIRs (this will disrupt the desired pressure balance).

Room air cleaners (RACs)

Room air cleaners (RACs) are readily available equipment that can be used anywhere to **provide clean air.** RACs allow improvement to air quality in any room. No detailed engineering knowledge is required to install or maintain RACs. These units are especially **useful in settings that may have inadequate or no mechanical ventilation and limited funds for upgrades.**

RACs with filter(s) are available in a variety of sizes and configurations, but all consist primarily of:

- A primary filter to remove small particles from the air
- A prefilter to remove larger particles and thereby prolong the life of the higher-efficiency filter
- A fan to pull the air through the filter and recirculate the filtered air into the room
- Controls, such as an on/off switch, timer, and fan speed (airflow rate) control

Portable, freestanding devices are the most common type of units. Ceiling-mounted and wall-mounted units are also available. Portable units have the advantage of greater flexibility and ease of installation and service. Permanent units are less vulnerable to tampering and theft, less likely to be in the way, and cannot be easily moved to a location where they will be less effective. RAC selection is based on the amount of "clean" air they deliver, usually expressed in CFM or m^3/h.

The critical performance factors or characteristics of an acceptable RAC include:

- **Clean air delivery rate** (CADR) necessary to provide the needed ACH in the room or setting
- Relatively quiet operation (<55 decibel A), even at the highest airflow rate
- Standard US 110-120V outlet or circuit compatibility
- Portable (floor or tabletop) or fixed (wall- or ceiling-mounted) capability to match setting needs
- Ability to induce airflow patterns and/or work in synergy with the existing HVAC system to ensure good air mixing in the room without causing drafts

For additional, detailed discussions on the use of RAC, see references 3, 4, and 5.

RAC filters

A RAC with filter will provide cleaned air to dilute infectious particles and can also remove infectious and other airborne particles. **HEPA filters** remove 99.97% of particles 0.3 µm in size (essentially all infectious particles in the size range of concern for TB) and are used in many available RAC units. However, it takes a powerful, possibly noisy fan to pull air through them. Other less efficient filters, such as a **MERV-13 or higher,** may be used at a higher airflow rate to provide a similar or greater CADR than a RAC with a HEPA filter. TB infectious particles are significantly larger than particles used to test HEPA filters, so RACs that use "near-HEPA" filters (like MERV-13 or higher) can remove the majority of particles of concern for TB and may be appropriate for use in healthcare settings. See ASHRAE (Standard 52.2-2017)[25] for further details.

Other technologies to remove or disinfect infectious particles include:

- UVC
- Electrostatic plates
- Ion generators

Clean air delivery rate (CADR)

CADR is the rate at which an air cleaning device or equipment, including RACs, delivers clean or disinfected air to a room or space. The CADR is measured in CFM or m^3/h.

For a **RAC with filter, the CADR is approximately the product of the actual airflow rate (CFM or m^3/h) and the filtration efficiency of the filter for the particle size of interest,** assuming no leakage around the filter.

- For a RAC with UVC, the CADR is approximately the product of the actual airflow rate (CFM or m^3/h) and the efficiency of UVC to inactivate a select microorganism in a single pass through the RAC. If a test microorganism other than *Mycobacterium tuberculosis* is reported, one must ensure the microorganisms selected is at least as susceptible to inactivation by UVC as *Mycobacterium tuberculosis.* If the RAC has a filter, other than a coarse filter to keep the UVC lamp clean, the CADR is a function of both inactivation by UVC and removal by filtration.

- When choosing a RAC (CADR ≤450 CFM for particulate and/or CADR ≤600 CFM for microorganisms), **look for an Association of Home Appliance Manufacturers (AHAM) Verifide® certificate* or other independent testing certificate** (see *Steps for selecting a RAC* for an example certificate). The U.S. Environmental Protection Agency (EPA) also provides guidance on smaller RACs.[34]
- Larger RACs (CADR >450 CFM for particulates and/or CADR >600 CFM for microorganisms) are not tested to any American National Standards Institute (ANSI)/AHAM standard and will not have an AHAM Verifide® certificate (must rely on an independent testing certificate).
- AHAM testing includes challenges against pollen (5 µm to 11 µm), dust (0.5 µm to 3.0 µm), and tobacco smoke (0.10 µm to 1.0 µm); HEPA filters are tested with 0.3 µm particles (noting that TB infectious particles of interest are 1-5µm). **Generally look at the tobacco smoke or dust results when considering use for TB IC** purposes.

Small RACs

Small RACs deliver 10 to 450 CFM (17-765 m^3/h) of "clean air." Most units include a two- or three-position fan speed (airflow rate) control but no other controls. Small RACs are useful for individual offices, on-site clinic rooms, and other smaller areas.

Small RACs are light enough to be easily carried around and placed on a desktop or other surface. These units are readily available from hardware stores and similar retail outlets.

Small RACs may use MERV-13 or higher efficiency filters, up to and including HEPA filters.

- The **key performance parameter of interest should be the CADR** of the RAC and not the filter classification used.

FIGURE 17.

RAC (low airflow rate)

Source: CITC

* AHAM Verifide® certificate requires one of these two standards is met: ANSI/AHAM Standard AC-1-2020: *Method for Measuring Performance of Portable Household Electric Room Air Cleaners*[3] and ANSI/AHAM Standard AC-5-2022: *Method for Assessing the Reduction Rate of Key Bioaerosols by Portable Air Cleaners Using an Aerobiology Test Chamber*.[4]

Large RACs

Large RACs can deliver from 450 to 1,000 CFM (765-1,700 m^3/h) of clean air and can be used in larger rooms in which groups of people may spend time, such as TV lounges or waiting rooms. **Since these RACs are generally not certified to meet AHAM requirements, independent test reports should be reviewed.**

These units usually have wheels so they can be moved from room to room. Like small RACs, large RACs include a two- or three-position fan speed (airflow rate) control and often a warning light to indicate when filter replacement is recommended.

Options may include a lockable cover for the controls to prevent tampering and an internal UVC lamp. Because the RAC removes most infectious particles in the TB size range, UVC offers minimal added benefit when combined with appropriate filtration.

Some large RACs are designed to exhaust all or a portion of the air to outdoors, creating a room that meets the negative pressure requirements of an AIIR.

Larger units are available from specialized medical equipment suppliers and industrial suppliers.

FIGURE 18.

RAC (high airflow rate)

Source: AeroMed/B. Palmer

Considerations for placement and use of RAC

- Provide portable RACs for all unventilated or poorly ventilated rooms frequented by patients or clients unless the rooms have an operable window or door that is usually kept open when the rooms are occupied.
- **Place small RACs off the floor and near staff so that the clean air generated by the RACs is delivered close to the breathing zone of the people that they are intended to protect.** Consider the HEPA filter unit primarily as a source of clean air and secondly as a removal device for contaminated air.
- Place units evenly throughout crowded rooms so that air movement can be observed in all parts of the room.
- **Select each RAC based on the CADR it produces when it is running at or near the low-speed setting.** RACs with HEPA filters can be noisy when running at higher speed settings. For this reason, people tend to operate them at low or medium speeds in small rooms during interviews. However, at lower fan speeds (airflow rates), the dilution effect is reduced because the RACs do not provide as much purified air as at higher fan speeds (airflow rates).
- Operate RACs continuously while rooms are occupied by patients or clients and for approximately 1 hour after they leave.

RAC selection

- Select RACs with a **CADR that provides an air exchange rate of at least 6 ACH for most general settings.**
  - ASHRAE recommends the minimum air change rate of **6 ACH for exam rooms and 12 ACH in selected areas of healthcare facilities** (e.g., emergency department waiting rooms, aerosol producing/generating procedure rooms, and AIIRs). Given the rate of TB among people who are unstably housed, a congregate group room is comparable to a hospital waiting room, and an interview room is comparable to an exam room.
  - While not ideal, if an existing HVAC system provides some of the necessary ACH, a RAC can be added to increase the total ACH for the space (e.g., HVAC provides 6 ACH + RAC provides 6 ACH = 12 ACH). A better solution would be an upgrade to the HVAC system.
- Note: The CADR listed for a unit is generally based on a clean filter. As the filter loads over time, airflow rate and the actual CADR will decrease.
  - To compensate for this, **add a safety factor of 50% to the required CADR.** The additional cost of buying a RAC with more capacity is usually not significant compared to the total cost of the RAC.
- Make RAC selection based on RAC's AHAM Verifide® certificate or other independent verification of CADR. Note that the reported CADR is based on the RAC operating at the highest airflow setting, if adjustable.
  - Unvalidated RACs may deliver less than the manufacturers' listed CADR and generally are not recommended.

Steps for selecting a RAC:

(See Table 4, *Selection of RAC based on room volume and CADR*)

1. Measure room then calculate the room volume (length x width x ceiling height). For example, a room that is 10 ft wide by 10 ft long with an 8 ft ceiling will have a volume of 800 ft^3 (or 22.7 m^3).
2. Determine the CADR needed for the room based on the room size. Six ACH is the minimum recommended for general room use for healthcare settings. The required CADR in CFM or (m^3/h) to achieve this air exchange rate is calculated as follows:
   - (Room volume x 6 ACH) / (60 minutes per hour) = airflow in CFM; or (Room volume x 6 ACH) = airflow in m^3/h
   - Add a safety factor to the desired CADR that takes into consideration the gradual loading of a filter over time. The recommended CADR that includes a 50% safety factor is listed as "Minimum CADR with 50% Safety Factor" in Table 4.
     - Example: Assume an 800 ft^3 room volume, to achieve 6 ACH and have a 50% safety factor, choose a RAC with a CADR of at least 120 CFM (204 m^3/h).

TABLE 4. **Selection of RAC based on room volume and CADR**

ROOM VOLUME	CADR FOR 6 ACH	MINIMUM CADR WITH 50% SAFETY FACTOR
800 ft^3 (22.7 m^3)	80 CFM (136 m^3/h)	120 CFM (204 m^3/h)
1,000 ft^3 (28.3 m^3)	100 CFM (70 m^3/h)	150 CFM (255 m^3/h)
1,500 ft^3 (42.5 m^3)	150 CFM (255 m^3/h)	225 CFM (382 m^3/h)
2,000 ft^3 (56.6 m^3)	200 CFM (340 m^3/h)	300 CFM (510 m^3/h)
4,000 ft^3 (113 m^3)	400 CFM (680 m^3/h)	600 CFM (1,020 m^3/h)
8,000 ft^3 (227 m^3)	800 CFM (1,360 m^3/h)	1,200 CFM (2,040 m^3/h)

3. Select RACs in which CADR has been independently verified or with an AHAM Verified® certificate.

- Caution: Units with CADR values listed may in reality not match the advertised efficiency, and additional calculations to determine ACH may be required. Read labeling carefully and **do not** automatically use the "room size" information given by manufacturers or the AHAM Verifide® certificate as they assume an 8 ft (2.4 m) ceiling height (see example below).
- If CADR values are given for tests against tobacco smoke, dust, and pollen, **use the CADR values given for tobacco smoke or dust** when choosing a unit for TB IC purposes. Particle ranges tested for tobacco smoke and dust both cover the size range of concern for infectious TB particles.
- See Figure 19 for an example of how an AHAM Verifide® certificate label may appear on a unit.

The AHAM site explains that the room size in square feet on the certificate **assumes a ceiling height of 8 ft.**

- If the room in which the RAC will be placed in has an 8 ft ceiling height, then comparing the square footage on the certificate works directly.
- If the room has different dimensions, multiply the square feet value given for the RAC x 8 ft height to **calculate comparable volume** that AHAM used (360 ft^2 x 8 ft = 2,880 ft^3 for room volume). The CADR performance listed for this unit will apply to a room of this volume.
- If the intended room measures: 18 ft long x 15 ft wide x 10 ft high = 2,700 ft^3 volume, the CADR needed for 6 ACH for a 2,700 ft^3 room is approximately 300 CFM. If a 50% safety factor is added, the desired CADR would be 450 CFM. Using the CADR performance for tobacco smoke of 240 CFM, two of these RACs would easily fulfill the needs or consider finding a different single unit with a higher CADR performance.

FIGURE 19.

Example AHAM Verifide® certificate label

Source: AHAM Verifide®

Note: Most RACs include a control switch that adjusts the airflow from a fixed minimum (low setting) to a fixed maximum (high setting). Because of the increased noise, people tend to use the units at the low setting. Therefore, if CADR values are given for the low setting, consider selecting a unit based on the CADR for lower airflow setting (e.g., for a unit with low/medium/high settings the CADR values may be listed as 100/150/200 CFM [170/255/340 m^3/h]). Many units only list the CADR achieved using the highest airflow setting.

Routine upkeep of RAC filters

- **Designate a staff person to be the in-house monitor of the RACs.** This person should be aware of the basic principles of RAC operation, including effective placement and maintenance. This person should also implement a written schedule for changing the prefilters and primary filters.

Maintenance consists of replacing the prefilter and the primary filter at regular intervals. The manufacturer's instructions should explain how this is done. **In general, replace the prefilters every 3-6 months, and replace the primary filters every 1 or 2 years.** Actual replacement time will depend mainly on how often the units are used and how dusty the room air is.

Advantages and disadvantages of RACs

ADVANTAGES	DISADVANTAGES
Can be implemented almost immediately	Unpredictable because, if controls are accessible, patients, clients, or staff members may: turn them down or off; move or unplug the units; place books or other items on top that may impede airflow; or even place under the bed to reduce noise
Can be implemented room by room	Can be drafty and noisy
Relatively inexpensive to plan, install, and maintain	Do not bring in outdoor air
Have adjustable airflow rate	Do not filter out odors
Can be portable	CADR/airflow rate decreases as the filter gets loaded with airborne particles
Remove other indoor air particles, such as dust and allergens	
Do not require costly equipment to evaluate	

Room air cleaner (RAC)

CASE STUDY

Catherine is a case manager in an inner-city homeless shelter. As part of her work, she interviews about six new clients every week. Her office has no ventilation and no window to the outdoors. Because clients have not been medically screened and because of the lack of ventilation, she is concerned about TB transmission. The clinic manager has set aside $150 to buy a RAC for the office once Catherine can tell her what size unit she would like.

Catherine wants a unit that will provide an air change rate of at least 6 ACH. She uses a tape measure and a calculator to estimate a suitable HEPA filter unit airflow based on the room's volume.

Room volume = width x length x height
= 8 ft x 10 ft x 9.5 ft
= **760 ft^3**

Airflow required for 6 ACH = room volume x 6 ACH
= 760 ft^3 x 6 ACH
= 4,560 ft^3/h ÷ 60 min/h
= **76 CFM**

The actual CADR may be less than advertised. To compensate, Catherine adds a 50% safety factor to get a required airflow of 114 CFM.

76 CFM x 1.5 = 114 CFM

Most units have an adjustable speed setting. They become noisier at the higher speeds. Catherine plans on running the unit at low speeds during interviews, so she decides to select a RAC with a low-speed CADR of at least 114 CFM (if the CADR was evaluated at the low airflow rate).

ASK:

Should Catherine aim to achieve 6 ACH or a higher rate? Why?

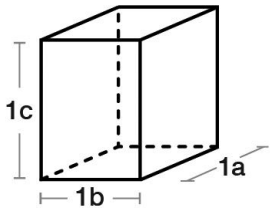
Aim for >6 ACH if possible because CADR will decrease as the filter loads (gets dirty).

Room Clearance Time Calculation Worksheet

Note: For information on how to use a manometer (Vaneometer™) see Chapter 4, *Airborne Infection Isolation Rooms*, section *Monitoring AIIR environmental controls*

Room or Booth # _____

Step 1: Calculate Room Volume



1a. = Room Length (l) — **1a.** _____ ft (m)

1b. = Room Width (w) — **1b.** _____ ft (m)

1c. = Room Height (h) — **1c.** _____ ft (m)

1d. = 1a x 1b x 1c = volume — **1d.** _____ ft^3 (m^3)

Step 2: Calculate Air Changes Per Hour (ACH)

2a. Measure the height (h) and width (w) of the exhaust grille — **2a.** h = _____ in (cm)
w = _____ in (cm)

2b. Calculate the area (**2b**) by multiplying the height by the width
2b = **h** x **w** — **2b.** _____ in^2 (cm^2)

2c. Convert in^2 to ft^2 by dividing **2b** by 144 in^2/ft^2
Convert cm^2 to m^2 by dividing **2b** by 1,000 cm^2/m^2 — **2c.** _____ ft^2 (m^2)

2d. Measure the average air velocity, at several points (directly at front of exhaust grille), using a Vaneometer™ or electronic velocity meter. — **2d.** _____ ft/min (m/s)

2e. Calculate the exhaust airflow rate by multiplying the exhaust grille area (**2c**) by the average velocity (**2d**)
2e = **2c** x **2d** — **2e.** _____ CFM (m^3/s)

2f. Convert CFM (ft^3/min) to ft^3/hr by multiplying **2e** by 60 min/hr
Convert m^3/s to m^3/hr by multiplying **2e** by 3,600 sec/hr — **2f.** _____ ft^3/hr (m^3/h)

2g. Calculate the Air Changes per Hour (ACH) by dividing the exhaust airflow rate (**2f**) by room volume (**1d**)
2g = **2f** ÷ **1d** — **2g.** _____ ACH

Step 3: Calculate Room Clearance Time (99% or 99.9%)

3a. Find the Uncorrected Clearance Time — **3a.** _____ min

Using Table A-1 (Table 1 of the CDC 2005 Guidelines) on next page, follow the first column down until the ACH value on line **2g** is found.

- A removal efficiency of >99% is acceptable; ideally the value in the third column (99.9% removal efficiency) should be used.
- Record this value (number of minutes). This is the amount of time that should elapse before staff or other patients enter a sputum induction area (booth, hood, or room) after sputum has been induced on a person with presumptive or known infectious TB and the patient has left, assuming the room has perfect air mixing.

3b. Choose Appropriate Mixing Factor (MF) for the Room/Booth Since perfect room mixing rarely occurs, the value on line **3a** must be multiplied by a mixing factor ranging from "1" for perfect mixing to "10" for poor mixing (a "1" represents perfect mixing, use 2 for good mixing and 3 for fair mixing; most healthcare settings have MF of 1 to 2). Smoke visualization and/or observations regarding supply diffuser or exhaust grille placement can help you in estimating your mixing factor.	**3b. MF =** _____
3c. Find the CORRECTED Room Clearance Time: 3a × 3b This is the amount of time, accounting for imperfect mixing, which should elapse before staff or other patients enter a sputum induction area (booth, hood, or room) after sputum has been induced on a person with presumptive or known infectious TB and the person has left.	**3c.** _____ min

TABLE A-1.

Air changes per hour (ACH) and time required for removal efficiencies of 99% and 99.9% of airborne contaminants*

ACH	99%	99.9%
	Minutes Required for Removal Efficiency†	
2	138	207
4	69	104
6	46	69
12	23	35
15	18	28
20	14	21
50	6	8
400	<1	1

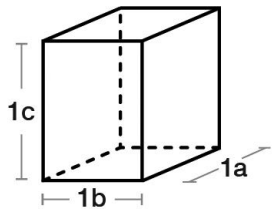
* This table can be used to estimate the time necessary to clear the air of airborne *Mycobacterium tuberculosis* after the source patient leaves the area or when aerosol-producing procedures are complete.

† Time in minutes to reduce the airborne concentration by 99% or 99.9%.

Room Clearance Time Calculation Worksheet: Example

Room or Booth # _____

Step 1: Calculate Room Volume



1a. = Room Length (l) — **1a.** 12 ft (m)

1b. = Room Width (w) — **1b.** 15 ft (m)

1c. = Room Height (h) — **1c.** 9 ft (m)

1d. = 1a x 1b x 1c = volume — **1d.** 1,620 ft^3 (m^3)

Step 2: Calculate Air Changes Per Hour (ACH)

2a. Measure the height (h) and width (w) of the exhaust grille

2a. h = 20 in (cm)
w = 20 in (cm)

2b. Calculate the area (**2b**) by multiplying the height by the width
2b = h x w = 20 in x 20 in = 400 in^2

2b. 400 in^2 (cm^2)

2c. Convert in^2 to ft^2 by dividing **2b** by 144 in^2/ft^2
2c = 400 in^2 ÷ 144 in^2 / ft^2 = 2.78 ft^2

2c. 2.78 ft^2 (m^2)

2d. Measure the average air velocity, at several points, using a Vaneometer™ or electronic velocity meter. Average velocity = **2d**

2d. 36 ft/min (m/s)

2e. Calculate the exhaust airflow rate by multiplying the exhaust grille area (**2c**) by the average velocity (**2d**)
2e = 2c x 2d = 2.78 ft^2 x 36 ft/min = 100 CFM

2e. 100 CFM (m^3/s)

2f. Convert CFM (ft^3/min) to ft^3/hr by multiplying **2e** by 60 min/hr
2f = 2e x 60 min/hr = 100 CFM x 60 min/hr = 6,000 ft^3/hr

2f. 6,000 ft^3/hr (m^3/h)

2g. Calculate the Air Changes per Hour (ACH) by dividing the exhaust airflow rate (**2f**) by room volume (**1d**)
2g = 2f ÷ 1d = 6,000 ft^3/hr ÷ 1,620 ft^3 = 3.7 ACH

2g. 3.7 ACH

Step 3: Calculate Room Clearance Time (99.9%)

3a. Find the Uncorrected Clearance Time

Rounded up 3.7 ACH to 4 ACH. Using Table A-1, followed the third column (99.9%) down until the ACH value on line **2c** is found.

3a. ~104 min

3b. Choose a Mixing Factor (MF) of 2, good air mixing, for the room

3b. MF = 2

3c. Find the CORRECTED Room Clearance Time: 3a × 3b

This is the amount of time, accounting for imperfect mixing, which should elapse before staff or other patients enter a sputum induction area (booth, hood, or room) after sputum has been induced on a person with presumptive or known infectious TB and the person has left.

3c. 208 min

VENTILATION **APPENDIX B:**

Airborne Infection Isolation Room (AIIR) Pressure Monitor Checklist

ROOM NAME and NUMBER _____

MONITOR MANUFACTURER and MODEL NUMBER _____

This form should be completed annually and updated monthly for each room pressure monitor.
Negative pressure should be verified **monthly*** to validate the monitor.
A copy of the completed form should be kept in the Policies and Procedures binder for the department.

MONITOR SETTINGS

Normal pressure reading (monitor reading with door closed) _____"wg (Pa)

Alarm will sound if pressure differential drops to _____"wg (Pa)

Time delay _____ seconds

Remote alarm location(s) _____

ANNUAL MONITOR CHECKS

Task	Date Completed	Signed Off By
Monitor calibrated in accordance with manufacturer's requirements		
Confirmed negative pressure using smoke tube testing (this test should be repeated **monthly*** and signed below to confirm)		
Verified alarm operation (by holding door open or blocking off exhaust grille)		
Alarm sounded after _____ seconds		
Pressure reading at alarm _____"wg (Pa)		
Monitor use and functions demonstrated to all floor staff		

MONTHLY* NEGATIVE PRESSURE CHECK

Initials _____ Month/Year _____	Initials _____ Month/Year _____	Initials _____ Month/Year _____
Initials _____ Month/Year _____	Initials _____ Month/Year _____	Initials _____ Month/Year _____
Initials _____ Month/Year _____	Initials _____ Month/Year _____	Initials _____ Month/Year _____
Initials _____ Month/Year _____	Initials _____ Month/Year _____	Initials _____ Month/Year _____

*When in use for suspected or known pulmonary or laryngeal TB patients, airborne infection isolation rooms should also be checked for negative pressure by using smoke tubes or other visual checks before **occupancy, then daily while occupied.**

VENTILATION **APPENDIX C:**

Minimum Efficiency Rating Value (MERV) Parameters

Adapted from Table 12-1, ASHRAE 52.2-2017[25]

Standard 52.2 Minimum Efficiency Reporting Value (MERV)	Composite Average Particle Size Efficiency, % in Size Range, µm*		
	Minimum mechanical ACH	Air recirculated	Minimum filter efficiency
1	N/A	N/A	E3 < 20
2	N/A	N/A	E3 < 20
3	N/A	N/A	E3 < 20
4	N/A	N/A	E3 < 20
5	N/A	N/A	20 ≤ E3
6	N/A	N/A	35 ≤ E3
7	N/A	N/A	50 ≤ E3
8	N/A	20 ≤ E2	70 ≤ E3
9	N/A	35 ≤ E2	75 ≤ E3
10	N/A	50 ≤ E2	80 ≤ E3
11	20 ≤ E1	65 ≤ E2	85 ≤ E3
12	35 ≤ E1	80 ≤ E2	90 ≤ E3
13	50 ≤ E1	85 ≤ E2	90 ≤ E3
14	75 ≤ E1	90 ≤ E2	95 ≤ E3
15	85 ≤ E1	90 ≤ E2	95 ≤ E3
16	95 ≤ E1	90 ≤ E2	95 ≤ E3

* E1 = 0.3-1.0 µm, E2 = 1.0-3.0 µm, and E3 = 3.0-10.0 µm

Summary of HVAC Systems Worksheet: Example

The following form should be completed to create a handy summary of information on the HVAC systems in a building. A sample of a blank template form is also included.

SUMMARY OF HVAC UNITS

Unit Location	Rooms Served by HVAC System	Thermostat Location	Filter(s) (#, size, MERV-#)
Attic above men's dorm	Women's and men's dorm	Large men's dorm	(1) 20" x 25" x 1", MERV-5
Filter is behind return grille in large men's dorm. Spare filters are stored in janitor's closet. Access to unit is through ceiling hatch in men's dorm.			
Janitor's closet in kitchen	Kitchen, meeting room, dining room, women's bathroom	Dining room	(1) 19" x 20" x 1", MERV-7
Filter is at unit; undo four screws to change. Spare filters are stored in janitor's closet.			
Roof above director's office	Offices, women's dorm, small men's dorm, men's bathroom	Women's room	(1) 22" x 22" x 1", MERV-9
Filter is near HVAC system on roof; ladder to get to roof is in shed. Spare filters are stored in janitor's closet.			

Summary of HVAC Systems Worksheet: Template

SUMMARY OF HVAC UNITS			
Unit Location	**Rooms Served by HVAC System**	**Thermostat Location**	**Filter(s) (#, size, MERV-#)**

VENTILATION **APPENDIX E:**

Ventilation Recommendations for Selected Areas in Healthcare Settings

ASHRAE Standard 170-2021[1]

Healthcare setting	Minimum mechanical ACH	Minimum outdoor ACH	Air movement relative to adjacent areas	Air exhausted directly outdoors	Air recirculated	Minimum filter efficiency
Anteroom for AIIR	10	**NR**	In/Out	Yes	No	MERV-8
AIIR	12	2	In	Yes	No	MERV-14
Autopsy suite	12	2	In	Yes	No	MERV-8
Bronchoscopy room	12	2	In	Yes	No	MERV-14
Emergency department and radiology waiting rooms	12	2	In	Yes	**NR**	MERV-8
Operating room or surgical room	20	4	Out	**NR**	No	MERV-16

NR = No requirement

Resources

General Infection Prevention and Control

Centers for Disease Control and Prevention (CDC)

- *Guidelines for preventing the transmission of Mycobacterium tuberculosis in health-care settings* (2005)
  https://www.cdc.gov/mmwr/pdf/rr/rr5417.pdf
- *Infection Control in Health-Care Settings Fact Sheet* (2016)
  https://www.cdc.gov/tb-healthcare-settings/hcp/infection-control/index.html
- Chapter 6: *Tuberculosis Infection Control. In Core Curriculum on Tuberculosis: What the Clinician Should Know, 7th edition* (2021)
  https://www.cdc.gov/tb/hcp/education/core-curriculum-on-tuberculosis-continuing-education.html

World Health Organization (WHO)

- *WHO Consolidated Guidelines on Tuberculosis: Module 1: Prevention – Infection Prevention and Control* (2022)
  https://www.who.int/publications/i/item/9789240055889
- *WHO Operational Handbook on Tuberculosis. Module 1: Prevention – Tuberculosis Infection Prevention and Control* (2023)
  https://www.who.int/publications/i/item/9789240078154

Occupational Safety and Health Administration (OSHA)

- Readers of this guide are encouraged to refer to their state and local regulations and contact their local OSHA office
  https://www.osha.gov/contactus/bystate

American National Standards Institute / American Society of Heating, Refrigerating and Air-Conditioning Engineers / Illuminating Engineering Society (ANSI/ASHRAE/IES)

- *Commissioning Process for Buildings and Systems. ANSI/ASHRAE/IES Addendum a to ANSI/ASHRAE/IES Standard 202-2018.* (2020)
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PART 2

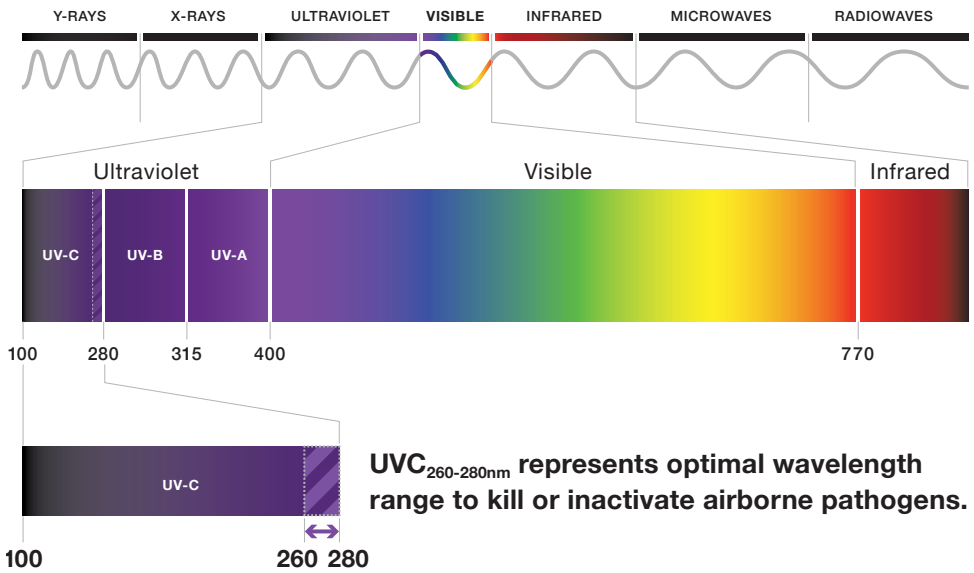
UVC

Using UVC to reduce TB transmission

What is UVC (UVGI)? And how do I apply it?

The term "ultraviolet" (UV) designates the region of the electromagnetic spectrum from 100-400 nanometers (nm), which is not visible to the human eye (see Figure 1). The visible light spectrum runs from approximately 400-700 nm. The International Commission on Illumination (CIE) divides the ultraviolet region into three subregions: UVA (315-400 nm), UVB (280-315 nm), and UVC (100-280 nm). There are no photobiologic or photochemical reasons for the exact delineation between these three subregions. Ultraviolet Germicidal Irradiation (UVGI), Germicidal Ultraviolet (GUV), and UVC refer to the use of ultraviolet energy to kill or inactivate microorganisms. In this manual, we will use UVC as a general term and use UVC_{254} when referring to the specific wavelength of 254 nm, in the UVC subregion, and fixtures that use this wavelength. UVC can be used to lower the risk of airborne transmission of *M. tuberculosis*, SARS-CoV-2, and other airborne pathogens.[1,2,3,4,5]

FIGURE 1. **Ultraviolet region for optimal germicidal activity**



Source: Adapted from *What is Blue Light?* (Eyesafe®)

Germicidal range: $UVC_{260\text{-}280}$ (UVC in the 260-280 nm range) is considered the optimal range of wavelengths to kill or inactivate most bacteria, viruses, and fungi, by damaging deoxyribonucleic acid (DNA), ribonucleic acid (RNA), and/or proteins. UVC in the 200-260 nm range is also germicidal, however not to same extent as $UVC_{260\text{-}280}$ (but may have a better safety profile with decreasing wavelength).[6]

The UVC dose required to inactivate TB is generally highly effective against most viruses and other bacterial pathogens. Fungal spores are more UV-resistant but are not spread from person to person.[7,8]

Sources for producing UVC

Historically, low-pressure mercury (Hg) lamps have been used in UVC fixtures as an efficient bactericidal source. These lamps primarily emit UVC at 254 nm (UVC_{254}) that can effectively kill or inactivate microbes of interest. Other UVC sources include Krypton-Chloride (primarily 222 nm), pulsed xenon (220-750 nm), and wavelength-specific light-emitting diodes (LEDs; primarily 260-280 nm). Some data suggest that LEDs that generate 405 nm blue light, which is outside the UVC region, may also be of use to inactivate some, but not all, microbes of interest. In general, the UVC output of UV-LEDs is relatively inefficient compared to other technologies.[9]

In this chapter, we will focus on air disinfection with UVC_{254} sources.

A note about sunlight:

Older textbooks often discuss the ability of sunlight to effectively kill M. tuberculosis *organisms, but this is misleading. Light generated by the sun does contain desired germicidal UVC wavelengths but most of this germicidal UVC is filtered out by the earth's atmosphere. At ground level, the amount of UVC in sunlight is not sufficient to effectively kill TB within a reasonable amount of time. The primary advantage of the use of outdoor space to reduce TB transmission is not because sunlight is disinfecting the air, but that dilution of organisms is significantly increased by the expansive natural ventilation.*[10]

Applications of UVC_{254} to decrease airborne transmission

UVC_{254} may be used to disinfect air, water, and surfaces; however, limitations exist and application should be tailored to the circumstances, site, and target pathogens. This chapter will cover details of use of UVC_{254} to disinfect air particularly for TB, but the same basic principles apply to other airborne pathogens.

The major applications of UVC_{254} to combat TB and other airborne pathogens include[1]:

- Irradiation of air in the **upper, unoccupied portion of the room (upper-room UVC_{254})**
- Irradiation of air in an **HVAC** (heating, ventilation, and air conditioning) **system (in-duct UVC_{254})**
- Irradiation of air in a **room air cleaner (RAC)**
- Direct irradiation of a **whole room or space**

Most common applications of UVC_{254} as part of a TB environmental control strategy:

Upper-room UVC_{254} (for more details, see section, *Upper-room UVC*)[1,11]

- Upper-room UVC_{254} refers to the use of UVC_{254} fixtures with radiation directed in the upper portions of a room to disinfect the air while the room is occupied. UVC_{254} fixtures are mounted high on walls or suspended from the ceiling and positioned to avoid unsafe exposure to occupants in the room. The ventilation system and/or auxiliary fans mix irradiated air with the air in the lower part of the room (breathing zone), resulting in reduction[12] of viable airborne microbes.
- Upper-room UVC_{254} is a useful environmental control for congregate, healthcare, public, and other settings with inadequate ventilation airflow rate, where susceptible people may have prolonged exposure to a person with unidentified infectious TB. Examples are homeless shelters, emergency department waiting rooms, houses of worship, and prison day rooms.

In-duct UVC_{254} (for more details, see section, *Irradiation of air in an HVAC System [In-duct UVC]*)[1]

- In-duct UVC_{254} is the installation of UVC_{254} lamps inside of a return or exhaust air duct to kill any *M. tuberculosis* that may be in the airstream. If air is recirculated, UVC_{254} may be installed before or after the cooling coil and is a useful supplemental environmental control in recirculating air systems. In-duct UVC_{254} is not recommended as an alternative for cleaning of exhaust air from airborne infection isolation rooms (AIIR). Better options would be direct exhaust to the outdoors or high-efficiency particulate air (HEPA) filtration for AIIR exhaust air.

Effectiveness of UVC_{254}

UVC_{254} effectiveness will increase when the following are increased[13]:

- **Irradiance:** a measure of radiant flux per unit area that is typically expressed in microwatts per squared centimeters ($\mu W/cm^2$). In simple terms, this can be understood as the brightness or intensity of the UVC_{254} lamp.
- **Length of pathogen exposure time:** duration the infectious particles containing the pathogen remain in the area of high irradiance. Exposure time will depend on how quickly air containing infectious particles moves past the lamp or through the disinfection (irradiated) zone.
- **Dose of UVC_{254}:** product of irradiance ($\mu W/cm^2$) x length of exposure (seconds) = microjoules per square centimeters ($\mu J/cm^2$). Effectiveness and safety criteria for UVC_{254} are based on dose.

- **Output of the UVC_{254} fixture:** depends on the UVC_{254} wattage (UVC_{254} wattage may be a fraction of the stated lamp wattage), lamp, and fixture condition. Lamp intensity decreases with age and dust accumulation. Design of the UVC_{254} fixture may also reduce the functional output of UVC_{254}.
- **Proximity of infectious particles to the UVC_{254} lamp or fixture:** depends on placement and number of UVC_{254} lamps used. Adequate room air-mixing is needed to move infectious particles within the disinfection zone to effectively inactivate pathogens when using upper-room UVC_{254}.

UVC_{254} effectiveness will decrease with the following[13]:

- **High humidity:** UVC_{254} dosing requirements increase when the humidity of the air is greater than 70%. In general, the UVC dose will need to be increased by up to two-thirds to compensate for constant humidity in this range.
- **Lower ambient temperatures:** UVC_{254} dosing requirements increase when the ambient temperatures are below 60ºF (15ºC).

The utility of UVC_{254} to disinfect room air and reduce the transmission of disease has been known since the late 1930s when first applied within schools to combat an epidemic of measles among children. Since then, much has been learned about the efficacy and safety of UVC_{254} to prevent TB transmission. A systematic review of current evidence, conducted by the World Health Organization (WHO), informed the 2019 guidelines that recommend use of upper-room UVC_{254} within healthcare settings to reduce TB transmission. Further details of the evidence base and recommendations can be found in the *WHO Guidelines on Tuberculosis Infection Prevention and Control: 2019 update.* See *Resources*.

UVC_{254} exposure, safety, and maintenance considerations

Ensuring safe radiation levels

Safety is a major consideration when using UVC_{254} as part of an infection control program. Exposure to UVC_{254} radiation can occur with direct or indirect exposure (for example, while cleaning a fixture with the lamp turned on, or if unexpected UVC_{254} is reflected off a UV-reflective surface on the ceiling and down to occupied areas). Overexposure to UVC_{254} can cause temporary, yet reversible, harm to the eyes (photokeratitis) and skin (erythema).[6] Proper design, installation, and safety and maintenance protocols are essential to minimize the chances of overexposure.

Safety features built into the design of UVC_{254} equipment may include:

- UVC_{254} systems for upper-room, in-duct, whole-room, and RACs equipped with a “power cut-off switch” that automatically turns the UVC_{254} system off when a baffle, door, or hatch is opened that gives direct exposure to the UVC_{254} lamp.
- RACs designed with UVC_{254} lamps fully enclosed (minimal chance of overexposure).
- Upper-room UVC_{254} systems with motion detectors designed to automatically turn off the UVC_{254} fixtures when something moves above a certain height above the floor.

To ensure both efficacy and safety (particularly with upper-room UVC_{254}), **measure and record UVC_{254} irradiance after installation, after maintenance, annually, or in case of any reported complaints (UVC_{254}-related).**

- An industrial hygienist, health physicist, qualified engineer, or hired professional trained in measuring UV should be able to complete this task. Training and competency in taking UVC_{254} measurements should be established. A listing of expected competencies based on professional role is available in *ANSI/IES RP-44-21: Recommended Practice: Ultraviolet Germicidal Irradiation (UVGI)* and will also be available in *ASHRAE GPC-37: Guidelines for the Application of Upper-air (Upper Room) Ultraviolet Germicidal (UVC) Devices to Control the Transmission of Airborne Pathogens* in 2024. See *Resources*.[14,15]

UVC_{254} radiometer

Irradiance* levels are measured with a device called a radiometer.[16]

Take measurements to confirm:

1. **Efficacy:** Check that UVC_{254} source (lamp) is working properly. The radiometer should be calibrated specifically to measure the UVC radiation wavelength of interest (e.g., UVC_{254}) based on the lamp manufacturers' specifications.
2. **Safety:** Check that levels of effective irradiance in the occupied areas are safe for people in the room (when using upper-room UVC_{254}).

A broad range of possible irradiation levels (0.1-2,000 $\mu W/cm^2$) is needed to measure both the low end of the range (to gauge safety levels in the occupied zone of a room) and the upper end of the range (to check lamp fixture performance). Proper radiometer and detector selection is critical to verify the expected irradiance levels. Depending on the type of radiometer, two separate devices may be needed to accurately obtain both sets of measurements.[14]

* The actual irradiance at each wavelength is referred to as the spectral irradiance. The total irradiance (for photobiologic activity) at each wavelength can vary and is different than the measured effective irradiance (except at 270 nm where they are the same). Most, but not all, radiometers are programmed to display results in total irradiance rather than effective irradiance. The relationship between effective irradiance and spectral irradiance for each wavelength requires a conversion factor. For UVC_{254}, multiply total irradiance by 2 to get the effective irradiance.

Choosing a UVC radiometer

Radiometer manufacturers' websites and representatives can assist in procuring the proper meter.

Check the manufacturer's specifications to determine if the radiometer has the following characteristics based on the UVC source being used:

Wavelength range: Choose a radiometer that measures wavelengths of 220-280 nm with a peak response at 254 nm for standard UVC_{254} low-pressure mercury lamps.

- If measuring sources other than UVC_{254} low-pressure Hg lamps, look for a radiometer calibrated to the peak output of the source you are using.
- If using more than one type of UVC fixture with different wavelengths, consider purchasing a radiometer that can be programmed to measure multiple wavelengths (rather than individual wavelength-specific meters).

Irradiance measurement range: Choose a radiometer that measures effective* irradiance within a recommended range of at least 0.1 - 2,000 $\mu W/cm^2$ for standard UVC_{254} low-pressure mercury lamps.

- The upper end of the range may need to be increased if high-output, unbaffled UVC fixtures are used.
- For wavelengths other than 254 nm, the range may need to be shifted up or down based on peak output of the lamp (check manufacturer's specifications or contact manufacturer directly).

Accuracy: May be referred to as "measurement uncertainty" under specifications. The radiometer should have an accuracy (measurement uncertainty) for both of the following criteria:

- Accuracy for measurements of UV irradiance >1 – 2000 $\mu W/cm^2$ should be: +/- 10% of the reading (note: not +/- 10% of the upper end of the radiometer range) to measure irradiance and confirm performance of the source/lamp.
- Accuracy for measurements of UV irradiance 0.05 to 1 $\mu W/cm^2$ should be: +/- 0.05 $\mu W/cm^2$ to measure safety levels for occupants.

Some radiometers meet both required accuracy criteria as listed above. There may be radiometers that meet only one criterion, so a second radiometer that meets the other criterion will be needed. Reputable companies will disclose this information; if it is not listed online, speak with a manufacturer's representative.

Calibration instructions: The radiometer should be calibrated according to the manufacturer's recommendations. If none is provided, then an annual calibration is recommended.

Field of view (FOV) cone: A cone is a separate accessory for the radiometer that should be used for all safety measurements. The cone should be +/- 40 degrees (80 degrees total) and must be compatible with the radiometer model.[17] If not listed in the model specifications, contact a manufacturer's representative to locate a compatible cone.

Note: The quality of radiometers or other tools (colorimetric cards or films) sold to measure UV output vary greatly and many do not measure the appropriate range of irradiance or meet the accuracy requirements for proper assessment of UVC safety and performance.

On average, the cost of a high-quality radiometer will be in the range of $2000-3000.

* Safety and performance standards presume dose measurements are calculated using effective irradiance. Most UVC_{254} radiometers measure total irradiance and total irradiance results should be multiplied by two (conversion factor to effective irradiance).

What level of UVC_{254} is safe?

Safety recommendations are based on dose of exposure (mJ/cm^2) for an individual; i.e., the intensity of the radiation (irradiance, $\mu W/cm^2$) from the source that reaches the individual and the duration of exposure time (seconds). Two sets of recommendations exist and vary somewhat from each other:

Recommended exposure limit (REL): The CDC/National Institute for Occupational Safety and Health (CDC/NIOSH) published a recommended exposure limit for ultraviolet energy at the UVC_{254} wavelength in 1973.

- The REL for UVC_{254} is 6 mJ/cm^2 for an eight-hour exposure for both eye and skin exposure.[18]

Threshold limit value (TLV®): In 2022, the American Conference of Governmental Industrial Hygienists (ACGIH) updated the TLV for ultraviolet radiation and designated separate values for eye exposure and for skin exposure by wavelength.[19]

- The TLV for UVC_{254} for eye exposure remained unchanged at 6 mJ/cm^2 while the TLV for UVC_{254} for skin exposure is now 10 mJ/cm^2 (most UVC consultants currently recommend following the updated TLV).

A guide to calculating the UVC_{254} exposure dose to ensure proper safety levels can be found in Appendix B, *UVC_{254} Exposure Dose Calculation*.

UVC_{254} safety education and signage[1]

Staff and clients may have concerns regarding health hazards from UVC_{254}. To address these concerns, provide simple education on the purpose, benefits, and risks associated with upper-room UVC_{254}.

- Facility staff should receive appropriate state and federal OSHA-required education and training for safe UVC_{254} use, including hazards of UVC_{254} and use of personal protective equipment (PPE).
- Consider posting a UVC_{254} information sheet on the wall of the room for occupants (staff and clients).
- Develop written site-specific protocols for testing, cleaning, maintenance, repair, and replacement of UVC_{254} fixtures and provide specialized training to appropriate staff.
- On/off switches for lamps should be accessible to appropriate staff members but not located where clients may turn off the fixtures. Consider lockable switches or placement of switches in staff-only restricted areas.

Take precautions to alert and protect the people using the room(s) in which the UVC_{254} is used.

Post warning signs, in all applicable languages, on the UVC_{254} fixtures and other locations as appropriate (for example, overhead storage areas). The signs should carry the following (or a similar) message depending on type of UVC_{254} system used:

EXAMPLE. **Educational sign at occupant level**

FOR YOUR SAFETY

THIS BUILDING IS EQUIPPED WITH UPPER-ROOM UVC_{254} AIR DISINFECTION SYSTEMS

EXAMPLE. **Safety warning sign near areas needing precaution**

CAUTION

Ultraviolet Energy

Turn off UVC_{254} lamps before entering the upper part of the room
(space above the UVC_{254} fixtures).

Routine upkeep

Designate a staff member to be the in-house monitor for UVC fixtures. This person should be trained in the basic principles of UVC operation and safety and should be responsible for cleaning, maintaining, and replacing the lamps. This may include regular maintenance by the engineering department.

- Verify UVC output and clean UVC lamps and fixtures every 3 months (or more frequently depending on local conditions). Ensure that lamps are not burned out or broken. If working, the tubes will emit a violet blue glow. (Note: this is not an indicator of the lamp's effectiveness which can only be confirmed by measuring output with a calibrated radiometer).
- Turn off the lamps before they are cleaned; clean with a lint-free cloth dampened with >70% alcohol.
- Check that the radiation level at each fixture meets the lamp manufacturer's recommendation. Most manufacturers will give a minimum irradiance* (μW/cm^2) value at 3 ft (0.91 m) from the UVC fixture, along the centerline. Tubes should be replaced once a year or as recommended by the manufacturer (or earlier if the irradiance levels are below the manufacturer's recommended minimum levels). Recycle used lamps as recommended by the lamp manufacturer and local or national regulations. A written policy on proper clean-up of a broken lamp should be included in the maintenance instructions. See *Resources*.
- Eyewear does not need to be UV specific; any clear glass or plastic eye shields will block UVC.

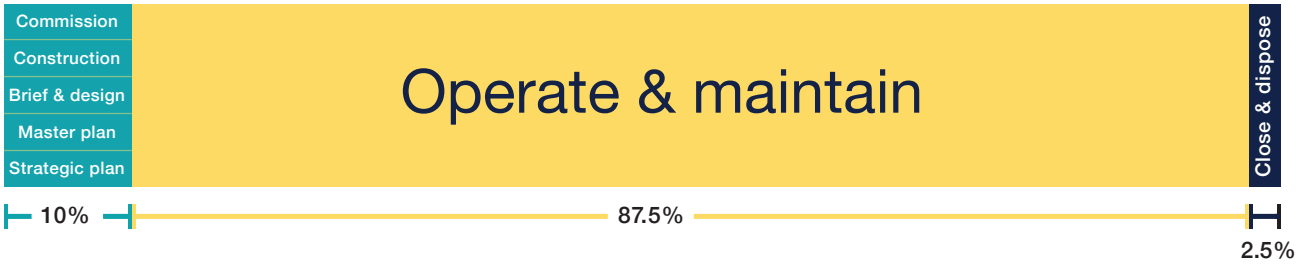
Keep a record of all maintenance and monitoring, including radiometer readings, dates, and remedial action taken if needed. This will help determine the average life of the lamps. Lamps should be purchased close to the planned replacement time because prolonged storage may result in a loss of radiation intensity.[14,15]

* Most manufacturers give irradiance based on effective irradiance. Most UVC_{254} radiometers measure total irradiance and total irradiance results should be multiplied by two (conversion factor to effective irradiance).

Cost considerations

Over the lifetime of an UVC_{254} system, the majority of the costs are typically for long-term operation and maintenance (Figure 2). As a general rule-of-thumb, the average annual cost of operating and maintaining upper-room UVC can be 10-20% percent of the initial acquisition cost. This represents a new annual budget line for operation and maintenance. See Appendix D, *UVC_{254} Cost Considerations*, for a more detailed breakdown of cost considerations.

FIGURE 2. **Estimated lifecycle cost for UVC_{254} system:**



Applications of UVC

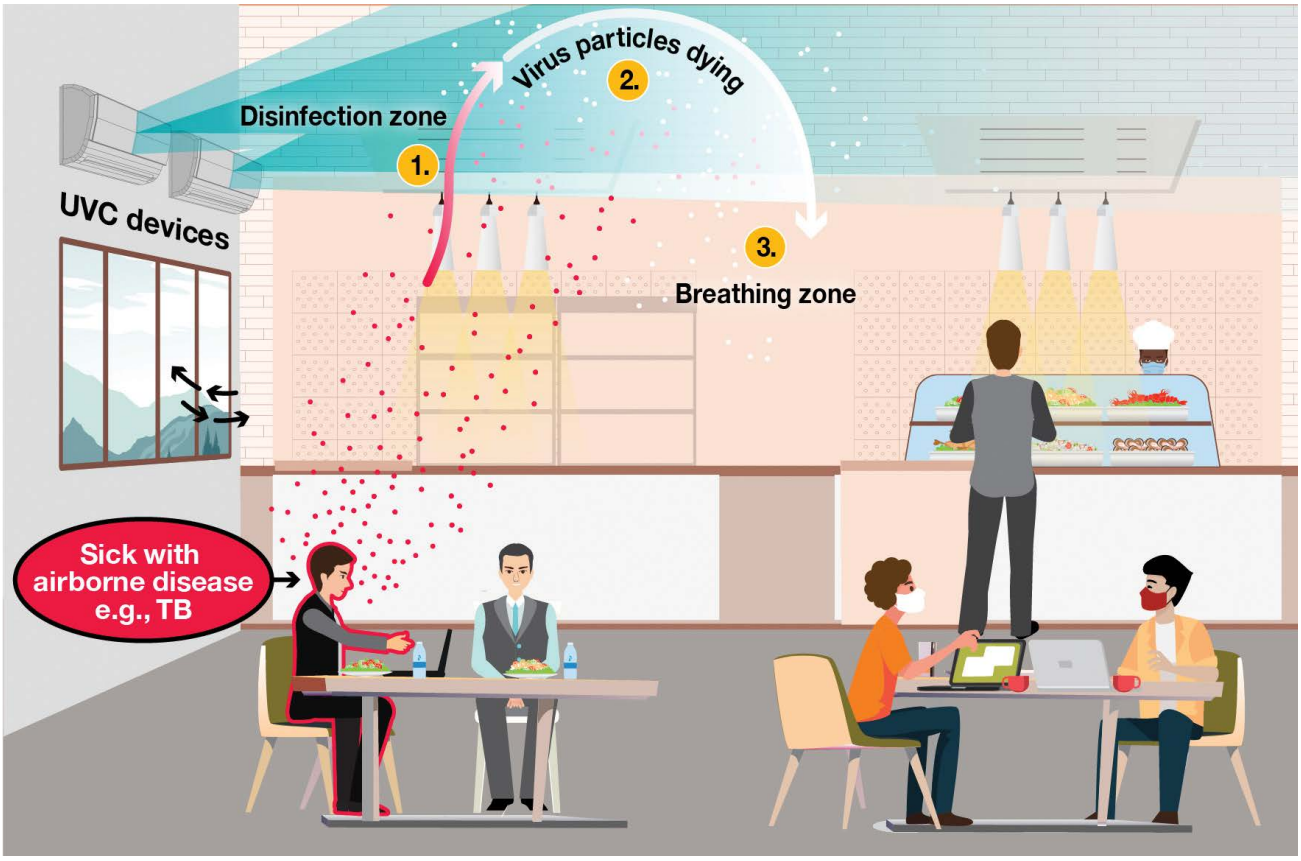
Upper-room UVC

Upper-room UVC refers to the creation of a UVC disinfection zone located above the people occupying a room to reduce the risk of disease transmission by infectious pathogens in the air (Figure 3). Airborne pathogens are killed or inactivated as they pass through the disinfection zone. Upper-room UVC may be considered as a supplement to ventilation strategies in high-risk areas, particularly those where unidentified infectious cases may be present. These settings may include emergency departments, waiting rooms, AIIRs, isolation areas, congregate settings, or homeless shelters.

HVAC systems in congregate areas can reduce, but not necessarily eliminate airborne pathogens/exposures. Adding more ventilation could help reduce the amount of time required to remove these particles; however, it may also be expensive to install and operate systems to further increase ventilation. If poorly designed or installed, ventilation systems may cause objectionable noise and drafts. In this case, consider using upper-room UVC to supplement ventilation. It can be added on a room-by-room basis without affecting the existing building ventilation system.

- The degree of disinfection achievable using upper-room UVC is based on UVC dose, room geometry, room air mixing, and other factors.[20]
- Appropriate installation of upper-room UVC has been shown in some studies to achieve up to an equivalent of 24 air changes per hour (eACH).[21]

FIGURE 3. **How upper-room UVC_{254} works**



Source: Adapted from CDC *Upper-Room Ultraviolet Germicidal Irradiation (UVGI)*

Airborne pathogens, e.g., TB, may be released by individuals occupying a room.

1. Airflow patterns move infectious pathogens up to a disinfection zone produced by the UVC lamps. Airflow may be produced by HVAC systems, fans, and/or open windows.

2. The airborne infectious pathogens are inactivated once they receive an appropriate amount of UVC dose. The particles remain in the air, but they are no longer infectious.

3. The best airflow strategy maintains continuous air movement upwards to be disinfected and then back down to the occupied breathing zone.

- For upper-room UVC_{254} systems to optimally disinfect the air, the air from the breathing zone must pass through the disinfection zone (upper-room) and return back to the breathing zone. Note: ASHRAE defines the breathing zone as "the region within an occupied space between planes at 3 and 72 in (0.08 and 1.8 m) above the floor and more than 2 ft (0.6 m) from the walls or fixed air-conditioning equipment.[22]"
- Pathogens must either receive enough dose to be inactivated while in the disinfection zone during one pass or they must pass through the disinfection zone multiple times, until they receive sufficient cumulative UVC dose to be inactivated.
- Adequate "air mixing" to move potentially infected air upwards to be disinfected and move cleaner air downward into the breathing zone is a key component in an upper-room UVC design plan. Existing ventilation systems may need to be supplemented with ceiling or wall fans, or different supply-air diffusers to accomplish adequate airflow patterns for this purpose. In the latter case, consider keeping the ventilation system fan operating at all times (i.e., constant air volume setting) during building occupancy to ensure adequate air mixing.
- Ideally, UVC in the upper room should be uniformly distributed for best efficiency and occupant safety.

Determining if upper-room UVC_{254} is suitable for the setting

A room must meet the following criteria for upper-room UVC to be used:

- Ceiling height at least 8 ft (2.4 m)
  - Note: For many commercially available UVC fixtures, a minimum ceiling height of 8.5-9 ft (2.6-2.7 m) is recommended by manufacturers.
- The UVC_{254} fixtures must be installed at a height of at least 7 ft (2.1 m) above the floor.[14,23] Many manufacturer's instructions recommend installation at a height of at least 7.5 ft (2.3 m). The goal is that people cannot look directly into the lamps or bump into the fixtures.
- In congregate settings such as homeless shelters and dormitories, bunk beds should not be used unless the rooms have very high ceilings and the appropriate UVC_{254} fixtures are installed at a height above the bunk bed to ensure someone sitting on the top bunk is not overexposed.
  - If the ceiling height (and thus lamp placement) is too low, a client who is sitting on the top bunk may be inadvertently overexposed to radiation in the upper room by direct and reflected UVC_{254}.
- In rooms with high ceilings ($\geq$3 m or $\geq$10 ft) and minimal structures in the upper room, UVC_{254} fixtures may be installed higher than 7 ft (2.1 m) and may be an open-style design (see section, *Choosing fixtures for upper-room UVC*) provided that the TLV for UVC_{254} exposure is met.[14,23]
- Room air mixing fans or appropriate ventilation diffusers are recommended to help enhance airflow patterns from the occupied space to upper room, and from the upper room and back to the occupied space. The room air fans or HVAC system fans should be operated continuously while the building is occupied.

Note: When assessing suitability of a room, consider architectural details as well as utilities and other engineering features in the upper room that can potentially alter efficiency of UVC coverage. Ceilings and walls may need to be repainted to reduce reflection and improve UVC_{254} safety. UVC energy can damage plants, degrade plastic, and fade wood or wallpapers, particularly in upper areas of a room (e.g., plants on tall shelving).

In rooms that already meet standards for air changes per hour (ACH) or clean air delivery rate (CADR) recommendations, upper-room UVC can still provide supplemental reduction in airborne disease transmission and should be considered on a site-specific basis.

Preparing for an upper-room UVC_{254} installation

Specialized expertise and equipment are needed to establish an effective upper-room UVC_{254} system. Only a qualified UVC contractor, working closely with a UVC fixture manufacturer's representative, should design, install, and test an upper-room UVC_{254} system.

- Ask for the manufacturer's proof of Environmental Protection Agency (EPA) registration (see *Resources*) and a listing of completed UVC installation projects.[24]
- Ask potential consultants or contractors about their experiences with previous UVC installations and confirm they are familiar with CDC/NIOSH and ASHRAE upper-room UVC_{254} guidelines.
- Ask to arrange a visit to a successful installation within a similar building or space. This will provide an opportunity to see an existing installation and to talk with another person about their experience with upper-room UVC_{254}.
- Ask the contractor about the possibility of a service contract for UVC_{254} monitoring, maintenance, and lamp replacement after the installation (some facility managers have negotiated up to 5 years of service into the initial purchase agreement). Maintenance generally includes lamp, reflector, and baffle cleaning. Ensure components are replaced with like components. UVC_{254} lamps should emit UVC_{254} and not produce ozone.
- In the installation contract, include a requirement that irradiation levels be measured after installation by an independent contractor who can verify that the UVC system meets desired safety and performance specifications (final acceptance testing) before the installation is accepted as complete.
- Require a written report of the final acceptance testing.

Installation design and considerations

Design solutions are generally customized and unique for each setting.

Dose of UVC_{254} needed: The target UVC_{254} dose required to effectively disinfect for TB can be calculated using the size in **volume** (height x width x length) or **area** (width x length; assumes a maximum functional ceiling height of 10 ft [3 m] or less) of a room.

- The minimum dose criteria for upper-room UVC_{254} will also inactivate most airborne bacterial and viral pathogens of interest (e.g., SARS-CoV-2, influenza, and others [notable exceptions are fungi and some adenoviruses]).[7,8]
- See Appendix A, *Upper-Room UVC_{254} Dosing Worksheets and Selection of Fixtures* for how to calculate a required UVC_{254} dose for a room/space.

Room/space dosing criteria for upper-room UVC_{254} [20,21,25]

- Volumetric dosing criterion is 0.34 mW/ft^3 (12 mW/m^3)
- Area dosing criterion is 0.0033 mW/ft^2 (0.035 mW/m^2); assumes a maximum functional ceiling height of 10 ft (3 m) or less

- Note: While the UVC_{254} dose criteria are used to gauge effectiveness of the UVC_{254} system to inactivate TB, separate exposure dose criteria are used to ensure safety for room occupants. See section, *What level of UVC_{254} is safe?*

Placement and number of fixtures: Locate UVC_{254} fixtures so that radiation in the upper room is relatively uniform, continuous, and complete.

- The number of fixtures needed to reach the target effective dose depends on the size of the room based on room volume (ft^3 or m^3), area (ft^2 or m^2), room shape, and the UVC_{254} output of the fixtures.
- See section, *Choosing fixtures for upper-room UVC_{254}* and Appendix C, *Choosing Upper-Room UVC_{254} Fixtures: Example Scenarios* for a worksheet and examples on how to calculate the number and output of fixtures needed based on room dimensions.
- **Airflow pattern requirements with UVC_{254}:** Adequate room airflow patterns (room-air mixing) from the breathing zone to the disinfection zone and back should be assured through the addition of mixing fans (ceiling- or wall-mounted) or proper selection of ventilation diffusers. The ventilation fans should be operated continuously while the space(s) are occupied. Ideally, the tests should be performed in various scenarios: high density of occupants (might enhance vertical air movement due to body heat generated); no occupants (no added air currents due to occupants); and HVAC on vs. off (assessing with or without added airflow from HVAC).
- The simplest way to check airflow patterns is with ventilation "smoke tubes" to visualize the air movement. The goal is to see the smoke moving up to the

disinfection zone and back to the breathing zone in several locations. The critical criterion is the direction of the smoke movement and not the speed of smoke movement.

- In a typical HVAC system, air may enter and exit near the ceiling. For some systems, air may enter near the floor and exit near the ceiling or vice versa (referred to as displacement ventilation). If air from the room exits near the ceiling and is recirculated to other parts of the building, upper-room UVC_{254} will help to disinfect the return air before it is recirculated. The pattern of airflow created by an HVAC system and the use of recirculated air (vs. direct exhausting of air to the outside) will influence UVC design planning.
- Room airflow patterns are also influenced by temperature gradients (i.e., hot air rises). The use of heating or cooling systems, or simply the presence of many warm bodies together in a room, can influence air movement.
- If there is insufficient air movement when the mixing fans or HVAC systems are off, program the HVAC fans to operate continuously while the building is occupied.
- For more details, see Chapter 2, *Environmental Controls: Part 1 - Ventilation,* section, *HVAC systems*.

Where do you measure irradiance levels in a room with UVC_{254} to ensure safety for occupants?[15,26]

Since each room/space is different, one must evaluate where occupants will be in relation to potential upper-room UVC_{254} exposure. Are they standing 100% of the time? Sitting? Constantly moving within a space?

- Once fixtures have been placed:
  - Until readings of irradiance levels in the occupied zone are verified below the NIOSH REL or ACGIH TLV criteria for UVC_{254}, the installation is not complete, and the lamps should not be used.
  - Take irradiance readings with a calibrated radiometer at 3 ft (0.91 m) from each lamp or at a "witness point" on the wall, opposite the fixture, in the upper room, to ensure that the UVC_{254} radiation intensity meets the manufacturer's specifications.
- In general, a radiometer, calibrated to the wavelength of interest, is used to take irradiance measurements at **standing height 71 in (1.8 m), at sitting height 51 in (1.3 m)** and at any other height above the floor deemed appropriate for the location and how the space is used.[14,27] Examples of location-specific measurements to consider in addition to standing and sitting heights include:
  - Sleeping and sitting levels of beds in shelter dormitories, particularly upper bunkbeds
  - Floor levels in a children's play area of a waiting room
- More specific "eye height" measurements may be used to assess potential eye exposure of occupants in the room based on standardized guidelines for specific workplaces (anthropometry guides).

- If there is more than one UVC_{254} fixture in a room, additional measurements should test the space for potential "hot spots" of irradiance. Hot spots can form if there are overlapping areas of irradiance from two separate fixtures or due to reflection of UV rays off reflective surfaces such as metal equipment or reflective paint.
- Some ceiling paints can reflect too much radiation down to the occupied room below, while others may be absorptive of UVC. If meter readings indicate excessive radiation in the occupied area, the ceiling may need non-reflective paint. This should be included in the budget for the planned installation.
    - Paint containing titanium dioxide is recommended for reducing reflection from surfaces. It is the paint ingredients, not the color (white vs. dark colors), that impact UV reflection.
- If irradiation levels are too high in any location, turn off the lamp or lamps causing the high irradiation levels and repeat measurements. To correct the problem, it may be necessary to adjust, relocate, or replace the fixtures and/or add non-reflective paint to the ceiling and walls.

Irradiance measurements are only the first step in calculating the safety risk for room occupants. Ideally, dose estimates would be made using the irradiance levels and the duration of exposure based on occupant activities (time sitting, standing, looking toward or away from lamp sources, etc.). These estimates are important because a worker could be exposed to a very high irradiance level for a short time and then to low irradiance levels for the remainder of an eight-hour work shift and the cumulative dose will still be below the UVC_{254} REL and TLV safety limitations.

- **Time-motion assessment:** This formal analysis tracks the actual movement and activities of those exposed to UVC_{254} within a room and can give a more comprehensive picture of UVC_{254} exposure risks. There are different methods for completing a time-motion assessment. One acceptable method is to have the person who spends the most time in the room keep a diary/log of their activities during a usual work shift and have irradiance measurements taken that correspond to their activities to allow an exposure dose calculation. A time-motion assessment is desirable for staff, residents, and clients in high-risk situations where prolonged periods of exposure are anticipated.
    - Appendix B, *UVC_{254} Exposure Dose Calculation, Example 2*, tracks a nurse's 8-hour shift with a description of activities and total dose calculation for exposure. This example also shows how a high irradiance reading for brief periods may be acceptable as long as the average exposure for the total 8-hour period stays within the safety limits.
- An alternative method is to have the person in the room wear a UVC_{254} dosimeter and keep a diary/log of their activities. A description of this methodology may be found in the paper by First (2005).

Time-weighted average (TWA) exposure: In a simplified approach, the UVC_{254} eye TLV dose limit of 6 mJ/cm^2 for an 8-hour period can be generalized as being equivalent to **an average irradiance level of 0.21 $\mu W/cm^2$ over the entire 8-hour period.** If the continuous UVC_{254} exposure was over a 4-hour period, with no other UVC_{254} exposure, the average irradiance level would be 0.42 $\mu W/cm^2$. This is called the time-weighted average (TWA) irradiance.

- Using TWA values can be a simple and practical way to assess safety in an area with UVC, particularly if exposure time for occupants is generally low.
- **Important:** the TWA does not represent the "maximum limit" of irradiance at any location in a space.

As an example of applying TWA measurements, consider a waiting room where visitors are primarily occupying the room for periods less than 8 hours.

- If visitors using the room are primarily seated, take the measurements at eye height when seated. If the irradiance measurement at a seated eye level of 1.3 m (51 in) is 0.21 μW/cm^2 or less, an occupant could be seated in the room at that location for 8 hours and not exceed the TLV for UVC_{254}.
- If measurements are taken throughout the room (standing, sitting, etc.) and all results are 0.21 μW/cm^2 or lower, the TLV_{254} would not be exceeded for an occupant moving throughout the room for 8 hours.
- Important: Based on how a room is used, finding an occasional irradiance measurement greater than 0.21 μW/cm^2 in a space can still be acceptable for maintaining exposures below the TLV_{254}. In many common scenarios the occupants of a room are moving through areas of variable exposure within a space (some higher or lower than 0.21 μW/cm^2) resulting in a TWA exposure below the TLV_{254}.
  - Under these circumstances, a general rule-of-thumb is that an irradiance* level of ≤0.4 μW/cm^2 or less, measured at eye height in the occupied space should not exceed the TLV_{254}

See Appendix B, *UVC_{254} Exposure Dose Calculation* for examples on how to calculate exposure dose for upper room UVC_{254}.

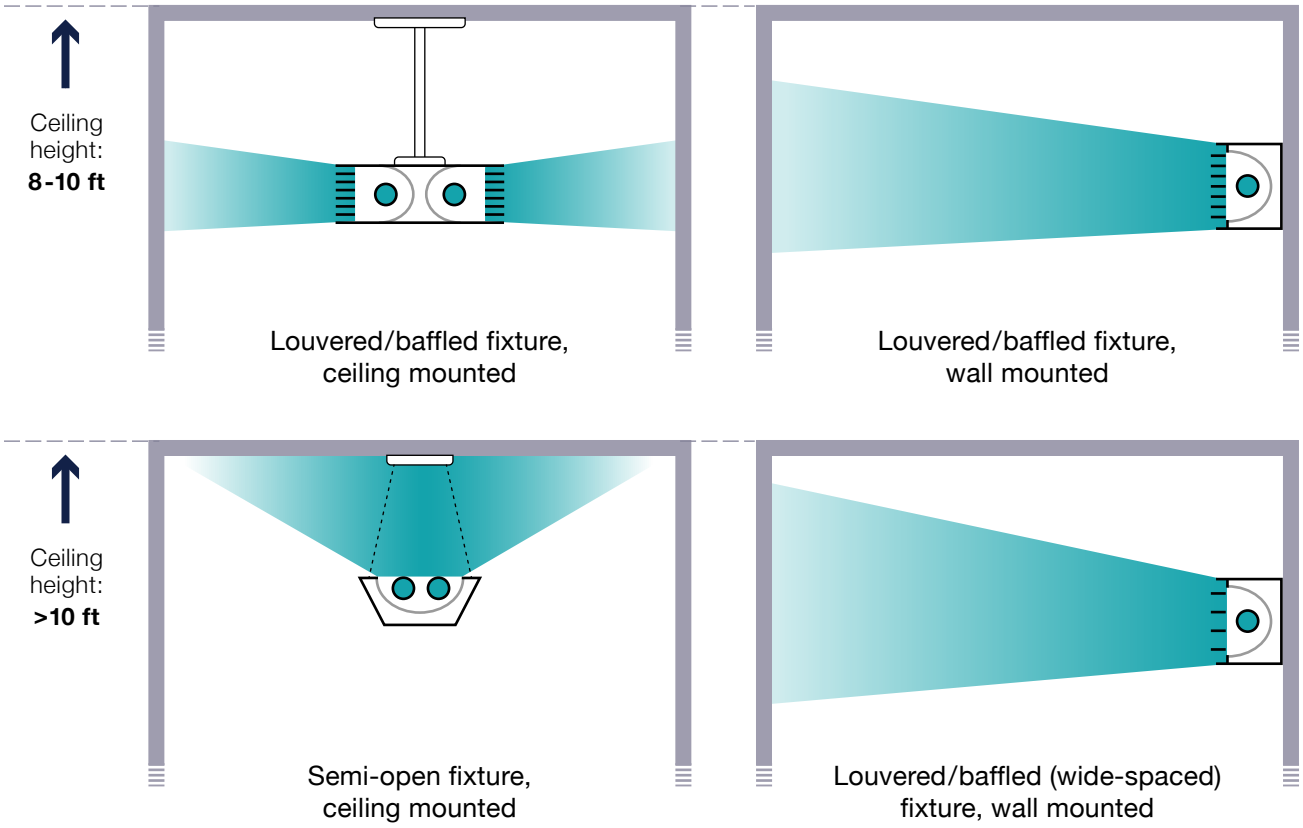
* Most UVC_{254} radiometers measure total irradiance and total irradiance results should be multiplied by two (conversion factor to effective irradiance) to compare against the ≤0.4 μW/cm^2 or less rule.

Choosing fixtures for upper-room UVC

For rooms with lower ceilings (8-10 ft or 2.4-3 m), a louvered or baffled UVC fixture is needed to ensure stray light does not overexpose occupants in the room/space (see Figure 4). In rooms with higher ceilings (≥10 ft or 3 m), UVC fixtures with wider spacing between baffles or open UVC fixtures may be used.

If the ceiling height is less than 8 ft (2.4 m), upper-room UVC cannot be safely used while the room is occupied. Consider the architectural features and finishes in the room when planning for upper-room UVC, as they may block, absorb, or reflect the UV radiation.

FIGURE 4. **Types of upper-room UVGI fixtures best suited for room height**



The worksheet in Appendix B, *UVC_{254} Exposure Dose Calculation* demonstrates **how to calculate the minimum UVC_{254} fixture output needed to disinfect a particular room/space.** Larger rooms/spaces may require more than one UVC_{254} fixture. This worksheet also includes three examples of different room sizes and considerations for:

1. Whether upper-room UVC_{254} can be used based on ceiling height (and architectural details).
2. Choosing between lamp intensity options and number of fixtures needed based on the calculated UVC_{254} output required for the room (UVC_{254} dose criterion based on normal vs. high-humidity conditions).
3. How lifecycle costs may impact choice.

Advantages and disadvantages of upper-room UVC systems

ADVANTAGES	DISADVANTAGES
• Inexpensive to buy and operate compared to a new HVAC system, and to a lesser extent, room air cleaners. • Can be implemented room by room. • Limited impact on structure and mechanical systems. • Do not cause noise or drafts (except for air flow needed for air-mixing).	• If improperly installed or maintained, potentially hazardous to people within the rooms in which they are located. • Requires specialized expertise to install and monitor. • Each installation is site-specific. • Only addresses TB and airborne pathogens; does not remove dust and other particles nor does it provide outside ("fresh") air. • Hard to tell if working appropriately without a specialized meter. • Not as effective under humid conditions (>70% relative humidity). • Glow from lamps may bother individuals who are trying to sleep. • Staff and/or clients may be concerned about radiation exposure.

Irradiation of air in an HVAC system (in-duct UVC)

UVC_{254} lamps have been used in HVAC systems for years to reduce or eliminate biofilm from growing on heat exchange coils, in condensation pans, and on other surfaces within the HVAC system. Similar systems have also been used to disinfect the air flowing through the duct. However, the UVC dose required to maintain clean HVAC surfaces is quite low because the surfaces are generally irradiated all day, every day. The UVC dose required to disinfect the moving air stream will be considerable higher. The faster the air moves through the duct, the higher the amount of UVC needed to inactivate airborne pathogens.

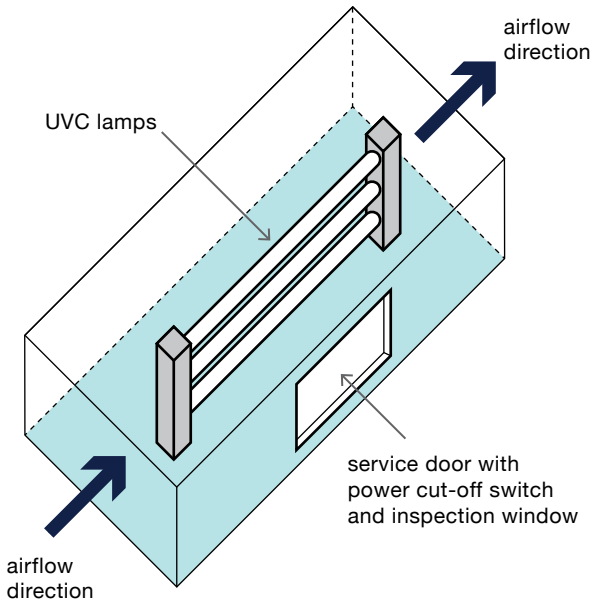
An in-duct UVC system can be effective for reducing the concentration of viable TB organisms in the airstream. For TB control purposes, a properly designed, installed, and maintained UVC_{254} system would be nearly equivalent to a 100% outside air system or HEPA filtration. UVC_{254} will inactivate susceptible microbial organisms, but does not provide dilution or removal of other contaminants in indoor air (e.g., odors, carbon dioxide, etc.) nor would it meet the requirements of the current CDC guidelines (2005) for containment.[1]

Installation and monitoring

An in-duct UVC system should be designed and installed by an experienced professional, such as a UVC lamp or fixture manufacturer representative, HVAC engineer, mechanical engineer, or mechanical or electrical contractor.

- To disinfect air, UVC_{254} lamps are installed parallel to the airflow direction (in-duct UVC_{254} lamps used to disinfect the cooling coil and drip pan surfaces are installed perpendicular to the airflow direction). The number and spacing of the lamps should be selected to ensure that all air is exposed to the UVC radiation. Detailed calculations and measurements based on airflow and duct size will be required. Figure 5 shows a sample installation. See Appendix E, *UVC_{254} In-duct Dose Calculation* for examples of UVC dosing calculations.

FIGURE 5. **Schematic of in-duct UVC_{254} system**



- The UV intensities (irradiance) used inside a duct can be, and should be, greater than the UV intensities for upper-room UVC because the lamps are mounted inside the ductwork, thereby reducing the risk of UV exposure to room occupants. The required intensity of the lamps will depend on air speed in the duct and the cross-sectional area of the duct.
  - Generally, the average irradiance for a typical in-duct UVC_{254} system is about 1,000 to 10,000 μW/cm^2 over an 8 ft (2.4 m) length of duct, with air moving at an average velocity of 500 fpm (2.5 m/s).
  - If the UV sources are located downstream of a cooling cable or in cold air, additional UVC_{254} lamps (sources) will be needed because of reduced UVC efficiency at temperatures below 60°F (15°C). This is similar to the noticeable effect on fluorescent lamps (similar technology) which do not work well in cold rooms and outdoors when the temperature is low.
  - In some laboratory studies, the efficacy of UVC_{254} has been shown to decrease at relative humidity greater than 70%. While the mechanism is not well understood, it is hypothesized that airborne water molecules, as well as the aqueous layer around airborne pathogens, absorb UVC_{254} (requires increase dosing by two-thirds to compensate).[28,29,30]
- Install a duct access door, with a glass viewing window (UVC does not penetrate normal glass or polycarbonate glass), so that the lamps can be cleaned, checked, and replaced. The duct access door should be electrically linked to the lamps' power supply so that the lamps are switched off when the access door is opened ("power cut-off switch"). This will protect maintenance staff from accidental exposure to UVC. Post a warning sign adjacent to the viewing window to alert staff of the danger to the skin and eyes from direct exposure to the bulbs. Anyone working in the vicinity of UVC-generating equipment should wear personal protective equipment (clothing and eyewear).

- Monitoring and maintenance are crucial because the intensity of lamps will fade over time.
- Most lamps will provide at least one year of continuous operation with effective irradiance inside a duct (many UVC system manufacturers offer lamps that last two years).
- Dust collection on lamp surfaces also leads to decreased UVC_{254} output.

- Be wary of in-room, stand-alone heating or cooling units (window, wall, or duct-less units) that purport to use UVC_{254} for air disinfection. UVC within these units can be less efficient at disinfecting air because of the limited UVC_{254} dose received by the airborne pathogens while passing through the unit (i.e., the air-borne pathogens are not exposed to the UVC long enough to inactivate them).

As previously mentioned, air-changes per hour (ACH) and clean air delivery rate (CADR; or clean airflow rate, CAR) are two parameters used to quantify the potential benefit of an environmental control. In a properly designed and maintained in-duct UVC system, assume that the equivalent mechanical airflow rate (eQ) is approximately the same as the CADR. To calculate the equivalent ACH produced using an in-duct UVC system, use the same ACH equation in Chapter 2, *Environmental Controls: Part 1 – Ventilation*, section, *Airflow rate and air changes per hour (ACH)* and Appendix A, *Room Clearance Time Calculation Worksheet*. The same limitations with respect to directional airflow apply to a system with in-duct UVC as to a system with in-duct filtration. Airflow patterns in the room must be such to allow infected air from the breathing zone to reach the in-duct UVC inside the ventilation system.

Advantages and disadvantages of in-duct UVC

ADVANTAGES	DISADVANTAGES
• In-duct UVC lamps, unlike HEPA or other filters, do not cause a significant resistance to airflow in the system. Therefore, they can inactivate most infectious particles in the air but do not significantly reduce the amount of airflow. • In-duct UVC_{254} is usually less expensive to install and operate than a 100% outside air supply system.	• UVC lamps are a more specialized type of equipment than almost all other components of a mechanical HVAC system and require specialized expertise to install and maintain. • Higher output of UVC_{254} lamps (than those used for upper-room UVC_{254} systems) places greater potential risk to maintenance staff if safety measures are not followed, not operational, or inadequate.

Irradiation of air in room air cleaners (RACs)

As with RACs with filtration, RACs with UVC may be used to supplement an existing HVAC system. While the UVC calculations and dosing requirements are the same for RACs and HVAC systems, a more powerful UVC lamp is needed to inactivate the pathogen. This is due to the short UVC exposure time of the pathogens passing through a RAC system. Before purchasing a RAC with UVC, ask the distributor or manufacturer for independent testing results showing the efficiency of the RAC to remove and/or inactivate pathogens.

Direct irradiation (whole-room irradiation)

Whole-room application of UVC in the United States is primarily used as a method to disinfect surfaces. The application of UVC_{254} (low-pressure mercury-vapor lamps) or $UVC_{260\text{-}275}$ (UV-LEDs) generally do not allow people to be in the directly irradiated room/space while in use, and therefore, is usually applied only for a fraction of a day when the space is unoccupied.[31]

- Surface disinfection is limited by the thickness and composition of the material containing the pathogen of interest (e.g., if mixed in expectorated sputum on a surface) as well as the inability of UVC_{254} to efficiently disinfect shadowed or non-smooth surfaces.
- Recently, UVC_{222} (222 nm) has been promoted as means to irradiate a whole room safely while occupied. In addition, UVC_{222} is absorbed by proteinaceous material and is less penetrating than UVC_{254}. To date, no epidemiologic or observational studies have been conducted to confirm the utility and safety of UVC_{222} for this application, and current expert consensus on its utility is mixed. There are a number of studies on the horizon.

Note: Additional applications of direct UVC for purposes beyond air cleaning and surface disinfection are outside the scope of this document and will not be covered.

UVC **APPENDIX A:**

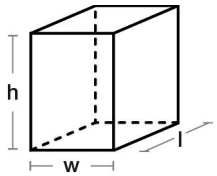
Upper-Room UVC_{254} Dosing Worksheets and Selection of Fixtures

UVC_{254} Volumetric Dosing Worksheet

Room Name, Location and Function: _____

Step 1: Measure room dimensions

Important:
If height is less than 8 ft (2.4 m) do not use upper room UVC_{254}.



- If any architectural or physical obstructions are noted and are lower than the measured "ceiling" height, use the floor to ceiling height of these structures in the decision to use upper-room UVC_{254} and for dose calculations below.
- If suspended ceiling, it may be possible to raise or remove to safely install upper-room UVC_{254}.

Room Height (h) _____ ft or m

Room Width (w) _____ ft or m

Room Length (l) _____ ft or m

Step 2: Calculate room volume (V)

Volume (V) = (h) x (w) x (l) _____ ft^3 or m^3

Step 3: Calculate required room UVC_{254} output (mW)

UVC_{254} volumetric dosing criterion: 0.34 mW/ft^3 or 12 mW/m^3

(V) x UVC_{254} dosing criterion = Required room UVC_{254} output (mW)

- Note: If natural room ventilation with high humidity, consider using up to 0.566 mW/ft^3 (20 mW/m^3).
- Remember – this is the dose required for TB pathogen inactivation. Separate safety requirements (UVC_{254} exposure dose limits) for occupants must be verified after installation.

Room V (ft^3) x 0.34 mW/ft^3 =

_____ mW required*

or

Room V (m^3) x 12 mW/m^3 =

_____ mW required*

* Small rounding difference between calculations in feet vs. meters

Step 4: Calculate type and number of UVC_{254} fixtures

a. Determine type of fixtures based on ceiling height.

b. From manufacturer testing data, find the total UVC_{254} output (mW) emitted per fixture for the selected model.

c. Calculate number of UVC_{254} fixtures needed by dividing UVC_{254} dose required for the space (step 3 above) by the manufacturer UVC_{254} output (mW) emitted per fixture (step 4b).

If full gonioradiometry data for selected UVC_{254} fixtures are available, a UVC CAD program may be used to estimate the UVC_{254} volumetric dose and required number of fixtures needed.

Type of UVC_{254} fixture based on floor to ceiling height (✔choice):

a. ___ If 8-10 ft (2.3-3 m) use **louvered/baffled** UVC_{254} fixtures

___ If 10 ft (3 m) use **open (or louvered/ baffled)** UVC_{254} fixtures

b. ___ mW emitted per fixture

c. ___ mW required ÷ ___ mW emitted per fixture = ___ # UVC_{254} fixtures

Step 5: Appropriate air mixing should be installed/verified.

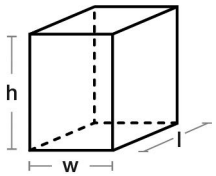
Step 6: Safety exposure for occupants should be considered during design and installation, then verified after installation.

UVC_{254} Area Dosing Worksheet

Room Name, Location and Function: _____

Step 1: Measure room dimensions

Important:
If height is less than 8 ft (2.4 m) do not use upper room UVC_{254}.



- If any architectural or physical obstructions are noted and are lower than the measured "ceiling" height, use the floor to ceiling height of these structures in the decision to use upper-room UVC_{254} and for dose calculations below.
- If suspended ceiling, it may be possible to raise or remove to safely install upper-room UVC_{254}.

Room Height (h) _____ ft or m

Room Width (w) _____ ft or m

Room Length (l) _____ ft or m

Step 2: Calculate room area (A)

Area (A) = (w) x (l) _____ ft^2 or m^2

Step 3: Calculate required room UVC_{254} output (mW)

UVC_{254} area dosing criterion: 0.0033 mW/ft^2 or .035 mW/m^2

(A) x UVC_{254} dosing criterion = Required room UVC output (mW)

- Note: If natural room ventilation with high humidity, consider using up to 0.058 mW/ft^2 (.0054 mW/m^2).
- Remember – this is the dose required for TB pathogen inactivation. Separate safety requirements (UVC_{254} exposure dose limits) for occupants must be verified after installation.

Room V (ft^2) x 0.0033 mW/ft^2 =

_____ mW required*

or

Room A (m^2) x .035 mW/m^2 =

_____ mW required*

* Small rounding difference between calculations in feet vs. meters

Step 4: Calculate type and number of UVC_{254} fixtures

a. Determine type of fixtures based on ceiling height.

b. From manufacturer testing data, find the total UVC_{254} output (mW) emitted per fixture for the selected model.

c. Calculate number of UVC_{254} fixtures needed by dividing UVC_{254} dose required for the space (step 3 above) by the manufacturer UVC_{254} output (mW) emitted per fixture (step 4b).

If full gonioradiometry data for selected UVC_{254} fixtures are available, a UVC CAD program may be used to estimate the UVC_{254} volumetric dose and required number of fixtures needed.

Type of UVC_{254} fixture based on floor to ceiling height (✔choice):

a. ___ If 8-10 ft (2.3-3 m) use **louvered/baffled** UVC_{254} fixtures

___ If 10 ft (3 m) use **open (or louvered/ baffled)** UVC_{254} fixtures

b. ___ mW emitted per fixture

c. ___ mW required ÷ ___ mW emitted per fixture

= ___ # UVC_{254} fixtures

Step 5: Appropriate air mixing should be installed/verified.

Step 6: Safety exposure for occupants should be considered during design and installation, then verified after installation.

UVC **APPENDIX B:**

UVC_{254} Exposure Dose Calculation

Units of Measurements

UVC Irradiance

flux of radiant energy per unit area

$1\ \mu W/cm^2 = 0.001\ mW/cm^2$
$= 0.01\ W/m^2$
$= 10\ mW/m^2$

UVC Dose

UVC irradiation absorbed, Irradiance multiplied by exposure time

$1,000\ \mu J/cm^2 = 1\ mJ/cm^2$
$= 10\ J/m^2$
$= 10,000\ mJ/m^2$

UVC Output

flux of radiant energy

1 Watt = 1 J per second

[Watt (W) = unit of power or radiant flux at rate of one joule per second; joule (J) = unit of energy]

Threshold Limit Value (TLV)

Maximum allowable UVC_{254} dose over an 8-hour shift[19]

- Eye exposure: 6 mJ/cm^2
- Skin exposure: 10 mJ/cm^2

Standardized/ergonomic eye-level heights[15]

- Sitting height: 51 in (1.3 m)
- Standing height: 71 in (1.8 m)

Steps for Calculating UVC_{254} Exposure Dose

1 Measure irradiance for eye level and orientation of person(s) occupying room using a calibrated radiometer with a field-of-view cone properly attached to the sensor.

- **a.** Choose positions of expected use (e.g., sitting at desk or waiting room chairs, standing at counter).
- **b.** Inspect room for possible "hot spots."
- **c.** Record all measurements documenting level above floor and orientation.
- **d.** Confirm if radiometer is measuring effective (weighted for safety) vs total (unweighted) irradiance*. If measuring total irradiance, multiply all values by 2 to convert to effective irradiance UVC_{254}.

2

- **a.** Determine expected duration of exposure at each measurement point (if multiple).
- **b.** Convert exposure time from hours/minutes to seconds.

3

- **a.** Calculate UVC_{254} dose at each measurement point (irradiance x time in seconds).
- **b.** Convert units to mJ/cm^2.

---

4 Add together all UVC_{254} dose estimates for total cumulative UVC_{254} dose (see Examples 1 and 2).

---

5 Compare total cumulative UVC_{254} dose to TLV maximum daily exposure safety limits.

Note: The TLV for UVC_{254} represents the **maximum running 8-hour exposure limit** for individuals exposed to UVC, whether moving through different rooms with UVC exposure or if longer than 8-hour shifts/day.

---

6 While the TLV UVC_{254} dose does not change, the TWA UVC_{254} allowable irradiance changes with exposure time. For instance, if one is only exposed to UVC_{254} for four hours, the TWA UVC_{254} dose remains 6 mJ/cm^2 for eye exposure and the TWA UVC_{254} irradiance is 0.42 $\mu W/cm^2$. If one is exposed to UVC_{254} for a 12-hour shift, **the UVC_{254} dose remains 6 mJ/cm^2 in any running 8-hour period and the TWA UVC_{254} effective irradiance may not exceed 0.21 $\mu W/cm^2$.**

For more detailed discussion, see section, *What level of UVC_{254} is safe?*

See the following three case scenario examples:

Example 1: Calculating UVC_{254} exposure dose for upper-room UVC_{254}.

Example 2: Time-motion assessment for UVC_{254} exposure dose.

Example 3: Time-motion assessment using running ("rolling") 8-hours for UVC_{254} exposure dose.

* Safety and performance standards presume dose measurements are calculated using effective irradiance. Most UVC_{254} radiometers measure total irradiance and total irradiance results should be multiplied by two (conversion factor to effective irradiance)

Example 1: Calculate UVC_{254} exposure dose for upper-room UVC_{254}

Calculate for a clinic waiting room with rows of visitor chairs facing forward (east). Average wait time for visitors is 0.5-1 hour. Choose the 1-hour duration as representative value for calculating UVC_{254} exposure dose to determine if the exposure is below the TLV for UVC_{254}.

Step 1:	Radiometer measurement of irradiance at seated eye level of 51 in (1.3 m) is 0.2 µW/cm² and measures the same in all rows of seats facing forward (east). Radiometer is measuring total irradiance (multiply value by 2 to convert to effective irradiance)	Irradiance = 0.4 µW/cm²
Step 2:	**a.** Expected duration of exposure = 1 hour **b.** Convert time to second	Exposure time = 1 hour = 60 minutes = 3600 seconds
Step 3:	**a.** UVC_{254} dose = irradiance x time (seconds) **b.** Convert units to mJ/cm²	UVC_{254} dose = Irradiance x time = 0.4 µW/cm² x 3600 s = 1440 µW • s/cm² = 1440 µJ/cm² = 1.44 mJ/cm²
Step 4:	Cumulative UVC_{254} dose for visitor would remain the dose for 1 hour (would not expect visitor to return and sit in waiting room again after appointment)	Total cumulative UVC_{254} dose = **1.44 mJ/cm²**
Step 5:	Compare total cumulative UVC_{254} dose calculation to UVC_{254} TLV maximum daily exposure safety limits	Total cumulative dose is safely below the maximum allowable UVC_{254} dose for eye-level (6 mJ/cm²) or skin-level exposures (10 mJ/cm²). Calculate as % of TLV_{254}: = (1.44 mJ/cm² ÷ 6.0 mJ/cm²) × 100% = **24% of UVC_{254} TLV**

Example 2: Time-motion assessment

A nurse kept track of her time and exposure during her eight-hour shift throughout facility with upper-room UVC_{254} to assess her individual risk based on usual work shift activities. She kept a diary/log of her activities and took eye-level irradiance measurements and recorded results accordingly.

Log of activity locations with irradiance measurements and time spent per location x 8-hour shift:

Corridor: ..... 0.5 μW/cm² for 10 minutes ..... (600 s)

Nurse's desk: ..... 0.05 μW/cm² for 3 hours ..... (10,800 s)

Patients' rooms: ..... 0.10 μW/cm² for 3 hours ..... (10,800 s)

Records area: ..... 0.125 μW/cm² for 1.5 hours ..... (5,400 s)

Break room: ..... 0.15 μW/cm² for 20 minutes ..... (1,200 s)

What was her total UVC dose during her shift?

Step 1: Radiometer measurement of irradiance (eye level) in usual position/orientation during activities.

Radiometer is measuring total irradiance (multiply value by 2 to convert to effective irradiance)

Cumulative UVC_{254} dose = ∑ (Irradiance x time)

	IRRADIANCE	x	TIME (sec)	=	UVC_{254} DOSE
Corridor:	1.0 μW/cm²	x	600 s	=	600
Nurse's desk:	0.10 μW/cm²	x	10,800 s	=	1,080
Patients' rooms:	0.20 μW/cm²	x	10,800 s	=	2,160
Records area:	0.25 μW/cm²	x	5,400 s	=	1,350
Break room:	0.30 μW/cm²	x	1,200 s	=	360

Step 2:

a. Record duration of exposure at each position/activity.

b. Convert time to seconds.

Step 3:

a. UVC_{254} dose = irradiance x time (seconds); calculate sum of UVC_{254} doses for total shift

b. Convert units to mJ/cm²

Total = 5,550 μJ/cm²

Convert units = 5.55 mJ/cm²

Step 4: Cumulative UVC_{254} dose for this nurse during 8-hour shift

Total cumulative UVC_{254} dose = **5.55 mJ/cm²**

Step 5: Compare total cumulative UVC_{254} dose calculation to UVC_{254} TLV maximum daily exposure limits

Total cumulative dose is below the maximum allowable UVC_{254} dose for eye-level (6 mJ/cm²) or skin-level exposures (10 mJ/cm²)

Calculate as % of TLV_{254}:

= (5.55 mJ/cm² ÷ 6.0 mJ/cm²) × 100%

= **93% of UVC_{254} TLV**

Example 3: Time-motion assessment using running ("rolling") 8-hours*

Mr. Bleu works the 8:00 am to 8:00 pm shift. His average hourly UVC_{254} dose is shown in the figure below. Because Mr. Bleu worked in various areas during his 12-hour shift, his hourly UVC_{254} dose was not constant.

Did Mr. Bleu exceed the eye TLV for UVC_{254} (noting that if eye criterion of 6 mJ/cm^2 is met, the skin criterion of 10 mJ/cm^2 will also be met)?

Step 1: Make a table with four columns:

- **Time**
- **Hourly UVC_{254} dose** (mJ/cm^2)
- **Cumulative UVC_{254} dose** (mJ/cm^2)
- **Running 8-hour cumulative UVC_{254} dose** (mJ/cm^2)*

Assume no UVC_{254} exposure prior to the beginning of the shift

Time	Hourly UVC_{254} Dose (mJ/cm^2)	Cumulative UVC_{254} Dose (mJ/cm^2)	Running 8-hr Cumulative UVC_{254} Dose (mJ/cm^2)
8:00	0.0	0.0	0.0
9:00	1.0	1.0	1.0
10:00	0.7	1.7	1.7
11:00	0.6	2.3	2.3
12:00	0.5	2.8	2.8
13:00	1.1	3.9	3.9
14:00	0.9	4.8	4.8
15:00	0.6	5.4	5.4
16:00	0.5	5.9	5.9
17:00	0.7	6.6	5.6
18:00	0.6	7.2	5.5
19:00	1.1	8.3	6.0
20:00	0.7	9.0	6.2

Step 2: Enter "Time" data in the first column and enter the "Hourly UVC_{254} dose" in the second column.

Columns 1 and 2 of table

Step 3: For each hour, starting at 08:00, add the UVC_{254} dose for that hour with the cumulative UVC_{254} dose from the previous hour.

Note: the UVC_{254} dose prior to 08:00 is 0.0 mJ/cm^2.

Column 3 of table

Step 4: For each hour, starting at 08:00:

- Calculate the running 8-hour cumulative UVC_{254} dose by summing the UVC_{254} dose 01:00 to 08:00 and enter this value at 08:00.
- Next, calculate the running 8-hour cumulative UVC_{254} dose by summing the UVC_{254} dose 02:00 to 09:00 and enter this value at 09:00.
- Then calculate the running 8-hour cumulative UVC_{254} dose by summing the UVC_{254} dose 03:00 to 10:00 and enter this value at 10:00.
- Continue through the end of the 12-hour work shift (20:00).

Column 4 of table

EXAMPLE CONTINUES ›

* The ACGIH Physical Hazards Committee has stated that the TLV for the eye is based on an eight-hour running ("rolling") average of exposure.

Example 3: Time-motion assessment using running ("rolling") 8-hours*

Step 5: Look at the "Running 8-hour cumulative UVC_{254} dose" column. At any time, did the UVC_{254} dose exceed the TLV of 6 mJ/cm^2?

Yes, the "Running 8-hour cumulative UVC_{254} dose" exceeded the TLV of 6 mJ/cm^2 at 20:00.

Step 6: What actions do we need to take?

Time	Hourly UVC_{254} Dose (mJ/cm^2)	Cumulative UVC_{254} Dose (mJ/cm^2)	Running 8-hr Cumulative UVC_{254} Dose (mJ/cm^2)
8:00	0.0	0.0	0.0
9:00	1.0	1.0	1.0
10:00	0.7	1.7	1.7
11:00	0.6	2.3	2.3
12:00	0.5	2.8	2.8
13:00	1.1	3.9	3.9
14:00	0.9	4.8	4.8
15:00	0.6	5.4	5.4
16:00	0.5	5.9	5.9
17:00	0.7	6.6	5.6
18:00	0.6	7.2	5.5
19:00	1.1	8.3	6.0
20:00	0.7	9.0	6.2

B. Note that an increase in UVC_{254} dose in any of the first eight hours would probably result in exceeding the TLV.

C. After 9 hours of his shift, even though the total cumulative dose is >6 mJ/cm^2, the TLV has not yet been exceeded because the running 8-hr cumulative dose has not exceeded the TLV.

A. Because the eye TLV of 6 mJ/cm^2 (over running 8-hrs) was exceeded during the last hour of the 12-hour shift, one should confirm that these measurements are representative of Mr. Bleu's "normal" UVC_{254} exposure. If yes, actions should be taken to reduce his hourly exposure.

UVC **APPENDIX C:**

Choosing Upper-Room UVC_{254} Fixtures: Example Scenarios

Choosing the most appropriate and cost-efficient UVC fixtures to create an effective upper-room UVC_{254} system is dependent on room shape and dimensions, type of fixtures available, and how occupants will utilize the space.

Three examples demonstrate how these factors can influence final fixture choices for upper-room UVC.

Example Room #1: Low-ceiling room

1 Floor to ceiling height is **too low to safely install upper-room UVC_{254}**	**Height 7.5 ft (2.3 m)** | Width 10 ft (3 m) | Length 10 ft (3 m)

Example Room #2: Standard office/exam room

1 Floor to ceiling height is **sufficient for upper-room UVC_{254}**	**Height 8.5 ft (2.6 m)** | Width 10 ft (3 m) | Length 10 ft (3 m)
2 **Calculate room volume:** (V) = (h) x (w) x (l)	V = 850 ft^3 (23.4 m^3)
3 **Calculate required room UVC_{254} output (mW):** Required UVC_{254} dose* = V (ft^3) x 0.34 mW/ft^3 **or** = V (m^3) x 12 mW/m^3 *Small rounding difference between calculations in feet vs.meters	**Req. UVC_{254} dose = 280-290 mW***
4 **Calculate type and number of UVC_{254} fixtures** **a.** Ceiling height is between 8-10 ft (2.4-3 m), use a **louvered/baffled style fixture** (ceiling not high enough to safely use an open design fixture). **b.** A manufacturer has louvered/baffled UVC_{254} fixtures with six different levels of UVC output. **c.** The goal would be to have enough fixtures (based on UVC_{254} output) to meet the required room UVC_{254} dose for adequate disinfection for the room size. **Here the goal would be a total room UVC dose of 280-290 mW.**	Manufacturer fixture options for louvered/baffled design (UVC_{254} output) 200 mW . . . . (0.2 W) 400 mW . . . . (0.4 W) 600 mW . . . . (0.6 W) 800 mW . . . . (0.8 W) 1,000 mW . . . . (1.0 W) 1,200 mW . . . . (1.2 W)
Cost consideration: In general, the cost of a UVC_{254} fixture with an output of 400 mW is not double the cost of a UVC_{254} fixture with an output of 200 mW. The cost of replacement lamps is nearly identical. In general, select the one UVC_{254} fixture with 400 mW output over two smaller UVC_{254} fixtures based on lifecycle cost (see Appendix D, *UVC_{254} Cost Considerations*), if the room configuration allows.	**One 400 mW UVC_{254} fixture or two 200 mW UVC_{254} fixtures** would meet required UVC_{254} dose for disinfection. If the risk of airborne transmission of TB is low (i.e., an area where one would not expect infectious TB patients), one 200 mW UVC_{254} fixture could suffice.
5 Appropriate air mixing should be installed/verified.	
6 Safety exposure for occupants should be considered during design and installation, then verified after installation.	

Example Room #3: **Large room, high ceiling** (with decorative acoustic ceiling panels)

1 Floor to ceiling height is **sufficient for upper-room UVC_{254}**

- **a.** In this example, decorative acoustic architectural panels are hung from the ceiling. The panel bases (lowest points) are 10 ft (3 m) above the floor.
- **b.** Use the floor to panel height for UVC_{254} considerations and calculations.

Actual Height 20 ft (6.1 m)

Ceiling Panel Height 10 ft (3 m)

Width 40 ft (12.2 m)

Length 50 ft (15.2 m)

2 **Calculate room volume:** (V) = (h) x (w) x (l)

V = 20,000 ft^3 (556 m^3)

3 **Calculate required room UVC_{254} output (mW):**

Required UVC_{254} dose* = V (ft^3) x 0.34 mW/ft^3 **or** = V (m^3) x 12 mW/m^3

Req. UVC_{254} dose = 6672-6800 mW*

*Small rounding difference between calculations in feet vs.meters

4 **Calculate type and number of UVC_{254} fixtures**

In this case, the functional ceiling is 10 ft (3 m) and these values will be used for the dosing calculations as well as for UVC_{254} fixture selection.

- **a.** Because of the decorative ceiling panels, use **louvered/ baffled fixtures** (if no panels were present, the >10 ft (3 m) high ceiling would have allowed open or semi-open UVC_{254} fixtures).
- **b.** A manufacturer has louvered/baffled UVC fixtures with six different levels of UVC_{254} output.
- **c.** Cost-effective choice would be to use as few fixtures as possible. **Six 1.2 W UVC_{254} fixtures would be a practical choice** if they can produce a relatively uniform distribution of UVC_{254} in the room. **Depending on the room geometry, a combination of fixture outputs may be needed.**

If there were no or very few obstructive items in the upper portion of the room, open or semi-open UVC_{254} fixtures could have been considered. Open UVC_{254} fixtures generally start at 3 W and higher in output. For this example, two-to-three open UVC_{254} fixtures would suffice if no panels were present hanging from the ceiling.

Fixtures needed per UVC_{254} fixture output to reach required room UVC_{254} dose of 6,800 mW

#	FIXTURE UVC_{254} OUTPUT
34	200 mW (0.2 W)
17	400 mW (0.4 W)
11	600 mW (0.6 W)
9	800 mW (0.8 W)
7	1,000 mW (1.0 W)
6	1,200 mW (1.2 W)

5 Appropriate air mixing should be installed/verified.

6 Safety exposure for occupants should be considered during design and installation, then verified after installation.

UVC **APPENDIX D:**

UVC_{254} Cost Considerations

Over the lifetime of an upper-room (UR) UVC_{254} system, the primary costs will be the long-term operation and maintenance costs. The following items are often included in calculation of the lifecycle cost of a UVC_{254} fixture, assuming the "life" of a UVC_{254} fixture is 15 years:

Initial costs	Recurring costs
• UR UVC_{254} fixture(s) • Shipping, customs, taxes • Air mixing system (diffusers, fans, etc.) • Layout design • Installation (fixture, fans, electrical, etc.) • Acceptance testing (UR UVC_{254} performance for inactivation and safety) • UVC meter	• Quarterly maintenance • Annual maintenance • Annual electricity • Annual calibration of UVC_{254} meter

As a general rule-of-thumb, the average annual cost of operating and maintaining UR UVC_{254} can be 10-20% percent of the initial acquisition cost. This represents a new annual budget line for operation and maintenance.

The lifecycle cost is critical to understand. See section, *UVC_{254} exposure, safety, and maintenance considerations*, Figure 2, *Estimated lifecycle cost for UVC_{254} system.* An estimate of lifecycle costs for three different quantities of UR UVC_{254} fixtures is shown below:

One UR UVC_{254} fixture	Ten UR UVC_{254} fixtures	Fifty UR UVC_{254} fixtures
UVC_{254} fixture cost . . . . . **$1,000** *(each, not including taxes, shipping, etc.)*	UVC_{254} fixture cost . . . . . **$1,000** *(each, not including taxes, shipping, etc.)*	UVC_{254} fixture cost . . . . . **$1,000** *(each, not including taxes, shipping, etc.)*
	Total lifecycle cost . . . . . **$46,475** *(all UVC_{254} fixtures)*	Total lifecycle cost . . . . . **$179,500** *(all UVC_{254} fixtures)*
Total lifecycle cost . . . . . **$13,495** *(per UVC fixture)*	Total lifecycle cost . . . . . **$4,648** *(per UVC_{254} fixture)*	Total lifecycle cost . . . . . **$3,590** *(per UVC_{254} fixture)*
Annualized lifecycle cost as a percentage of UR UVC fixture cost . . . . . **$900 or 90%**	Annualized lifecycle cost as a percentage of UR UVC_{254} fixture cost . . . . . **$310 or 31%** *(per UVC fixture)*	Annualized lifecycle cost as a percentage of UR UVC_{254} fixture cost . . . . . **$239 or 24%**

As shown, the annualized lifecycle costs will decrease as the number of UR UVC_{254} fixtures increases.

For additional details on lifecycle costs of UR UVC_{254} systems, see the technical information sheet, *Disinfecting room air with upper-room (UR) germicidal UV (GUV) systems*, developed by the Stop TB Partnership's End TB Transmission Initiative (ETTi). See *Resources*.

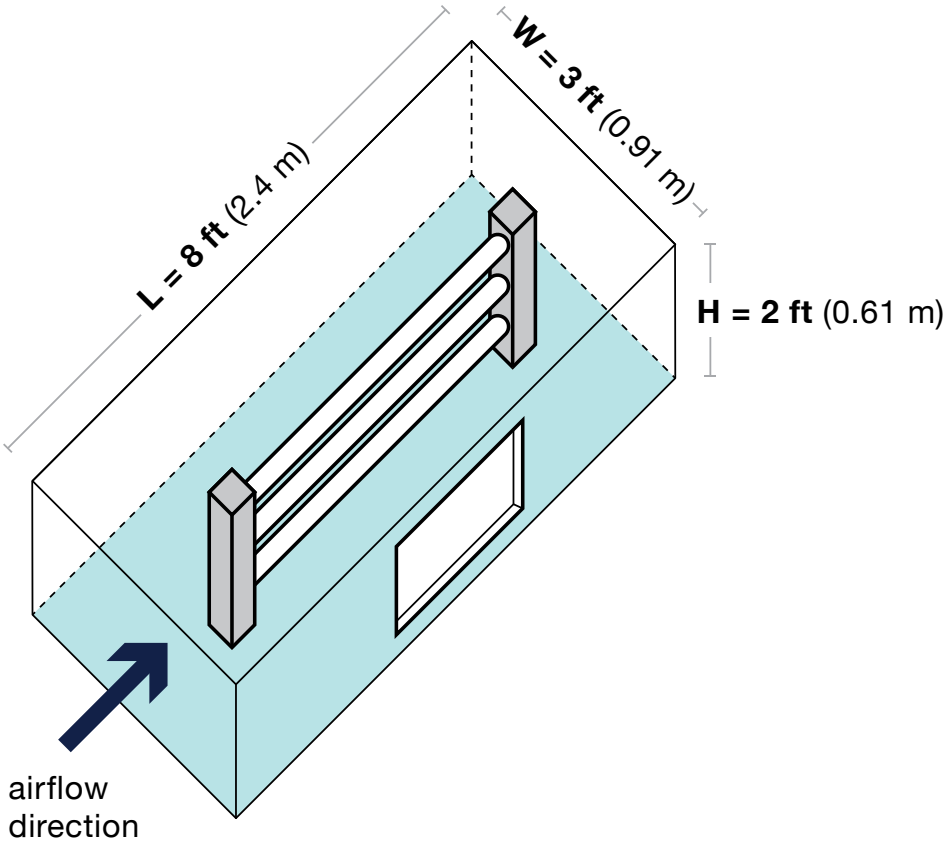
UVC **APPENDIX E:**

UVC_{254} In-duct Dose Calculation

When designing a new in-duct UVC_{254} system, or installing one into an existing HVAC system, the UVC_{254} dose required will be a function of the average UVC_{254} irradiance in the duct (based on output of the lamp) and the exposure time (based on airflow speed) in the system. Because an in-duct lamp does not require baffles, the UVC_{254} output approaches 100% of the lamp output and can be highly efficient.

Because of the technical requirements — any installation of in-duct UVC_{254} should have a qualified review to verify adequate UVC_{254} dosing is achieved for the purposes of disinfection.

Diagram of in-duct UVC_{254} lamp placement:



Step 1:	Identify specifications of the HVAC system and calculate expected air velocity within duct.	**1. Airflow Rate (Q)** = 3,000 cfm (5,100 m^3/hr) per manufacturer's specifications and Testing & Balancing (T&B) report. **2. Area of Duct (A)** = H x W = 2 ft x 3 ft = 6 ft^2 (0.56 m^2) **3. Velocity of Air (V)** = Q / A = 3,000 cfm/6 ft^2 (5,100 m^3/hr/0.56 m^2/3,600 sec/hr) = 500 ft/min (2.5 m/s)
Step 2:	Identify available length of ductwork for UVC placement (check if manufacturer recommends a specific length designated for UVC).	If not designated by the manufacturer, a minimum of 8 ft (2.4 m) for large HVAC systems is often used for installing an in-duct UVC system (vs 2-4 ft for a residential-size system).
Step 3:	Calculate exposure time based on length of in-duct UVC_{254} lamp placement.	Exposure time (t) in the 8 ft length (L) of irradiated duct = L / V = 8 ft/500 ft/min* 60 sec/min (or 2.4 m/2.5 m/s) [convert to meters and seconds] = 0.95 s
Step 4:	Calculate if recommended minimum average irradiance required for in-duct UVC is met.	**Minimum average irradiance for in-duct UVC: 1,000-10,000 µW/cm^2** (ASHRAE 2019, chapter 62*) Note: Average UVC_{254} dose received by an airborne pathogen when the average irradiance in the duct is 10,000 µW/cm^2 is: Dose (µJ/cm^2) = 10,000 µW/cm^2 * 0.95 s = 960 µW*s/cm^2 = 960 µJ/cm^2

* Riley et al. [1976] estimated the UVC_{254} dose necessary to inactivate 90% of *M. tuberculosis* to be 576 µJ/cm^2 while Kowalski [2006] estimated the dose to be 1,080 µJ/cm^2. Given the UVC_{254} dosing in the example above, approximately 90% of the airborne *M. tuberculosis* passing through the HVAC system should be inactivated in a single pass.

Resources

Part 2. UVC

American National Standards Institute/Illuminating Engineering Society (ANSI/IES)

- *ANSI/IES RP-44-21: Recommended Practice: Ultraviolet Germicidal Irradiation (UVGI)*
  https://store.ies.org/product/rp-44-21-recommended-practice-ultraviolet-germicidal-irradiation-uvgi/?v=7516fd43adaa
  Listing of expected competencies based on professional role

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)

- ASHRAE Epidemic Task Force *Filtration and Disinfection Guidance*
  https://www.ashrae.org/file%20library/technical%20resources/covid-19/ashrae-filtration_disinfection-c19-guidance.pdf
- ASHRAE 2020 Handbook—HVAC Systems and Equipment: Chapter 17, *Ultraviolet Lamp Systems*
  https://www.ashrae.org/file%20library/technical%20resources/covid-19/i-p_s20_ch17.pdf
- ASHRAE 2019 Handbook – HVAC Applications: Chapter 62, *Ultraviolet Air and Surface Treatment*
  https://www.ashrae.org/file%20library/technical%20resources/covid-19/i-p_a19_ch62_uvairandsurfacetreatment.pdf
- ASHRAE *Positions on Infectious Aerosols*
  www.ashrae.org/file%20library/about/position%20documents/pd_infectiousaerosols_2020.pdf
- ASHRAE GPC-37: *Guidelines for the Application of Upper-air (Upper Room) Ultraviolet Germicidal (UVC) Devices to Control the Transmission of Airborne Pathogens* (available in 2024)

Centers for Disease Control and Prevention (CDC)

- *Upper-Room Ultraviolet Germicidal Irradiation (UVGI)*
  https://www.cdc.gov/coronavirus/2019-ncov/community/ventilation/uvgi.html

U.S. Environmental Protection Agency (EPA)

- *Recycling and Disposal of CFLs and Other Bulbs that Contain Mercury*
  https://www.epa.gov/mercury/recycling-and-disposal-cfls-and-other-bulbs-contain-mercury
- *Cleaning Up a Broken CFL: Recommendations for When a CFL or Other Mercury-Containing Bulb Breaks*
  https://www.epa.gov/mercury/cleaning-broken-cfl
- Compliance Advisory: *EPA Regulations About UV Lights that Claim to Kill or Be Effective Against Viruses and Bacteria*
  https://www.epa.gov/compliance/compliance-advisory-epa-regulations-about-uv-lights-claim-kill-or-be-effective-against

Stop TB Partnership's End TB Transmission Initiative (ETTi)

- Technical information sheet: *Disinfecting Room Air with Upper-room (UR) Germicidal UV (GUV) Systems*
  https://www.stoptb.org/file/10924/download

World Health Organization (WHO)

- *WHO Guidelines on Tuberculosis Infection Prevention and Control: 2019 Update*
  https://apps.who.int/iris/bitstream/handle/10665/311259/9789241550512-eng.pdf

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Part 2. UVC

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Personal Protective Equipment

Overview

The purpose of this chapter is to provide practical information on the rationale and role of personal protective equipment (PPE) against airborne *Mycobacterium (M.) tuberculosis.* Surgical (procedure) masks are traditionally used for keeping the surgical field or environment sterile. They are also used in healthcare settings as personal protection from droplet-borne disease transmission. However, surgical masks offer minimal protection against airborne *M. tuberculosis*. Rather, they are best used to reduce the release of infectious aerosols into the room air by persons with infectious TB. To be protected against airborne infectious particles, a person will need to wear a well-fitting respirator (e.g., N95 respirator shown in Figure 1). Although masks have often been strongly associated as a symbol of infection prevention and control (or potentially a trigger for stigma or political discord), it is essential to know that respiratory protection is but one component of an integrated program of TB infection prevention and control for protecting healthcare personnel (HCP) from airborne *M. tuberculosis*.[1]

FIGURE 1.

TB healthcare provider wearing an N95 respirator

Source: CITC

Why are respirators needed?

TB was the first disease proven to be transmitted by the airborne route, and more recently, viable *M. tuberculosis* have been isolated from cough aerosols and exhaled breath aerosols from persons with TB.

- Most of the particles in these aerosols are smaller than 5 micrometers (µm) in diameter, a size that can be inhaled and deposited deep into the lungs where they can establish infection and possibly disease.
- Respirators reduce the risk of inhaling infectious particles and can mitigate the occupational risk for TB transmission to HCP.[2]

Although not all persons with TB are infectious, there currently is not an accurate way to determine which persons are most infectious. The range of infectious aerosol production from persons with TB varies over 1000-fold, suggesting why some persons may be “super-spreaders” and some not infectious at all. However, an often-quoted statement remains relevant for all settings: The most infectious persons with TB are those not yet on appropriate antitubercular therapy.[3]

Who should wear respirators?

HCP working with persons undergoing evaluation for active TB disease or with confirmed infectious TB disease should wear respirators, even if they are in an airborne infection isolation room (AIIR), because there may be a higher amount of infectious aerosol close to the person with TB as they breathe and cough. HCP outside the AIIR (e.g., in the adjacent hallway), however, do not need to wear a respirator as long as the ventilation system in the AIIR is functioning correctly. HCP on the frontlines of care (e.g., in emergency rooms or ambulances) should wear respirators when evaluating and caring for persons who are undergoing evaluation for presumptive TB disease, as the most dangerous situation for potential TB transmission is during the care for a person before TB is diagnosed and appropriate treatment started. Anesthesia, surgical, and pathology staff may benefit from PPE if a person with disseminated TB is undergoing a procedure in which there may be a risk of aerosolization (e.g., from the use of bone saws). Laboratorians should also use respirators when manipulating specimens with *M. tuberculosis*, outside of a biological safety cabinet.[4,5]

FIGURE 2.

Surgical mask worn by person with infectious TB during transit through facility

Source: iStock.com/Sasirin Pamai

Note: The most appropriate use for **surgical masks** (rather than a respirator) is for use on infectious persons with TB when they are outside of an AIIR (e.g., in transit to radiology or during an outpatient clinic visit). See Figure 2.

- The use of surgical masks on persons with TB has been shown to decrease transmission to guinea pigs by over 50%.[6]
- Given the increased work of breathing associated with pulmonary TB, it may not be appropriate to ask persons with TB to wear respirators as they have more resistance to breathing than surgical masks.
- There may be circumstances where it may be reasonable to ask a person with TB to temporarily wear a surgical mask inside an AIIR (e.g., if a procedure is being done close to the head of that person). However, due to the benefit of rapid dilution ventilation in the AIIR, constant use of a mask by a patient inside an AIIR is not normally required.

Where should HCP wear respirators?

Some settings appropriate for respirator use have been previously mentioned. PPE should be used in tandem with administrative and environmental controls and **never be used instead of**, or as a substitute for, those control measures. For example, if a resident in a nursing home becomes ill and is considered a presumptive TB case, the HCP caring for that person should wear a respirator in the person's room while transport to another facility with an appropriate AIIR is being arranged. In addition, the person with presumptive TB should wear a surgical mask.

Which respirators are best for protection against *M. tuberculosis*?

There are four major types of respirators[7]:

- Filtering facepiece respirators (FFR); includes N95 respirators
- Powered air-purifying respirators (PAPR)
- Elastomeric half mask respirators
- Elastomeric full facepiece respirators

This chapter will focus on N95 respirators and briefly discuss powered air-purifying respirators (PAPRs) for the protection of HCP. The use of respirators in healthcare settings is relatively new, having been first implemented in the early 1990s for protection of HCP against multidrug-resistant TB due to multiple outbreaks.

In the United States, the most common respirator recommended for protection against TB is the N95 respirator. See Figure 3.

FIGURE 3. **Examples of N95 respirators**

Sources: Centers for Disease Control and Prevention (CDC) and jocic/Shutterstock.com

The 'N' designation refers to its approval for use against non-oil aerosols, and the '95' means that the filter material is at least 95% efficient at removing the most penetrating (0.3-micron size) particles. See Table 1.

Note: This **does not mean** that the N95 respirator is 95% protective; this is a common misunderstanding. Wearing a properly fitted N95 respirator is estimated to provide a factor of ten reduction in infectious particles in the air that is inhaled by the wearer. Hence, there is a ≥90% reduction in inhaled particles, or one is inhaling <10% of the aerosol concentration in the environment.

TABLE 1. **National Institute of Occupational Safety and Health (NIOSH) approved FFR filter classes and efficiencies**

(also applies to elastomeric respirator filters).
The N, R, and P designations refer to the filter's oil resistance as described.

FILTER CLASS	DESCRIPTION
N95, N99, N100	Filters at least 95%, 99%, 99.97% of airborne particles. Not resistant to oil.
R95, R99, R100	Filters at least 95%, 99%, 99.97% of airborne particles. Somewhat resistant to oil.
P95, P99, P100	Filters at least 95%, 99%, 99.97% of airborne particles. Strongly resistant to oil.
HE (high efficiency) PAPR100-N, PAPR100-P	Filters at least 99.97% of airborne particles.

Source: Adapted from CDC/NIOSH National Personal Protective Technology Laboratory

Although the N95 is the most common FFR respirator used in the U.S., global colleagues should be aware of similar respirators used and certified by countries other than the U.S.

- These include the FFP2 in Europe, the KN95 in China, the P2 in Australia and New Zealand, the Korea 1st class (or KF94) in South Korea, the DS2 in Japan, and the PFF2 in Brazil.

The filter efficiency in most of these respirators is certified to be ≥ 94%. Although some of these respirators, e.g., KN95, were approved for use during the early phase of the COVID-19 pandemic under an emergency use authorization, this authorization was revoked for imported, non-CDC/NIOSH approved respirators on June 30, 2021.

- HCP can also check the authenticity of their respirator on the CDC/NIOSH website. See *Resources*.

Some of the KN95 models did not offer adequate protection as marketed during the COVID pandemic and are not authorized for use in the U.S. HCP or administrators should consult their local respiratory protection and public health guidelines in selecting appropriate respirators.

N95 respirators are classified as FFRs

All types of FFRs are disposable respirators, and although also described as "single-use respirators," CDC/NIOSH respirator regulations (42 CFR 84.2)[8] allow for reuse by an individual wearer and describes conditions under which use should be stopped: "Single-use respirator means a respirator that is entirely discarded after excessive resistance, sorbent exhaustion, or physical damage renders it unsuitable for further use."

- The actual protection provided by a respirator is a function of the filter characteristics, face seal, and, if present, leakage through an exhaust valve.
- The Occupational Safety and Health Administration (OSHA) has coined the term "assigned protection factor (APF)" to account for total inward leakage (i.e., room air potentially containing infectious particles may leak under the respirator with inhalation rather than be filtered through the respirator). OSHA describes APFs for various types of respirators. Note that an N95 respirator has the same APF as an N100 respirator.[9]

A common practice during the COVID-19 pandemic was to wear a surgical mask over the N95 respirator to prevent contamination of the N95 respirator. In response to the SARS outbreak of 2003, CDC[10] developed interim guidelines that if N95 respirators were being reused, that HCP "consider wearing a loose-fitting barrier that does not interfere with fit or seal (e.g., surgical mask, face shield) over the respirator." In addition, the Institute of Medicine published a report in 2006[11] that N95 respirator users exposed to influenza can "protect the respirator from external surface contamination when there is a high risk of exposure to influenza (i.e., by placing a medical mask or cleanable face shield over the respirator so as to prevent surface contamination but not compromise the device's fit)" as shown in Figure 4. Definitive data supporting this practice are lacking, but there is likely low risk for harm for most HCP. Of note, individuals with medical conditions impacting cardiopulmonary reserve may not, in general, be able to tolerate the additional work of breathing presented by any prolonged respirator use with or without an additional layered mask.

FIGURE 4. **TB healthcare provider wearing a recommended unvalved respirator with surgical mask**

Source: CDC

It is critically important that the surgical mask **not be placed under** the respirator (see Figure 5) as this will result in a poor fit at the face seal allowing leakage around the respirator as the wearer inhales. The other dangerous practice is providing infectious patients with a respirator with an exhaust valve. While this may provide more comfort to the patient, it will result in the exhalation of infectious aerosol (e.g., *M. tuberculosis*, influenza, and SARS-CoV-2) outside of the respirator unless a surgical mask is worn over the N95 respirator.

FIGURE 5.

Do not wear a surgical mask under your respirator

Source: CITC

N95 respirators appear similar to the surgical masks frequently used in healthcare, which may have improved HCP's acceptance of respirators.

- The major limitation of N95 respirators is the complaint from HCP that the respirators are less comfortable than surgical masks because of the tight face seal and increased breathing resistance required to inhale air through the filter material. This provides an important clue. If a particular N95 respirator feels as comfortable as a surgical mask, it is probably **not providing adequate protection.**

Half-mask elastomeric respirators

Some HCP or facilities may wish to use a non-disposable FFR or reusable respirator, such as a **half-mask elastomeric respirator** (see Figure 6).[12] These are made of a lightweight flexible material that is a rubber-like polymer of various types.

FIGURE 6.

Half-mask elastomeric respirator

Source: anmbph/Shutterstock.com

- They typically have two replaceable cartridges with either N95 (95% efficient) or P100 (>99.97% efficient) filters.
- These may feel more comfortable and secure on the face, but they still require fit testing.
- Even with the more efficient filters, they are not rated as more protective than N95 respirators by OSHA.
- Major limitations are that they appear more 'industrial', and they may interfere with the ability to communicate clearly while being worn.
- Although they cost more per unit, half-mask elastomeric respirators can be more cost-effective than disposable N95 respirators depending on the frequency of use of the disposables.

Elastomeric full-facepiece respirators that are generally used in industrial applications (e.g., confined spaces and high dust/vapor/fume workplaces) can offer a little more protection. However, they are not recommended for healthcare settings due to their cost, interference with communication, and appearance that may be frightening to patients.[13]

Powered air-purifying respirators

Powered air-purifying respirator (PAPR; Figure 7) hoods offer the best protection for airborne-transmitted diseases and are the only respiratory protection option for situations where individuals cannot wear N95 or other respirators because of the inability to an achieve adequate seal of the respirator to the face (e.g., facial hair, face anthropometrics). Healthcare facilities may have state or local mandates to make PAPRs available for high hazard procedures (e.g., bronchoscopies and other aerosol-generating procedures) for individuals who cannot wear N95 respirators or elastomeric respirators.

- PAPRs operate by drawing air through a high-efficiency filter (HE, PAPR100-N, or PAPR100-P) and then blow the clean, filtered air into the hood above the face (and therefore can also be cooler than other respirators).
- Other advantages are that they offer face and eye protection, and the face shield allows patients to see the wearer's full face (important if they depend on reading lips or other non-verbal cues).
- One drawback is that the moving air inside the hood can mask noises for the wearer and interfere with communication.
- Two major limitations are the need for equipment maintenance and the dependence on keeping battery packs fully charged.
- Although fit testing is not required, training for safe and effective use of hooded PAPRs, including proper cleaning and disinfection, is needed.

PAPR models that have the motor and filter unit on a belt in the back have the risk of interfering with mobility (e.g., knocking over specimens or materials on trays or countertops). This can be avoided by using a "controlled air-purifying respirator (CAPR)," a version of PAPR with the air blower and motor unit in the headgear (see Figure 8). A drawback for the CAPR is that the disposable headliners and face shields are sometimes difficult to assemble and remove. The APF of a loose-fitting or hooded PAPR is 25 (96% reduction). In healthcare settings, HCP using PAPRs will generally wear a hood.

Note: The protection provided by a PAPR with a hood, after the battery runs out, approaches zero (i.e., no protection).

FIGURE 7.

Powered air-purifying respirators (PAPR)

Source: CDC and 3M

FIGURE 8.

Controlled air-purifying respirator (CAPR), a special type of PAPR

Source: CDC, courtesy of MaxAir

What is fit testing and when should I do it?

The major limitation in the protection offered by respirators is the potential degree of air leak between the respirator and the face. Fit testing is required to assure a tight fit of the assigned respirator. This is analogous to making sure that shoes fit; few people would buy shoes without trying them on to confirm that they fit.

- Fit testing provides a means to determine which respirator model and size fits the wearer best and to confirm that the wearer can don the respirator properly to achieve a good fit.
- Periodic fit testing of respirators can also serve as an effective, hands-on training tool in conjunction with the infection prevention and control content included in employee training and retraining.

FIGURE 9.

Qualitative fit testing

Source: iStock.com/Pornpak Khunatorn

The frequency of periodic fit testing should be determined based on:

- Risk for transmission of *M. tuberculosis* (e.g., HCP in high-TB prevalence or high-risk job settings may benefit from annual fit testing)
- Changes in facial features of the wearer
- Medical conditions that would affect respiratory function
- Changes in the physical characteristics of respirator (despite the same model number)
- Changes in the model or size of the assigned respirator
- Local or national regulations

Fit testing (see Figure 9) uses a test agent, either:

- Qualitatively detected by the wearer's sense of taste, smell, or involuntary cough (irritant smoke).
- Quantitatively measured by an instrument (ratio of aerosol concentration outside the respirator to aerosol concentration inside the respirator) to verify the respirator's fit.

CDC/NIOSH researchers reported similar results with fit testing using the qualitative fit test with Bitrex and the TSI PortaCount® with the N95-Companion.[14]

See *Resources* for additional information on fit testing, how to verify if a respirator model is certified, and manufacturer instructions for users.

Note: A "user seal check" (formerly called "fit check") is not to be confused with a respirator fit test. Absent manufacturer's user seal check instructions, OSHA describes a positive and a negative test. The benefit of a user seal check is controversial. Researchers have shown an absence of good correlation between passing a user seal check and passing a respirator fit test.[15] Focus on selecting well-fitting respirators and conducting periodic respirator fit testing. See Table 2.

How to check if a respirator is a CDC/NIOSH-certified respirator?

See Table 2 and Figure 10.

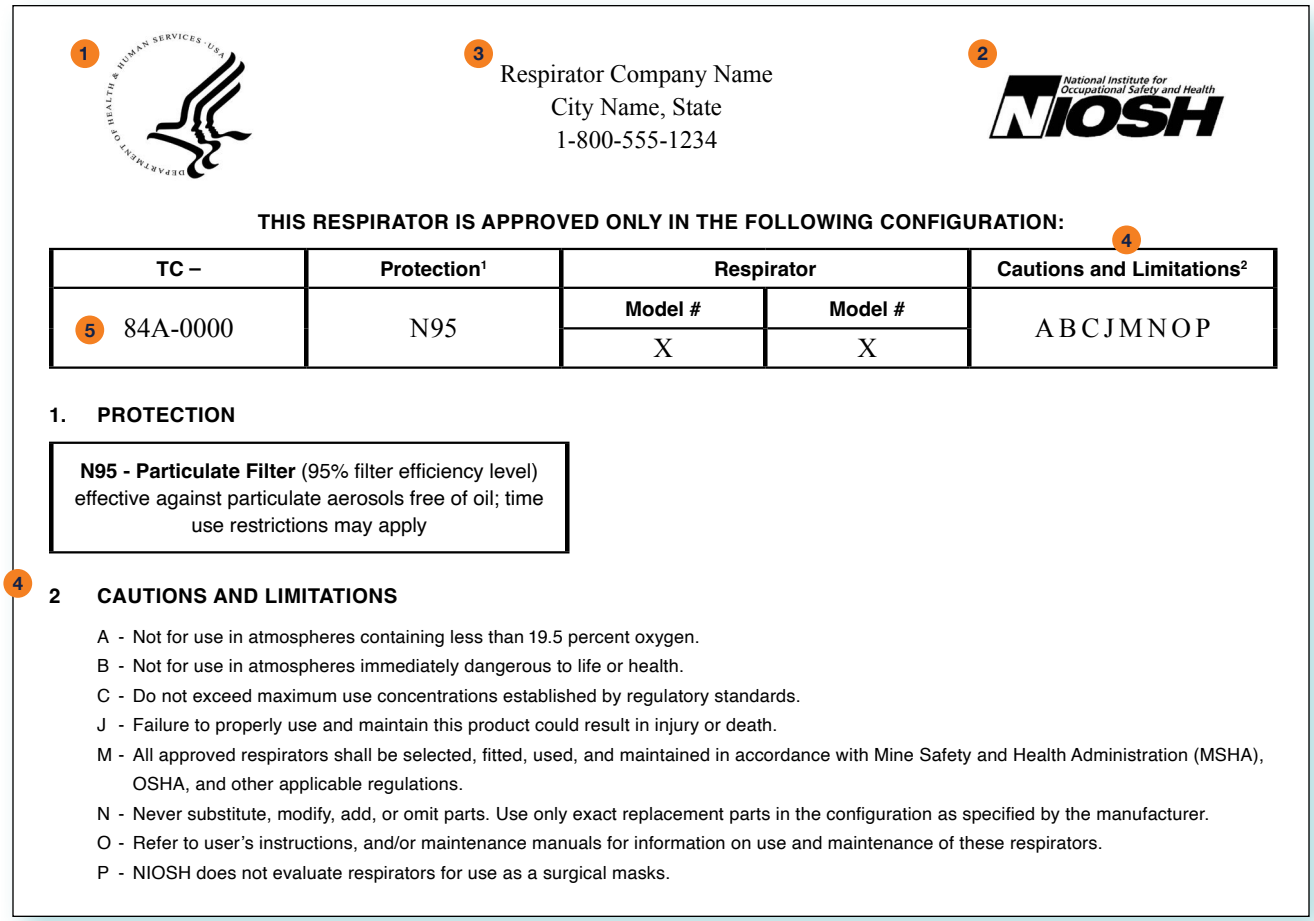
TABLE 2. **Steps to verify if a "respirator" is a CDC/NIOSH-certified respirator**

Step 1:	Does the respirator box and/or insert contain the "approval label" with the information included in Figure 10?
Step 2:	Does the label (stencil) on respirator contain the following information? • Name of the applicant/manufacturer. • Name and letters or numbers by which the respirator or respirator component is designated for trade purposes. • Lot # (filters and N95 respirators) and/or serial # (elastomeric respirator or PAPR). • Approximate date of manufacture.
Step 3:	Is the "respirator" listed on the CDC/NIOSH website? See *Resources*.

If the answer is **no to any** of the three questions above, **the respirator is not CDC/NIOSH approved.**

If the answer is **yes to all** of the questions above, **the respirator is likely CDC/NIOSH approved.** The respirator under consideration must also pass fit testing.

FIGURE 10. **Sample certification label for a N95 filtering facepiece respirator**
(one model with two sizes)



1

Respirator Company Name
City Name, State
1-800-555-1234

2

THIS RESPIRATOR IS APPROVED ONLY IN THE FOLLOWING CONFIGURATION:

TC –	Protection[1]	Respirator		Cautions and Limitations[2]
		Model #	Model #	
5 84A-0000	N95	X	X	A B C J M N O P

4

1. PROTECTION

N95 - Particulate Filter (95% filter efficiency level) effective against particulate aerosols free of oil; time use restrictions may apply

4 **2 CAUTIONS AND LIMITATIONS**

A - Not for use in atmospheres containing less than 19.5 percent oxygen.
B - Not for use in atmospheres immediately dangerous to life or health.
C - Do not exceed maximum use concentrations established by regulatory standards.
J - Failure to properly use and maintain this product could result in injury or death.
M - All approved respirators shall be selected, fitted, used, and maintained in accordance with Mine Safety and Health Administration (MSHA), OSHA, and other applicable regulations.
N - Never substitute, modify, add, or omit parts. Use only exact replacement parts in the configuration as specified by the manufacturer.
O - Refer to user's instructions, and/or maintenance manuals for information on use and maintenance of these respirators.
P - NIOSH does not evaluate respirators for use as a surgical masks.

Six critical elements to check on the label or package insert from a box of respirators:

1. Seal of the U.S. Department of Health and Human Services
2. Emblem of NIOSH
3. Applicant's/manufacturer's name and address
4. Where appropriate, restrictions or limitations placed upon the use of the respirator by CDC/NIOSH
5. Approval number assigned by CDC/NIOSH, designated by the prefix TC
6. Lot # (filters and N95 respirators) and/or serial # (elastomeric respirator or PAPR) may be found on label, respirator, or box (not pictured here)

See *Resources* for CDC's *Counterfeit Respirators/Misrepresentation of NIOSH Approval*.

In summary:

- Respirators should always be used in concert with administrative and environmental controls.
  - The most important TB infection prevention and control measure is the rapid diagnosis and effective treatment of pulmonary TB (a primary aim of administrative controls).
  - Environmental controls can provide for an environment where infectious aerosols are reduced as much as possible.
- In most settings where persons with active or infectious TB are seen, N95 respirators are appropriate PPE for HCP.
- Some individuals cannot use N95 respirators or elastomeric respirators because of the inability to achieve an adequate seal and will require access to a PAPR for appropriate protection.

Resources

Respirator authenticity and manufacturer's user instructions (CDC/NIOSH)

- *NIOSH-Approved Particulate Filtering Facepiece Respirators*
  https://www.cdc.gov/niosh/npptl/topics/respirators/disp_part/default.html
- *Counterfeit Respirators/Misrepresentation of NIOSH Approval*
  https://www.cdc.gov/niosh/npptl/usernotices/counterfeitResp.html

Fit testing

- *Guidelines for Preventing the Transmission of Mycobacterium tuberculosis in Health-Care Settings*, 2005, *MMWR* 2005; 54 (No. RR-17)
  https://www.cdc.gov/mmwr/preview/mmwrhtml/rr5417a1.htm
- *General guidance* (OSHA)
  https://www.osha.gov/respiratory-protection/general
- Video (English and Spanish) describing quantitative and qualitative fit testing (OSHA)
  https://www.osha.gov/video/respiratory-protection/fit-testing
- *Fit test FAQs* (CDC/NIOSH)
  https://www.cdc.gov/niosh/npptl/topics/respirators/disp_part/respsource3fittest.html

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4

Airborne Infection Isolation Rooms

What is an airborne infection isolation room (AIIR)?

AIIRs use dilution ventilation principles to reduce the concentration of airborne infectious particles within the rooms. AIIRs also use mechanical containment methods to keep contaminated air in the rooms from potentially moving into shared corridors or other adjacent indoor spaces.

To achieve airborne infection isolation conditions, a negative pressure differential is created relative to adjacent spaces by exhausting more air from the room than the amount supplied. These are sometimes referred to as **"negative pressure" rooms.**

Basic information and mechanical ventilation principles are described in Chapter 2, *Environmental Controls: Part 1 – Ventilation.* These include:

- Description and definitions for mechanical airflow rate, clean air delivery rate (CADR), air changes per hour (ACH), and room clearance (includes worksheet); see Chapter 2, *Environmental Controls: Part 1 – Ventilation* and Appendix A, *Room clearance time calculation (and ACH) worksheet.*
- Description of airflow and pressure differentials; see Chapter 2, *Environmental Controls: Part 1 – Ventilation*, section, *Using negative or positive pressure to reduce TB transmission.*
- Description, configuration, and components (e.g., air supply and recirculation, placement of supply diffusers and exhaust grilles) for heating, ventilation, and air-conditioning (HVAC) systems; see Chapter 2, *Environmental Controls: Part 1 – Ventilation*, section, *HVAC systems.*
- General summary of how negative pressure is used to contain and prevent spread of infectious particles and basic description of AIIRs (more fully detailed in this chapter); see Chapter 2, *Environmental Controls: Part 1 – Ventilation*, sections, *Mechanical ventilation* and *Negative pressure: Airborne infection isolation rooms.*

Tuberculosis (TB) infection prevention and control (IPC) policies and interventions are commonly organized in a hierarchy: Administrative (or work practice) controls are the most important, followed by environmental controls, and then respiratory protection. All three components should be in place for an effective TB IPC program and are covered in detail in designated chapters within this manual. **Aspects specific to planning for and managing AIIRs are covered in this chapter.**

Administrative controls for AIIRs

Administrative controls for TB IPC are interventions through institutional policies, protocols, education, and oversight to reduce or prevent both exposure to and transmission of TB within a facility. Facilities with AIIRs should have a clear and comprehensive IPC plan that includes the following TB IPC components:

- TB IPC facility risk assessment and IPC plan addressing specific standard operating procedures for use and management of AIIRs. The IPC plan for AIIR use should include criteria and procedures for initiation and discontinuation of isolation, including a discussion of the legal and ethical considerations.[1]
- Monitoring and evaluation plan for conducting AIIR checks (e.g., confirm negative pressure is functioning appropriately).
- IPC training and education programs for healthcare personnel (HCP) that includes proper use and basic IPC principles of AIIRs.
- AIIR signage, e.g., when AIIR is in use, post an *"Airborne infection isolation"* sign on the door to the corridor, and warnings to *"Keep door(s) and windows closed to maintain negative pressure"* on room and anteroom doors. A *"Cover your cough"* sign can be used inside the room for the patient.
- Personal respiratory protection policy for use of N95 or more protective respirators (e.g., powered air-purifying respirator) by all HCP entering an AIIR occupied by a person with presumptive or known TB disease. Once unoccupied, persons entering the room should continue to wear a respirator until the time required for at least 99% of the airborne contaminants to be removed from the room has elapsed. See Chapter 2, *Environmental Controls: Part 1 – Ventilation,* section, *Room clearance*, Table 2, for ACH and clearance times.

For more general information on administrative controls, see Chapter 1, *Administrative Controls.*

Environmental controls for AIIRs

An improperly designed and/or improperly operating AIIR can place HCP, other patients, and other people in the vicinity of an AIIR at risk for TB infection and disease. In this situation, infectious particles may not be contained in the room, and/or their concentration inside the room may not be adequately reduced. Staff members who rely on such an AIIR may have a false sense of security.

This section provides basic information about how to assess and improve the design and operation of an AIIR. It also includes options to convert an existing patient room into an AIIR, advice on monitoring of AIIRs, and information on guidelines and regulations covering AIIR environmental controls.

See *Resources* for additional guidance on mechanical ventilation principles for AIIRs.

Architectural considerations

Architecturally, an AIIR should meet all the detailed requirements for a single-patient room, including a dedicated bathroom that is part of the AIIR suite. An anteroom is not required but may be part of the design concept.

Architectural design elements should also meet IPC building standards (American Society of Heating, Refrigerating and Air-Conditioning Engineers [ASHRAE] 170-2021[2], Facility Guidelines Institute [FGI] 2022a, FGI 2022b, FGI 2022c)[3,4,5] and local code requirements. For example:

- Minimum clearance around the bed
- Minimum room area
- Personal protective equipment storage and disposal areas at the entry to the room

Location of AIIR: The location of the proposed AIIR should also be considered. Avoid, if possible, areas prone to strong drafts, such as those near elevators or doors to the outside.

Doors: AIIR doors should be equipped with self-closing devices.

Dedicated bathroom: Ideally, an AIIR should have a dedicated bathroom that is part of the AIIR suite and only for use by the isolated patient. This is not always the case with AIIRs found in clinics that are not designed for long-term occupancy by patients. The advantage of a dedicated bathroom is that the patient will not have to leave the suite, minimizing the times the suite door is opened and closed. When the bathroom is part of an AIIR suite, exhaust ventilation (volumetric airflow rate) of the dedicated bathroom is considered when calculating the ACH requirements.

Sealing an AIIR: To increase the effectiveness of negative pressure, the architectural elements should ensure that the AIIR suite is well sealed, except for a nominal air gap under the door. Further discussion on sealing AIIRs can be found in the section, *Upgrading or converting an existing room into an AIIR* and Chapter 2, *Environmental Controls: Part 1 – Ventilation,* section, *Negative pressure: AIIRs.*

The mechanical design elements of a new hospital AIIR should, at a minimum, meet all local code requirements, as well as Centers for Disease Control and Prevention (CDC) recommendations, ASHRAE standards, and other applicable codes, standards, and regulations.

Determining the correct airflow rate and negative pressure

CDC 2005[6] recommendations specify that AIIRs should:

- Have a **minimum of 12 air changes per hour (ACH)** (including 2 ACH supplied from outdoor air) for dilution of TB or other airborne infectious microorganisms.
- Have a **minimum pressure differential, relative to surrounding areas, of at least 0.01 inches of water gauge ("w.g.) (2.5 Pa)** such that air flows into the AIIR for containment of airborne TB or other microorganisms.

  Note: AIIRs are **generally set for a minimum of 0.05 "w.g. (12.5 Pa)** to maintain containment during small fluctuations in HVAC system airflow rates.
- Maintain a negative pressure (pressure differential) relative to surrounding spaces. The minimum airflow differential (exhaust vs. supply) should be at least 10% or 100 CFM (>170 m^3/h), whichever is greater, for maintaining a negative pressure relative to surrounding spaces.

Variable air volume (VAV) systems should not be used for AIIRs. VAVs are installed systems whose primary purpose is to vary the airflow rate based on room temperature and may not reliably meet the requirements for contaminant control.

ACH: One air change occurs in a room when a volume of air equal to the volume of the room is supplied and/or exhausted, whichever is greater. The air exchange rate in ACH is the volume of air supplied or exhausted every hour divided by the room volume. By calculating the ACH, the room airflow rate can be compared to published standards, codes, and recommendations. It can also be used to estimate the length of time required to remove infectious particles.

- See Chapter 2, *Environmental Controls: Part 1 – Ventilation*, Appendix A, *Room Clearance Time Calculation Worksheet* for step-by-step instructions for calculating ACH and room clearance time.
- For AIIRs, **the total exhaust airflow rate should be used to calculate the ACH,** rather than the supply airflow. The total exhaust airflow rate is the exhaust airflow rate directly from the AIIR plus the exhaust airflow rate of the dedicated bathroom (assuming no separate supply airflow directly to the dedicated bathroom). The ACH of the dedicated bathroom or anteroom, when present, should also be calculated separately from that of the AIIR itself. See section, *Upgrading or converting an existing room into an AIIR – Case Study: AIIR with dedicated bathroom.*

Maintaining negative pressure: Negative pressure is achieved when exhaust airflow rate exceeds supply airflow rate and the room is well sealed (except for a gap under the door).

- CDC and ASHRAE guidelines recommend a negative pressure differential of at least 0.01 "w.g. However, in practice, a differential pressure this low may be inadequate. Negative pressure may not be consistently maintained if there are other external factors, such as fluctuating air currents caused by elevators, doors, or windows to the outside. Because of these fluctuations, a differential pressure of a **minimum of 0.05 "w.g. (12.5 Pa)** is often used.
- On occasion, higher pressure differentials up to 0.10 "w.g. (25 Pa) are used; however, this differential may be difficult to maintain and requires more powerful ventilation equipment, stronger ductwork, and a tightly sealed room.

Electronic pressure monitor: An AIIR may include the installation of an electronic pressure monitor.

- When properly selected, installed, and maintained, a room pressure monitor can provide continuous qualitative and/or quantitative confirmation of negative pressure across a room boundary and connect to a local alarm or an alarm through the HVAC system.
- Several room pressure monitors are available with added options, e.g., a "warning" light that illuminates when negative pressure is lost; an adjustment for use in positive pressure rooms; and a remote control for a fan or damper to maintain and control negative pressure.
- Pressure differentials across room boundaries can be very low, often in the range of thousandths of an inch. For example, CDC[6] and ASHRAE[2] recommend that negative pressure be at least 0.01"w.g. Some devices that measure differential pressure are not accurate to this level. Before purchasing a room pressure monitor, make sure that the device is capable of accurately and reliably measuring a pressure differential this low.
- Room pressure monitors may be used as a supplement to, but not a replacement for, daily visual checks when the room is in use. See section, *How to do a daily visual check for negative pressure: Smoke/fog, tissue, or simple swing-vane velometer.*

Airflow patterns and air mixing

Design of the HVAC system for an AIIR must also include consideration of the airflow patterns and air mixing within the room.

- **Directional airflow:** Ideally, the clean supply air will be introduced near areas used by the HCP, while exhaust air will be removed near the patient.
- **Placement of supply air diffuser and exhaust grilles:** Positioning of the supply air diffuser should be at a distance far enough from the exhaust grille (optimally, locate the exhaust grille in the vicinity of the patient or head of the bed) to **avoid "short-circuiting"** of clean air (supply air is exhausted before mixing with room air to support dilution of infectious particles).
- **Air mixing:** Both the design and selection of the supply air diffuser and the placement of supply air diffusers and exhaust grilles are important to ensure adequate air-mixing within the room. Caution: Room occupants may find drafts with airflow velocities of >50 feet per minute (FPM) (>0.25 m/s) uncomfortable.

For further discussion, see Chapter 2, *Environmental Controls: Part 1 – Ventilation,* sections, *Using directional airflow to reduce TB transmission; Air supply and exhaust;* and *Components: Diffusers and grilles.*

Exhaust ductwork and discharge

Exhaust air removed from AIIRs is likely to contain infectious aerosols. Consequently, this air should be discharged directly outside the building where the particles can be diluted by outdoor air.

Exhaust ductwork

Dedicated exhaust system:

- While not included as a minimum recommendation by the CDC 2005 guidelines, **the optimum type of exhaust system should serve only AIIR suites, (i.e., a dedicated exhaust system).** Where applicable, this exhaust system may also serve the dedicated AIIR bathroom and anteroom.
- In some jurisdictions this is mandated by the building code for new or renovated rooms. Because most building codes are not retroactive, it is usually acceptable for an existing AIIR to combine the exhaust air with other exhaust systems. ASHRAE Standard 170-2021 allows for mixing of AIIR exhaust air (except bathroom exhaust air) with other exhaust streams only after the AIIR exhaust has passed through a HEPA filter.[2] Note that exhaust air from bathrooms should never be recirculated.

The engineering department staff at the facility should trace the path taken by the exhaust air duct after it leaves the AIIR. If applicable, they should also check the exhaust duct serving the bathroom and anteroom, if present.

- For the record, a set of "as built" drawings should be generated (or an existing design set marked) to show the location and design specifications of the ductwork, filters, and fan.
- Also check the exhaust ductwork and fan for optimum performance. Conditions that should be corrected include excess air leakage at duct joints, damaged ductwork, incorrectly adjusted dampers, and fans in need of servicing.

Over time, dust and lint can collect at exhaust grilles and in exhaust ducts. Also, seals at duct joints break down and leak. These two effects result in diminished exhaust airflow from the AIIR and loss of required negative pressure.

- To compensate, AIIR exhaust ducts and fan systems should be sized for the required airflow rate with fully-loaded filters, plus a 10% safety factor.

Recirculating air systems

- If air from an AIIR is returned to a recirculating HVAC system that does not include filtration, this room should no longer be used for isolation. Staff and patients in rooms served by this system may be exposed to airborne *M. tuberculosis* from patients in isolation.
- **The risk of exposure from a recirculating mechanical system is affected by dilution of the return air with outside air and by the efficiency of the filter in the mechanical system.** The risk is reduced as the percentage of outside air is increased and the efficiency of the filter is increased. Filtration in hospital HVAC systems is usually better than in clinics because hospitals are typically covered by stricter building codes and have larger facility and maintenance budgets.

Exhaust air discharge

- The exhaust fan discharge should be located and designed to minimize the possibility that this air is inhaled by people who are outdoors or inside the building. Exhaust air should be directed away from occupied areas (e.g., walkways) or openings into the building (windows or outside air intakes).
- To promote dilution, the exhaust discharge should be directed vertically upward and at least 10 ft (3 m) above the adjoining roof level. The discharge location should be at least 25 ft (7.6 m) away from public areas, openings into a building, and HVAC air intakes.
- If a suitable discharge location is unavailable, then the exhaust air stream can be cleaned using a HEPA filter. In this case, a HEPA filter must be installed in the discharge duct upstream of the exhaust fan. However, this is not a desirable option because it will be considerably more expensive to install, maintain, and operate than simply exhausting to the outdoors.

Duct and fan labeling

Maintenance personnel and contractors often re-route ducts to accommodate new services, change-out filters, or perform other maintenance that may require turning off exhaust fans.

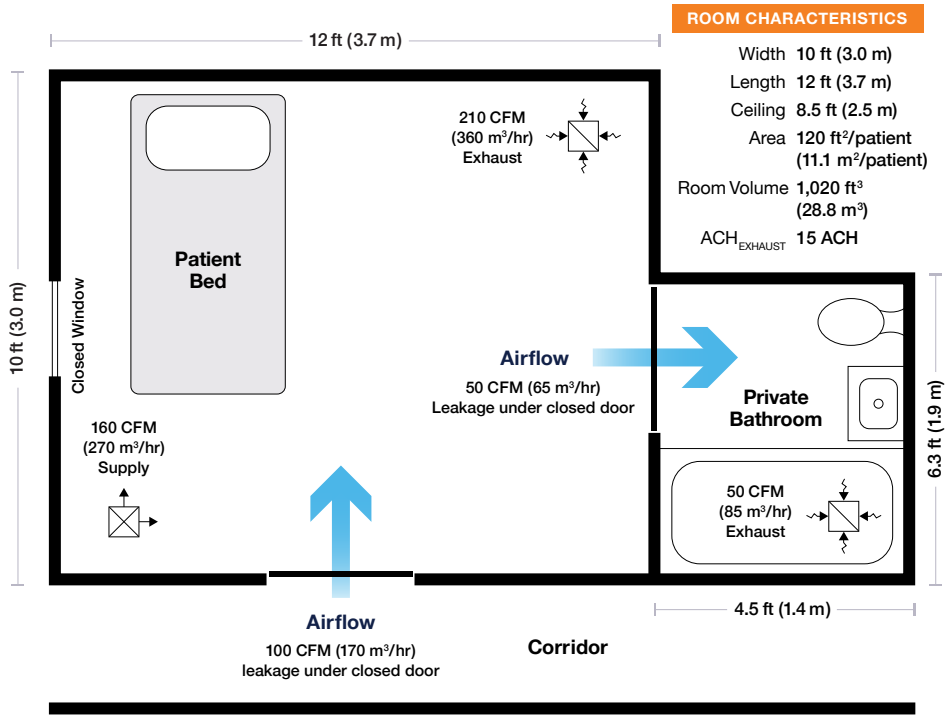
- To help protect these workers, **exhaust ducts, fans, and filter housings should be permanently labeled clearly** with the words, *"Caution — TB contaminated air"* or *"TB-contaminated air — Contact infection prevention and control coordinator before turning off fan or performing maintenance,"* or other similar warnings. The labels should be attached, at most, 20 ft (6.1 m) apart, and at all floor and wall penetrations. Additional signage located on the fan and filter housings should include the telephone number of the IPC coordinator and the room number(s) of the AIIR(s) exhausted by the fan or through the filter.[6]

AIIR anteroom and bathroom considerations

Anterooms are not required with AIIRs. An example of an AIIR without an anteroom is shown in Figure 1 (for a detailed description of the airflows and pressure differentials for this AIIR example, see Chapter 2, *Environmental Controls: Part 1 – Ventilation*, section, *Negative pressure: Airborne infection isolation rooms).* When planning an AIIR, an anteroom (Figure 2) may be provided between the AIIR and the corridor, based on risk assessment. An anteroom will further help prevent infectious particles in the AIIR from escaping into the corridor and provide HCP with a space to change clothes as well as don and doff personal protective equipment (PPE). The ventilation requirements of the AIIR with or without an anteroom remain the same:[6]

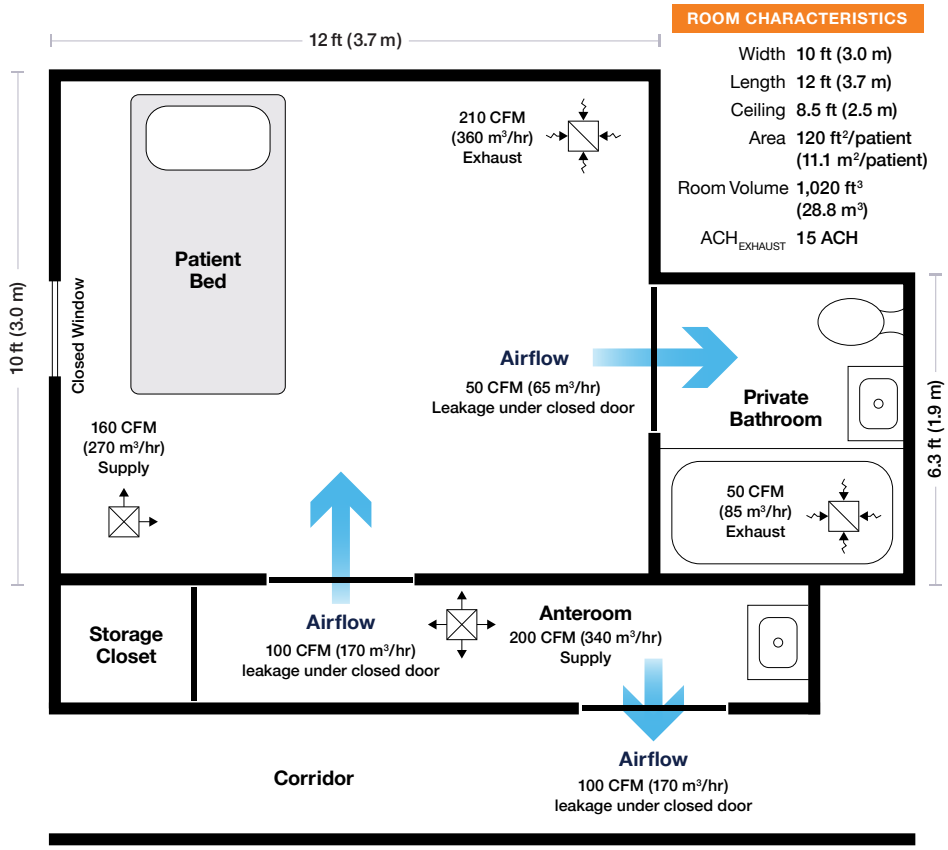
- Minimum of 12 ACH (including 2 ACH supplied from outdoor air)
- Minimum pressure differential, relative to surrounding areas (e.g., corridor, anteroom), of at least 0.01 "w.g. (2.5 Pa) such that air flows into the AIIR
- Minimum airflow differential (exhaust vs. supply) should be at least 10% or 100 cubic feet per minute (CFM) (170 m^3/h), whichever is greater

FIGURE 1. **AIIR without anteroom**



Source: Adapted from CDC *Core Curriculum on Tuberculosis*, Chapter 6, 2021

FIGURE 2. **AIIR with anteroom**



Source: Adapted from CDC *Core Curriculum on Tuberculosis*, Chapter 6, 2021

When an AIIR door is open, pressure differential is immediately lost. If there is an anteroom that is negative to the corridor, then the overall integrity of the suite is maintained. The anteroom provides an "air buffer" between the AIIR and the rest of the facility.

An anteroom should be at positive pressure with respect to the AIIR, and at neutral, positive, or negative pressure with respect to the corridor. See *Case Study: AIIR with dedicated bathroom*, Figure 11, for an example of an AIIR with a positive-pressure anteroom (positive to both the AIIR and to the corridor). Because smoke may migrate from the corridor if there is a fire, some codes and regulations mandate that the anteroom be neutral or positive to the corridor, rather than negative. It is not easy to balance airflow to a space so that it will be positive at one door and neutral at the other. Furthermore, air pressure in the corridor will vary due to external factors such as elevators and corridor doors to the outside.

Consult local codes regarding other design elements of anterooms for AIIRs. For example, requirements under the FGI guidelines include:

- Adequate space for staff to don/doff PPE
- Provision for storage of unused PPE
- Disposal container for used PPE
- Handwashing station

A dedicated bathroom should be negative pressure relative to the AIIR, and the AIIR should be negative pressure relative to the anteroom (or corridor if no anteroom). In other words, not only must the total exhaust for the AIIR plus bathroom exceed the total supply for AIIR plus bathroom, but the AIIR exhaust should also exceed the AIIR supply. This is illustrated in *Case Study: AIIR with dedicated bathroom.*

- The bathroom exhaust ventilation should comply with local requirements. For example, ASHRAE Standard 170-2021[2] mandates an air change rate of 10 ACH, negative pressure, and direct exhaust to the outdoors for bathrooms. In general, an offset of 50 CFM (85 m^3/hr) is sufficient between the bathroom and the AIIR. The negative pressure of the bathroom in relationship to the AIIR room also serves to control odors and moisture.

Monitoring AIIR environmental controls

Failed environmental controls in AIIRs have been identified as factors in documented hospital TB outbreaks. Regularly scheduled assessments of environmental controls will identify and may help prevent failures.[7]

AIIR monitoring includes:

- **Measuring airflow rate and calculating ACH**
- **Evaluating airflow patterns (air mixing)**
- **Verifying negative pressure**

Conduct and document comprehensive evaluations of the AIIR (verifying airflow patterns and quantifying airflow rate, ACH, and negative pressure) and the electronic pressure monitor on an annual basis or as needed if any irregularities arise during use.

Regularly scheduled assessments of environmental controls will identify and may help prevent failures.

Table 1 summarizes three ways to quantify negative pressure and airflow differential with the corresponding units of measurement and the measuring device for each method.

TABLE 1. **How to quantify negative pressure and airflow differential**

PARAMETER	UNITS OF MEASUREMENT	MEASURING DEVICE
Pressure differential	• inches of water gauge ("w.g.) • Pascals (Pa)	Manometer
Speed of air under the door	• feet per minute (FPM) • meters per second (m/s)	Velometer
Airflow differential	• cubic feet per minute (CFM) • cubic meters per hour (m^3/hr)	Air capture hood

Verification of negative pressure also includes simple daily checks and documentation by staff to confirm negative pressure is working, ensuring containment when an AIIR is in use as an isolation room for someone with potential or known infectious TB.

AIIR monitoring details should be clearly outlined within the IPC Plan. The next sections in this chapter will describe some of these monitoring methods in more detail.

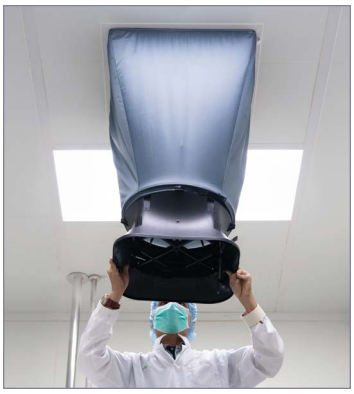
Measuring AIIR airflow rate and calculating ACH

Annual airflow and ACH testing:
Measure airflow rates and calculate ACH at least once a year to ensure that the rates have not deviated more than 10% from the initial values.

- The airflow rate in a room is usually measured at the individual exhaust air grilles and supply air diffusers using an air capture hood. This is a device that consists of a hood (sometimes called a tent), a velocity sensor, and a microprocessor (Figure 3). The hood is placed over, and should completely cover, the air diffuser or grille. The hood directs all air entering or leaving the outlet past a velocity-sensing grid. The microprocessor then calculates and displays the quantity of air being exhausted or supplied. Air capture hoods usually provide an airflow rate reading in CFM or cubic meters of air per second (m^3/s).

FIGURE 3.

Air capture hood



Source: Shutterstock

- The standard size of an air capture hood is 24" × 24" (61 cm x 61 cm), although an assortment of different hood sizes can be adapted to the instrument frame for measuring outlets with other shapes and sizes. If there is insufficient space around some outlets to easily use an air capture hood, air velocity should be measured in the duct that serves the outlet.
- If the room airflow rate is found to be inadequate (i.e., resulting in <12 ACH), the airflow rates should be rebalanced. For information on modifying existing room airflow rates, see section, *Upgrading or converting an existing room into an AIIR.*
- The airflow measurements and calculations should be performed by a certified testing and balancing agency or by in-house engineering staff with appropriate HVAC instrumentation and training.[8]

Evaluating AIIR airflow patterns (air mixing)

Annual evaluating of airflow patterns within the AIIR:
Airflow patterns should be verified using smoke/fog devices so that the movement of air within the AIIR remains as specified in the IPC plan.

- Air, as demonstrated by the movement of smoke/fog, should move from the bottom of the door and into the AIIR.
- Air should also flow from cleaner areas to less-clean areas (e.g., corridor › HCP › patient › exhaust grille and/or bathroom exhaust), with no observed areas of air stagnation.

Verifying AIIR negative pressure

After a new AIIR is constructed or renovated and before it is occupied, the mechanical contractor will adjust the airflow rates as directed by the engineer to ensure that it operates as designed. However, mechanical systems do drift out of balance over time.

Routine monitoring of AIIR room pressurization should include:

- **Annual calibration of electronic pressure monitors** (or per manufacturer specifications; repeat as needed during the year if malfunction concerns arise): Recalibration should be performed by the original equipment manufacturer, a certified testing and balancing agency, or by in-house engineering staff with appropriate HVAC instrumentation and training.
- **Intermittent checks of electronic pressure monitors:** Calibration should be done by trained personnel using a micromanometer to verify the readings and/or alarms functions (e.g., monthly, quarterly, or if a discrepancy between electronic pressure monitor and visual check is noted). Note that both an electronic pressure monitor and a micromanometer may give an incorrect readout if the tubing is not connected properly.
- **Daily negative pressure verification while the room is occupied;** documentation should include both readings from the permanent room pressure monitor and additional visual checks (smoke/fog or tissue testing) to confirm that the negative pressure is functioning.

> CDC 2005 guidelines state: "All rooms should be checked for negative pressure by using smoke tubes or other **visual checks before occupancy,** and these rooms should be **checked daily when occupied by a patient** with presumptive or confirmed TB disease."[6]
>
> This policy statement was originally developed because of the poor performance of physical and electronic pressure monitors.

If the AIIR's HVAC system is operating as intended, there will be an air current moving into the room from under the door. Use smoke/fog tests, tissue tests, or a simple hand-held swing-vane velometer (e.g., Vaneometer™) at the gap under the entrance door to the AIIR as a qualitative daily check to confirm negative pressure is working. Note that most electronic velometers will measure velocity of air but will not indicate direction of airflow.

For more details on how to use these tests for monitoring daily negative pressure status, see section, *How to do a daily visual check for negative pressure: Smoke/fog, tissue, or simple velometer.*

Documentation of AIIR monitoring

Keep records of all AIIR environmental control tests and measurements. Local regulatory agencies may require that these records be kept for a number of years. For example, California Division of Occupational Safety and Health (Cal/OSHA) requires that records be kept for a minimum of five years.

See Chapter 2, *Environmental Controls: Part 1 – Ventilation*, Appendix B, *Airborne Infection Isolation Room Pressure Monitor Checklist* for a template to record results.

How to do a daily visual check for negative pressure: Smoke/fog, tissue, or simple swing-vane velometer

Smoke tube/fog test

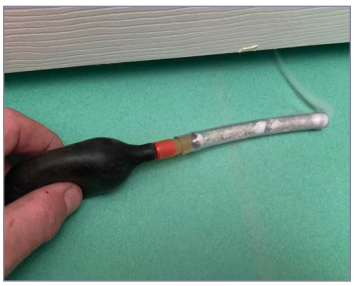
- Smoke tube/fog testing must be performed outside the room with the door closed. Explain the testing to the room occupant so as not to cause worry when smoke is seen entering the AIIR (Figure 4).
- If commercial smoke/fog-generating devices are not available, incense sticks may be used (consider use of two sticks held side-by-side, Figure 5). However, incense smoke has a strong odor, and is not as visible or as controllable as smoke produced from commercial smoke tube kits.

To check the negative pressure in a room, hold the smoke tube or fogging device near the bottom of the door in a horizontal orientation, approximately 2 in (5 cm) in front of the door. Generate a small amount of smoke by gently squeezing the bulb (or fog per device instructions).

- Hold the device parallel to the door and release the smoke/fog slowly to ensure that the velocity of the release of the smoke/fog does not overpower the air velocity. The smoke/fog will travel in the direction of airflow.
- If the room is at negative pressure, the smoke/fog will travel under the door and into the room (from higher to lower pressure, Figure 4). If the room is not at negative pressure, the smoke/fog will be blown outward (Figure 5) or will remain relatively stationary.
- If there is an anteroom, release smoke/fog at the inner door undercut (bottom of the door), with both the anteroom-corridor and anteroom-AIIR doors shut.
- In addition to a pedestrian entry, some AIIRs or areas are accessed through a wider wheeled-bed stretcher door. Check smoke/fog at all door entrances to AIIRs.
- To check the exhaust ventilation in the room, hold the smoke tube or fogging device near the face of the exhaust grille (Figure 6). This will only confirm if you have some exhaust airflow but does not confirm there is adequate exhaust airflow or desired airflow rate.
- If room air cleaners (RACs),with HEPA or other high-efficiency filter, are being used in the room, they should be running during the test.

FIGURE 4.

Smoke tube at door



Source: P. Jensen

FIGURE 5.

Incense sticks at door

Source: CITC

FIGURE 6.

Smoke tube at grille

Source: P. Jensen

As a general rule, an air velocity of 100 ft/min (0.5 m/s) under the door would be desirable to assure adequate negative pressure. Because 100 ft/min is approximately the same as 1.5 ft/s, a puff of smoke/fog moving (somewhat) horizontally through the air at this velocity would move 3 feet over 2 seconds. To visually estimate air velocity, activate the smoke/fog and note the distance the smoke/fog travels while counting "one, one-thousand, two, one-thousand." If the smoke/fog moves at least 3 feet over this time, the air velocity is probably sufficient.

- While this type of visual approximation can offer a rough sense of adequate versus stagnant/minimal air movement, simple devices like a swing-vane velometer (e.g., Vaneometer™) can give a quantitative velocity measurement as well as an indication of direction of airflow. See section, *Velometer (swing-vane model) measurement*.

Because some smoke/fog may be irritating if inhaled, take care to prevent direct inhalation. The quantity of smoke/fog emitted from the devices is minimal and should not be detectable at short distances from the point of release.

Tissue test

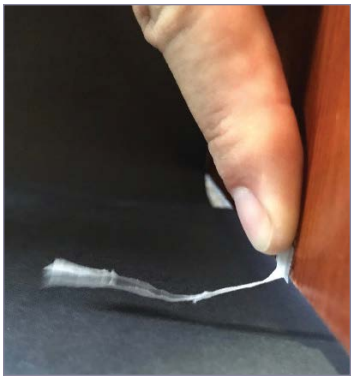
If smoke-generating devices are not available, or if the room is occupied by a patient who may be vulnerable to the potential irritant properties of smoke, a thin strip of tissue can be used to determine whether a room is at negative, neutral, or positive pressure relative to the surrounding area. Hold a thin strip of tissue parallel to the gap between the floor and bottom of the door (Figure 7). The tissue movement will indicate the direction of air movement. The horizontal flutter of the tissue may also give a rough guide of the air velocity (strong versus weak).

A second simple tissue test can visually indicate that the negative pressure is working. This method entails releasing a small piece of tissue at the gap between the floor and bottom of the closed AIIR door from the corridor (or anteroom if present). If air is moving from the corridor/anteroom into the AIIR room as desired, the small piece of tissue should be quickly drawn under the door with the airflow into the AIIR (Figure 8).

FIGURE 7.

Tissue strip test

Thin strip of tissue held at base of door inside AIIR confirms inward air movement.



Source: CITC

FIGURE 8.

Tissue test from corridor/anteroom

Small piece of tissue placed outside AIIR will be whisked under door into AIIR if negative pressure present.

Source: CITC

Velometer (swing-vane model) measurement

Simple velometer devices can demonstrate airflow direction and measure air velocity.

- With the AIIR door closed, place the velometer on the floor at base of door inside of the AIIR (Figure 9). The swing-vane within the device will indicate both the airflow direction and the air velocity as measured on the device.

Note: All methods to verify negative pressure should be repeated at least three times until the results are consistent.

Non-AIIR use of velometer when calculating airflow rate and ACH

Velometers may also be used to measure air velocity to calculate airflow rate and ACH for settings such as non-AIIR clinic exam or waiting rooms (see Chapter 2, *Environmental Controls: Part 1 – Ventilation* and Appendix A, *Room Clearance Time Calculation Worksheet* for more details and considerations for performing these measurements).

- Identify and confirm all sites of **air exhaust** from the room under normal use conditions (i.e., open or closed windows/doors, use of fans or RAC, or HVAC system settings); noting that actual airflow and ACH will be based on these same conditions being used.
- Measure the dimensions (to calculate area) for all sites of air exhaust for the ACH calculations in the worksheet. If multiple sites of exhaust are identified, they should all be included in the calculations. Calculate the area of each exhaust grille (Figure 10A).
- Hold the velometer horizontally, level to the exhaust grille (Figure 10B), check in several places, divide the face of the grille into a grid, and average the readings over multiple points to confirm that the measured air velocity is consistent.
  - If air is exhausting through an open window or door, the device may be held steady against vertical or horizontal window or door frames.
  - Note: These simple swing-vane velometers only measure velocities in the horizontal direction and only measure velocities up to 400 fpm (2 m/s). If sites of air exhaust are in ceilings, alternate measuring methods will be required (e.g., electronic velometers or air capture hood).
- Ideally, these measurements should be done by trained facilities engineers or other HVAC professionals.
- Calculate the airflow rate and the ACH as described in Chapter 2, *Environmental Controls: Part 1 – Ventilation* and Appendix A, *Room Clearance Time Calculation Worksheet.*

FIGURE 9.

Velometer

Vaneometer™ swing-vane velometer demonstrating airflow moving from under door into room (R to L) at a velocity of 0.85 m/s (170 FPM).

Source: CITC

FIGURE 10A.

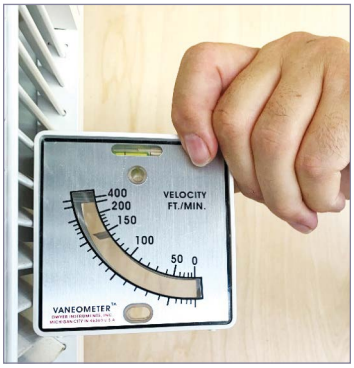
Measuring exhaust grille dimensions

Source: P. Jensen

FIGURE 10B.

Measuring air velocity at exhaust

Airflow moving (R to L) from room into exhaust at a velocity of 140 FPM (0.7 m/s)



Source: P. Jensen

Upgrading or converting an existing room into an AIIR

This section covers methods of improving the ventilation characteristics of an existing room to make it more effective for use as an AIIR. Methods to support the conversion include:

- **Disconnect recirculating air system.** A first step is to ensure that contaminated air from the room is not directly recirculated to other areas. The air removed from the room must either be exhausted directly outdoors to a safe location or filtered (HEPA or other high-efficiency filter). If the room exhaust is currently connected to a recirculating air system that does not include a HEPA or other high-efficiency filter, it should be disconnected from this system.
- **Install HEPA or other high-efficiency filter in existing return air system.** Theoretically, correcting a recirculating system by replacing the existing filter with a HEPA or other high-efficiency filter could be an option within an existing HVAC system. However, it is often not feasible to use HEPA or other high-efficiency filters in HVAC systems not specifically designed to accommodate them. HEPA or other high-efficiency filters are physically larger than most filters and require more powerful fans to overcome the increased resistance to airflow. For more information on types of filters, see Chapter 2, *Environmental Controls: Part 1 – Ventilation,* section, *Filters*.

There are two basic approaches to upgrading or creating an AIIR.

- The **preferred option is to adjust the building HVAC system to create a permanent AIIR.**
- A **temporary solution is to add a recirculating RAC with HEPA or other high-efficiency filter** to supplement, or even replace, the building HVAC system.

Sealing the room: When upgrading an existing AIIR or converting an existing room to operate at negative pressure, it is important to make the best use of the excess exhaust by sealing the room as tightly as possible to reduce unwanted air from leaking into the room. For a given airflow differential, the better the room is sealed, the greater the amount of air that will flow into the room under the door and the greater the negative pressure.

Steps that can improve a room's airtightness include:

- Apply gasketing at the sides and top of the room door.
- Caulk around windowpanes and window frames.
- Apply gasketing at the connection of all ceiling and wall penetrations such as those around medical equipment, lighting, plumbing, and electrical outlets.
- Replace acoustic ceiling tiles with non-porous tiles (e.g., vinyl or drywall) and apply gasketing and clips at the tile connection to the ceiling grid. Ideally, ceilings should be plaster/sheetrock rather than removable ceiling tiles.
- Replace traditional recessed light fixtures with surface-mounted fixtures.

For additional discussion on AIIR leakage and sealing, see Chapter 2, *Environmental Controls: Part 1 – Ventilation,* section, *Negative pressure: AIIRs.*

Adjusting the HVAC system

If the room is not currently connected to an exhaust system, it should either be connected to an existing exhaust system or a new system should be installed. Consult with the building facilities department staff, who may hire a mechanical engineering consultant to design this work and oversee the construction.

Connect to an existing exhaust system or add a new one: If there is an accessible exhaust air duct nearby, it may be possible to make a new exhaust connection to the existing exhaust grille. Otherwise, a new exhaust air fan and ductwork system should be installed.

- New exhaust ducts, and new or existing exhaust fans serving AIIRs, should have the same warning labels used for new AIIRs.

Rebalance existing HVAC system: To increase room exhaust airflow rate and/or create, or increase, negative pressure, the existing HVAC system needs to be adjusted to exhaust more air. The supply airflow rate may also need to be increased. Airflow is varied using dampers or other controls.

Adjust dampers: Dampers are devices that control the flow of air in ducts, similar to the way valves control the flow of fluids in pipes. Dampers are usually located above the ceiling and should only be adjusted by a facility engineer or certified air-balance contractor. To increase exhaust airflow rate, the dampers in the ducts serving the room should be opened wider. It usually takes an air balancer multiple adjustments to obtain the desired airflow rates, airflow differentials, and level of negative pressure.

- The exhaust airflow rate should result in at least 12 ACH.
- The supply should be approximately 100 CFM (170 m^3/hr) less than exhaust. However, the most important aspects of the supply air are that the room is supplied with at least 2 ACH of fresh, outdoor air and that occupant comfort (temperature and humidity) can be maintained. So, more or less supply air may be required. Similarly, depending on how well the room is sealed, more air may need to be exhausted to achieve the required pressure differential (0.01 "w.g. or 2.5 Pa).

Most AIIRs do not have a dedicated HVAC system. They are connected to a ventilation system that serves other rooms in the building. Before and after adjusting the AIIR airflow rates, the air balancer should measure the airflow in some of these other spaces to make sure that the AIIR adjustments do not have an adverse effect on ventilation elsewhere.

Ensure appropriate air mixing and airflow patterns: Adequate levels of air mixing and optimized airflow patterns within the room should be considered as upgrades or renovations are planned. Evaluate how effectively air is being distributed within the room. Smoke testing can be used to visualize the AIIR airflow patterns during initial assessments to identify potential problems, and again after remediation to assess improvements.

Adding a room air cleaner (RAC)

It may not be economically feasible or time-efficient to modify the existing HVAC system. RACs are readily available equipment that can be used in many spaces to **provide "clean" air.** RACs allow improvement of air quality in any room. Limited engineering knowledge is required to install or maintain RACs. These units are especially **useful in settings that may have inadequate or no mechanical ventilation and limited funds for upgrades.** There are two basic ways to use RACs in AIIRs:

- RACs can be used to increase the ACH of a room (by providing additional clean air) without affecting room pressurization.
- Many large RACs may be configured to create or increase negative pressure in a room if adapted to exhaust a portion of the room air outdoors. See *Case Study – AIIR: Part 2*.

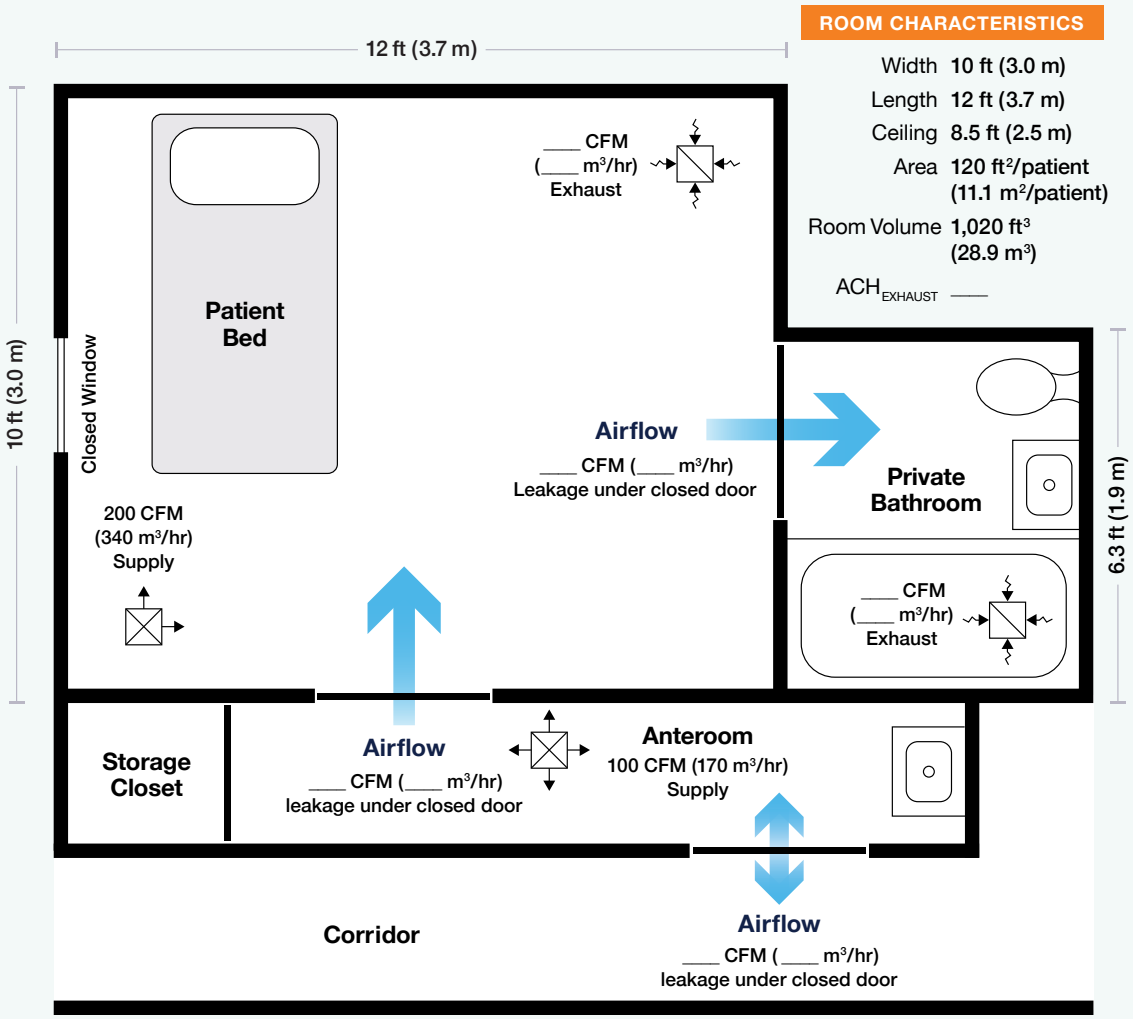
Select a RAC to meet your CADR ventilation strategy. CADR is the airflow rate at which an air cleaning device or equipment, including RACs, delivers clean or disinfected air to a room or space. The CADR is measured in CFM or m^3/h.[9,10]

For more information on RACs, CADR, and selecting a RAC based on room size, see Chapter 2, *Environmental Controls: Part 1 – Ventilation,* section, *RACs*.

CASE STUDY

AIIR with dedicated bathroom

FIGURE 11. **AIIR with anteroom and dedicated bathroom**



Background

The setting is an AIIR with a dedicated bathroom. You are installing a new exhaust fan in the AIIR.

Description

- The supply airflow rate to the AIIR is 200 CFM (340 m^3/hr) from a supply air diffuser in the AIIR ceiling.
- The supply airflow rate to the anteroom is 100 CFM (170 m^3/hr) from a supply air diffuser in the anteroom ceiling.
- The AIIR (without bathroom) volume is 1,020 ft^3 (10 ft x 12 ft x 8.5 ft) or 28.9 m^3 (3.0 m x 3.7 m x 2.6 m).
- The bathroom volume is 240 ft^3 (4.5 ft x 6.3 ft x 8,5 ft) or 6.8 m^3 (1.4 m x 1.9 m x 2.5m); bathroom supply air comes from the AIIR
- Assuming no other air entering the AIIR, the ACH_{SUPPLY} is 12 ([300 CFM x 60 min/hr] / 1,020 ft^3).
- There is currently no air exhausted from the dedicated bathroom because the exhaust fan is not functional.

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CASE STUDY

CONTINUED FROM PREVIOUS PAGE

New exhaust fan

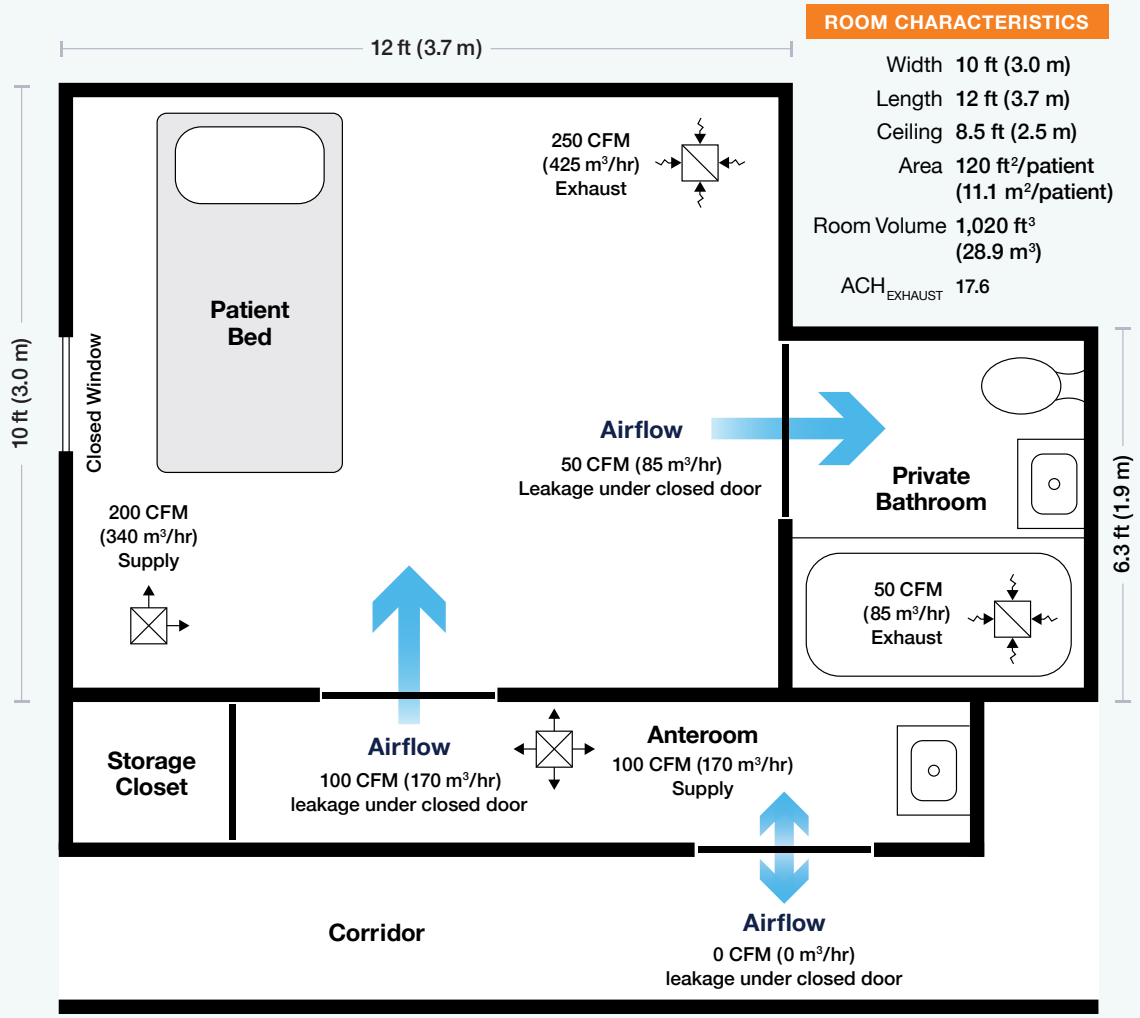
The new exhaust fan with a capacity of 300 CFM (510 m^3/hr) will serve the AIIR suite (AIIR with dedicated bathroom).

- Local codes mandate a minimum of 10 ACH in bathrooms; a minimum of 40 CFM (67 m^3/hr) exhaust is required.
- The anteroom door to the corridor has airtight seals installed on all four sides; no air from the anteroom will escape to the corridor.

ASK: How should the 300 CFM (510 m^3/hr) of exhaust air be split up between the AIIR and bathroom?

The best option:

FIGURE 12. **AIIR with anteroom and dedicated bathroom — best option**



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- **Note: the minimum airflow differential between total supply and exhaust in the AIIR should be at least 10% of the total supply airflow rate** (i.e.,10% of 300 CFM is 30 CFM) or at least 100 CFM (170 m^3/h).
- The total airflow differential in the AIIR is 100 CFM
  - 200 CFM supply air in the AIIR
  - 250 CFM exhaust air directly from the AIIR
  - 50 CFM exhaust from the bathroom
  - (250 CFM + 50 CFM) – 200 CFM = 100 CFM airflow differential
  - The 100 CFM airflow differential is drawn from the anteroom into the AIIR

The reason

This arrangement results in both a total of 100 CFM (170 m^3/hr) off-set across the AIIR door and an equal volume of air moving through the AIIR.

- This option provides more exhaust than supply in the AIIR itself, resulting in negative pressure, and increases airflow toward the head of the bed.
- Some local codes may require that direct exhaust from the AIIR itself (excluding the bathroom exhaust) exceed direct supply air.

The calculations

ACH_{AIIR} equals the sum of the total airflow rate into the AIIR as well as equal to the sum of the total airflow rate out of the AIIR.

ACH_{AIIR} = (100 CFM from anteroom + 200 CFM from HVAC supply) * 60 min/hr / 1,020 ft^3

= 17.6 $ACH_{AIIR\text{-}Supply}$

= (250 CFM from AIIR HVAC exhaust + 50 CFM to bathroom) * 60 min/hr / 1,020 ft^3

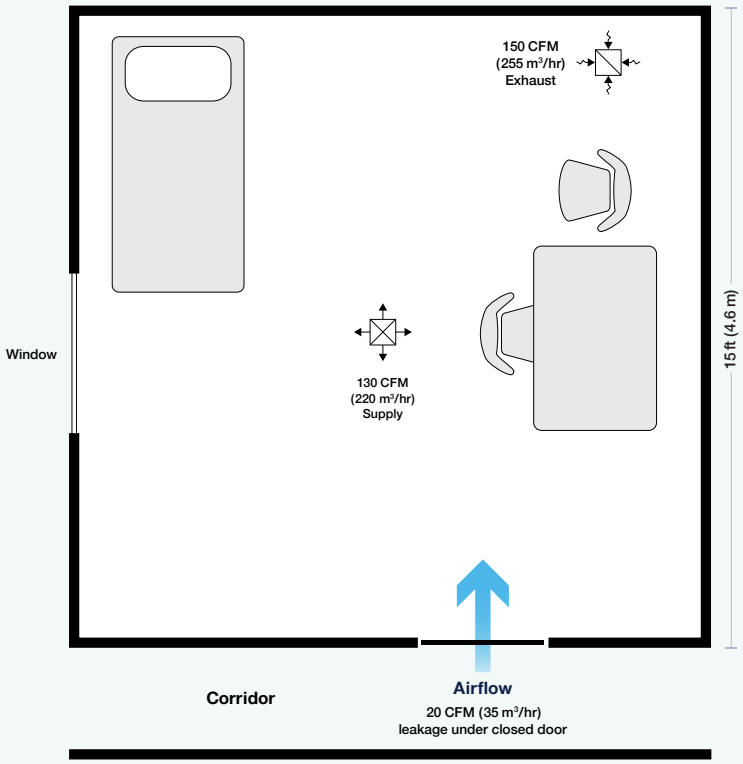
= 17.6 $ACH_{AIIR\text{-}Exhaust}$

Note: This AIIR meets the minimum requirement of 12 ACH for AIIRs[6]

CASE STUDY

AIIR: Part 1

FIGURE 13. **Treatment and exam room for potential and confirmed TB patients – original HVAC design**



Background

An employee at a TB clinic was diagnosed with latent TB infection using a TB blood test (interferon-gamma release assay [IGRA]). He is a clerk in the billing department and has no patient contact and had a baseline negative IGRA upon hire one year ago. He has a history of diabetes but no known TB exposure or travel to TB endemic areas. The TB clinic is in a small, single-story county building. Concerned because of his new TB test conversion, the employee suspected his only possible exposure was at work and informed the clinic manager, Janet.

Assessment

Janet was concerned because the billing department shares a corridor with the room used to isolate TB patients. After confirming that the employee's clinician did not find other possible reasons for his verified IGRA-positive conversion, Janet wondered whether *M. tuberculosis* transmission may have occurred due to failed environmental controls in the AIIR.

Janet tested pressurization of the AIIR with a piece of tissue. The room clearly had positive pressure with respect to the corridor. She felt airflow from the supply diffuser. Even after wiping off the considerable amount of dust on the exhaust grille, air was moving into the corridor from the AIIR. A tissue held against the exhaust grille was not pulled toward the grille as would be expected.

The county facilities department sent out a maintenance engineer, Cynthia, to investigate further. The original HVAC design is shown in Figure 13.

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CASE STUDY

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Cynthia remembered converting this room into an AIIR for TB patients about 2 years ago. She had sealed the room and installed a small, dedicated rooftop exhaust fan. But now she found the fan making squealing noises and the fan motor was very hot to the touch. She replaced the fan and motor. Exhaust was now measured and found to be the design airflow rate of 150 CFM (250 m^3/hr).

Room airflow supply (fresh air) was measured to be 130 CFM (220 m^3/hr), which was 20 CFM (35 m^3/hr) less than the exhaust airflow rate. However, a series of smoke tests showed that the room was now at neutral pressure rather than negative pressure. Room air leakage exceeded the 15% airflow differential. Cynthia then noticed the window was not closed completely. Upon closing the window completely, air from the corridor moved into the AIIR.

Calculate air exchange rate

The room was square-shaped (15 ft [4.6 m] each side) with a ceiling height of 8.5 ft (2.6 m). The exhaust ACH was calculated as follows:

Room volume = 15 ft x 15 ft x 8.5 ft
= **1,910 ft^3**

$$\mathbf{ACH_{AIIR}} = \frac{150 \text{ CFM} \times 60 \text{ min/hr}}{1910 \text{ ft}^3} = \mathbf{4.7}$$

Janet's staff tested the AIIR daily and noticed the speed of the air going under the door slowly decreased and the room went neutral relative to the corridor after two weeks. Therefore, even with the exhaust fan replaced, the AIIR was unsuitable for isolation because it was at neutral pressure relative to the corridor.

Clearly, something had to be done.

ASK: What steps should be taken to achieve negative pressure in the AIIR?

See *Case Study – AIIR: Part 2* for conclusion.

CASE STUDY

AIIR: Part 2

Calculate required additional airflow

Although Janet, the clinic manager, wanted to bring the AIIR into compliance with CDC environmental control recommendations, she thought her budget was too limited to install a new HVAC system.

Cynthia, the engineer, suggested a portable RAC with a HEPA filter as an affordable upgrade option. The RAC would provide additional airflow of clean air. If a portion of the air from the RAC were ducted outside, it would also create additional negative pressure.

The first step was to calculate the additional airflow required:

$$\textbf{Airflow required for 12 ACH} = \frac{1910\ ft^3 \times 12\ ACH}{60\ min/hr} = \textbf{380 CFM}$$

$$\textbf{Additional airflow rate required} = 380\ CFM - 150\ CFM = \textbf{230 CFM}$$

Sizing and installing a portable RAC with a HEPA filter

A RAC with HEPA filter that produced at least 230 CFM (390 m^3/hr) airflow rate was required. Cynthia contacted a mechanical equipment supplier. Two units were available: a smaller unit rated at 150 to 300 CFM (250-500 m^3/hr); and a larger unit rated at 250 to 750 CFM (420-1,270 m^3/hr). Each unit had a multi-speed switch and an optional connection that could be used to exhaust some or all the air outdoors.

Janet suggested buying the smaller RAC to save money. If run at high speed, it would provide more than enough additional airflow. However, Cynthia explained that most people turn down the fan speed switch because the units can be noisy at their high-speed setting. The RACs may also produce less airflow than the manufacturer's catalog claims. Cynthia suggested adding a 50% safety factor, then buying a RAC listed for this airflow at low or medium speed. The larger RAC had three airflow rate settings: 250, 500, and 750 CFM (420, 850, and 1,270 m^3/hr) with a clean HEPA filter.

$$\text{Required airflow rate of RAC} = \text{Additional airflow rate required} + \text{safety factor}$$

$$230\ CFM + 50\% = \textbf{345 CFM}$$

Based on this calculation, the larger RAC was selected and placed in the room. Cynthia replaced a windowpane with a sheet metal panel. She connected a flexible duct from the RAC discharge to a hole in the sheet metal panel, set the RAC to about 500 CFM (850 m^3/hr), and diverted almost half of the discharge air, 150 CFM (250 m^3/hr), to the outdoors. The RAC was located where the clean air from the RAC mixes well with the air in the room. See Figure 14.

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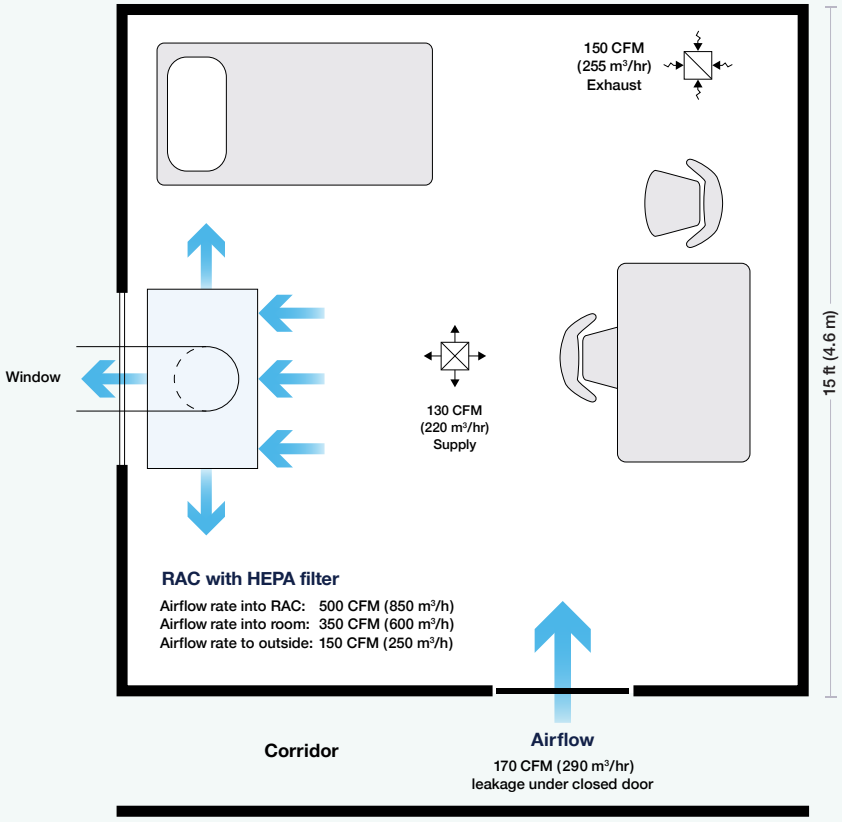
FIGURE 14. **Treatment and exam room for potential and confirmed TB patients: Addition of RAC with HEPA filter**



Assuming a clean HEPA filter, the ACH_{AIIR} is 20 ([150 CFM of room exhaust + 500 CFM CADR of RAC] x 60 min/hr / 1910 ft^3 = 20). Because the pre-existing exhaust ventilation system was weak and the RAC airflow rate will decrease as the HEPA gets loaded with airborne contaminants, higher initial airflow rate/ACH is a good practice to ensure the ACH_{AIIR} remains at or above 12. The additional air (170 CFM [290 m^3/hr]) will come from the corridor and under the door. Luckily, there was a 2 in (50 mm) gap under the door; otherwise, the air might "whistle" as it went under the door.

The happy ending

The room was now clearly at negative pressure relative to the corridor, the overall ACH was improved significantly, and the noise from the RAC was acceptable.

Janet will include RAC maintenance into the clinic budget (including coarse and HEPA filter replacement per manufacturer recommendation) and update the IPC plan to include regular RAC performance verification.

Cynthia's final measurements showed that the RAC was pulling approximately 500 CFM (850 m^3/hr) from the room, with 150 CFM (250 m^3/hr) of this airflow discharged outside and the remaining 350 CFM (600 m^3/hr) recirculating back into the room.

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CASE STUDY

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ASK:

How often should the negative pressure be verified for this AIIR?

When occupied, daily using smoke/fog. When unoccupied, monthly.

How often should airflow rates be verified?

At least annually, but preferably every six months.

How often should the HEPA filter be changed?

Per manufacturer's recommendation, when the airflow rate decreases below an acceptable level (e.g., room at low negative pressure), or if the filter is damaged.

Is upper-room UVC an alternative to the RAC?

Yes and no.

Yes, upper-room UVC will inactivate airborne *M. tuberculosis* at efficiencies equal to or greater than a RAC.

No, upper-room UVC does not provide or enhance negative pressure.

Resources

Centers for Disease Control and Prevention (CDC)

- General guidance, including use of negative pressure for TB IPC
  Guidelines for Preventing the Transmission of Mycobacterium tuberculosis in Health-Care Settings, 2005
  https://www.cdc.gov/mmwr/pdf/rr/rr5417.pdf
- AIIRs
  Guidelines for Environmental Infection Control in Health-Care Facilities, Recommendations of CDC and the Healthcare Infection Control Practices Advisory Committee (HICPAC) – 2019 update
  https://www.cdc.gov/infection-control/media/pdfs/guideline-environmental-H.pdf

Facilities Guidelines Institute (FGI)

- *Guidelines for Design and Construction of Hospitals* (2022)
  https://shop.fgiguidelines.org/products/digital-2022-user-hospital
- *Guidelines for Design and Construction of Outpatient Facilities* (2022)
  https://shop.fgiguidelines.org/products/digital-2022-user-outpatient
- *Guidelines for Design and Construction of Residential Health, Care, and Support Facilities* (2022)
  https://shop.fgiguidelines.org/products/digital-2022-user-residential

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Clinics

Introduction

Persons who are at high risk for TB often receive care at public health and community clinics prior to diagnosis and treatment. Clinics can be high-risk settings for transmission of TB for several reasons. Persons at risk for TB often receive care at public health and community clinics prior to diagnosis and treatment. Clinic funding does not generally allow for facility renovation or installation of enhanced ventilation. In addition, clinic teams do not always include personnel who are experienced in infection prevention and control, occupational health, or mechanical engineering.

This chapter offers a basic view of TB infection prevention and control (IPC) for clinics, including practical considerations and linkages to guidance and tools, using the IPC hierarchy of controls: administrative, environmental, and respiratory protection.

To help reduce the risk of exposure to TB, clinics should have an overall IPC plan in place that addresses TB IPC considerations based on the clinic's TB risk profile.

Source: iStock

Administrative controls for clinics

Administrative control measures are often the most effective IPC activities to implement. They represent the first level of the IPC hierarchy of controls and are intended to reduce the risk of exposure to persons with infectious TB and other communicable diseases. The following discussions will focus on TB IPC but may also apply to other airborne infectious diseases of concern.

A facility's administrative IPC policies and procedures should reflect the site-specific TB risk, **recognizing that for many clinics within the United States (U.S.), the TB risk may be low and not all TB IPC measures will be applicable.**

For more details on administrative controls, see Chapter 1, *Administrative Controls*.

Administrative control **priorities for all healthcare facilities** to implement include:

- Assigning clinic responsibility for IPC (including TB IPC)
- Conducting a TB IPC facility risk assessment
- Developing a TB IPC plan (appropriate to the level of site-specific TB risk and services offered)
- Conducting baseline TB screening and evaluation of employees
- IPC training and education of employees, patients, clients, and visitors (including TB IPC)
- Using appropriate signage and support for respiratory hygiene (Figure 1)
- Applying triage ("fast-tracking") and airborne precaution protocols
- Ensuring proper cleaning of equipment
- Collaborating with clinical and laboratory services
- Collaborating with local or state health departments for consultation and referrals, and to understand and align with regulatory requirements

FIGURE 1.

Source: Adapted from CDC *Cover Your Cough* signage

TB IPC plan for clinics

Employers who fall within the scope of federal or state Occupational Safety and Health Administration (OSHA) TB compliance requirements must establish and comply with an effective written TB IPC plan.

- The information in the TB IPC plan must be specific to the facility and available to any employee who requests it.
- The effectiveness of the TB IPC plan (as part of a general IPC plan) should be evaluated annually and following any occupationally-acquired TB infection.
- Each facility must also ensure that the final IPC plan accurately reflects current TB risks, clinical practice, and the clinic's environmental controls.

Because regulations vary from county to county and from state to state, **each facility should review its local and state regulations before finalizing its TB IPC plan.**

- Refer to state and local regulations and contact the local OSHA office. For contact information, see *Resources*.

Based on the types of medical services offered, the clinic TB IPC plan should include the development and implementation of policies and procedures to ensure prompt identification, isolation, evaluation, and treatment of persons likely to have TB.

Based on the types of medical services offered, the clinic TB IPC plan should include the development and implementation of policies and procedures to ensure prompt identification, isolation, evaluation, and treatment of persons likely to have TB.

- If appropriate diagnostic testing and treatment for TB is not available within the clinic, policies and procedures for referral including contact information for TB clinical services, public health TB notification, and appropriate transfer of care with safe transport should be included in the IPC plan and readily available for clinic staff.
- For links to examples and templates of TB IPC plans, see Chapter 1, *Administrative Controls*.

See *Resources* for websites that contain general infection prevention information and IPC standards.

TB facility risk assessment and classification

Assessing a facility's risk for *Mycobacterium (M.) tuberculosis* transmission is the first step in developing an IPC plan.

- A **comprehensive resource for conducting a TB risk assessment** can be found in the Centers for Disease Control and Prevention (CDC) 2005 *Guidelines for Preventing the Transmission of Mycobacterium tuberculosis in Health-Care Settings*.
  - Including a **TB IPC risk assessment within an annual IPC risk assessment of the facility** is helpful to determine if any lapses in TB control occurred within the preceding year.

- Appendix B in the CDC 2005 guidelines includes a **TB risk assessment worksheet** for healthcare and nontraditional facility-based settings. Updates are noted in the 2019 implementation companion document from the American College of Occupational and Environmental Medicine and the National Tuberculosis Controllers Association, Appendix 1. See *Resources*.

- **TB risk classification** for facilities can be categorized as **low risk, medium risk, or potential ongoing transmission**. The classification considers the general likelihood of TB exposure within the facility due either to exposure to persons with TB disease, potential contact with specimens containing *M. tuberculosis*, or evidence within the past year for person-to-person transmission of TB at the facility (Table 1).

TABLE 1: **Facility TB risk classification**

RISK CLASSIFICATION	DESCRIPTION
Low risk	› Should be used for settings in which persons with TB disease are not expected to be encountered. › Exposure to *M. tuberculosis* in these settings is unlikely.
Medium risk	› Should be used for facilities or settings in which the risk assessment has determined that healthcare personnel (HCP) will possibly be exposed to persons with TB disease. › Medium risk classification can also be used for settings in which healthcare or lab personnel will be working with or collecting clinical specimens and potentially come in contact with specimens that may contain *M. tuberculosis*.
Potential ongoing transmission	› Should be temporarily assigned to any setting where there is evidence of person-to-person transmission of *M. tuberculosis* in the past year.

Source: *Core Curriculum on Tuberculosis: What the Clinician Should Know: Chapter 6, Tuberculosis Infection Control*, CDC, 2021.[1]

- A reassessment of the clinic's risk level should be part of the annual IPC plan review. This includes an analysis of any employee TB exposures with evidence of person-to-person transmission. Factors that may have contributed to TB exposures or transmission will be reviewed and interventions to prevent recurrence will be implemented.
- The TB risk assessment includes knowledge of local community and/or state incidence of TB. See *Resources* for annual CDC updates of state/city-level TB incidence, and list of state, big city, and territory TB program contacts from the National TB Coalition of America (NTCA; note 2023 name change from National TB Controllers Association).

TB screening program

An **employee TB screening program** should be included in a facility IPC plan. CDC defines this process as including an individual TB risk assessment, symptom evaluation, TB testing for latent TB infection (by either an interferon-gamma release assay [IGRA] or a TB skin test) for HCP without documented evidence of prior latent TB infection or TB disease, and additional workup for TB disease for HCP with positive TB test results or symptoms compatible with TB disease.[2]

The 2019 update[2] and 2020 implementation companion document[5] to the 2005 CDC guidance[3] contained notable changes for HCP TB screening, testing, and treatment. The changes were recommended based on findings from a systematic review that found a low percentage of HCP in the U.S. had a positive TB test at baseline and upon serial testing. CDC surveillance data (1995-2007) also documented that TB incidence among U.S. HCP was similar to the general U.S. population.[4]

Table 2 compares the 2005 and 2019 recommendations.

TABLE 2. **Summary of updates to TB screening, testing, and treatment recommendations** (adapted from CDC *Core Curriculum on Tuberculosis: What the Clinician Should Know, Chapter 6, TB Infection Control*, 2021)[1]

	2005 RECOMMENDATIONS*	2019 RECOMMENDATIONS: Key Changes**
Screening	• Recommended for all healthcare personnel pre-placement/upon hire • Annual screening may be recommended based on risk assessment of healthcare facility and setting	• Individual baseline TB risk assessment (new) • Annual TB screening no longer routinely recommended for most healthcare personnel unless occupational risk or ongoing exposure (new)
Post-exposure testing	• Recommended IGRA or TB skin test for all healthcare personnel when an exposure is recognized • If that test is negative, do another test 8-10 weeks after the last exposure	• No change
Treatment of positive TB test	• Referral to determine whether latent TB infection (LTBI) treatment is indicated • Treatment for LTBI should be considered in accordance with CDC guidelines	• Treatment is strongly encouraged for all healthcare personnel with untreated LTBI (new emphasis) • Shorter course (3 to 4 month) treatments encouraged over the longer (6 or 9 month) regimens because they are easier to complete (new)
TB education	• Recommended annually for all healthcare personnel • The level and detail of training will vary based on job responsibilities and facility risk classification	• Annual education should include information about TB risk factors, the signs and symptoms of TB disease, and TB infection control policies and procedures (new emphasis)

* CDC 2005 *Guidelines for Preventing the Transmission of Mycobacterium tuberculosis in Health-Care Settings*[3]
** This column combines information from the 2019 *Tuberculosis Screening, Testing, and Treatment of U.S. Health Care Personnel: Recommendations from the National Tuberculosis Controllers Association and CDC*[2] and the companion 2020 document *Tuberculosis Screening, Testing, and Treatment of US Health Care Personnel: ACOEM and NTCA Joint Task Force on Implementation of the 2019 MMWR Recommendations*[5]

Key considerations for HCP TB screening guidance:

- Baseline pre-placement TB screening is recommended, but routine annual screening is not recommended for most HCP.
  - **If tuberculin skin tests (TST) are used, a two-step testing process at baseline is recommended.** A two-step test is used to detect individuals with TB infection acquired in the remote past who may now have diminished skin test reactivity. Two-step baseline testing avoids misinterpretation of a later repeat test that has a boosted reaction being mistakenly classified as a new infection.
  - **A two-step process is not required for programs using IGRA tests.**
  - Repeat screening or testing of HCP should be limited to situations required in the evaluation of a known TB exposure or sites with evidence of ongoing TB transmission.
  - Serial screening may be considered for groups of HCP with higher occupational risk for TB exposure (e.g., pulmonologists, respiratory therapists, laboratory staff handling respiratory specimens) particularly in higher-TB incidence areas or settings with recent or ongoing transmission concerns, but the decision to do so should be individualized to local TB risks. Consultation with the local or state TB health departments is highly encouraged.[2]
  - If a **positive result is found in a low-risk individual** who is asymptomatic, unlikely to be infected with TB, and at low risk for progression based on their individual risk assessment, a second test (either IGRA or TST) would be recommended. For more information on TB diagnostic testing (including in low-risk individuals), see the 2017 American Thoracic Society, Infectious Diseases Society of America, and CDC diagnostic guidelines.[6] If both TB tests are positive, the result should be considered confirmed. **A new positive result post-TB exposure** would be accepted without repeat testing, and further clinical evaluation would be indicated.

- A stronger **emphasis on latent TB infection (LTBI) treatment for all HCP** is encouraged as part of the national strategy toward TB elimination. Poor to variable acceptance and completion of LTBI treatment has been noted among HCP.[7,8,9] Shorter treatment regimens should support this process.
  - See *Resources* for a CDC website that provides information about shorter LTBI regimens.
  - HCP with untreated LTBI should receive a yearly symptom review and TB education.[5]

Individual TB risk assessment tools are available to support and simplify HCP assessment. See an example in Appendix A, *CDC Healthcare Personnel (HCP): Baseline Individual TB Risk Assessment.*

- See *Resources* for a CDC website that offers more information on the use of TB screening and testing of HCP, with specific guidance on the following topics:
  - HCP TB screening, testing, and education
  - Post-exposure screening and testing
  - TB blood testing (IGRAs)
  - TST and two-step testing
  - Individual TB risk assessment form

TB evaluation, infectiousness, and isolation

The clinical evaluation to determine the clinical suspicion for active TB disease and decisions for starting and stopping isolation based on transmission risks are beyond the scope of this manual. Further study and analysis of TB transmission factors and guidance on isolation are ongoing. For more information on TB evaluation, infectiousness, and isolation, see *Resources*.

Programs are also advised to monitor public health regulations that apply based on the clinic location (state, local, and U.S. territories TB jurisdictions).

Environmental controls for clinics

Environmental controls, the second level of the TB control hierarchy, can reduce TB transmission by decreasing the concentration of *M. tuberculosis* infectious particles in the air by exhausting them from the space or through germicidal inactivation.

For more details about specific environmental controls, see Chapter 2, *Environmental Controls* and Chapter 4, *Airborne Isolation Infection Rooms*.

Facility environmental controls description

To better understand and monitor the facility's IPC protective strategies, perform routine walkthroughs to check that environmental control systems are working as planned. **Describe the facility's ventilation system and use of any ultraviolet C light (UVC, also referred to as ultraviolet germicidal irradiation [UVGI]) or room air cleaners (RACs).** The description should be part of the environmental controls section in the facility IPC plan and can also serve as a useful guide for clinic staff to understand the IPC measures in place.

Examples of environmental control system descriptions include:

- This clinic uses a single-pass air system (air is not recirculated, 100% of supply air comes directly from outdoors, and all air from these areas is exhausted) in the following areas where infectious TB patients receive care:

  Room locations _____.

  Alternate examples of systems may include:

  - This clinic uses a recirculating central heating, cooling, and air-conditioning [HVAC] system with ___% of supply air provided directly from outdoors.

    Note: If there is a combination of HVAC, RACs, and natural ventilation, include a description of each component and how it is used.
  - This clinic uses ___% efficient (MERV ___ filter) in the central ventilation system (see Chapter 2, *Environmental Controls: Part 1 — Ventilation*, Appendix C, *MERV Parameters*).

- The fan setting on thermostats is maintained in the "on" position whenever the clinic is occupied for continuous air movement and filtration.

- Portable RACs with high efficiency particulate air (HEPA) or other high-efficiency filters are located in the following rooms/areas:

  Room locations _____.
- Permanently-mounted RACs with HEPA or other high-efficiency filters are located in the following rooms/areas:

  Room locations _____.
- Airborne infection isolation rooms (AIIRs) are available for isolating persons with presumptive or confirmed infectious TB:

  Room locations _____.
- UVC is used in the following areas as an adjunct to ventilation and RACs:

  Room locations _____.

Adjust and add any additional environmental control features that are in place at the facility.

If the results of a facility risk assessment or investigation after an incident of TB transmission within the clinic suggest **major renovations of environmental control measures** are needed, consult with an engineer or other professional with expertise in IPC for healthcare settings. In some situations, simple, cost-effective interventions may be applied. See Chapter 2, *Environmental Controls* for more details and example case studies.

Considerations for TB risk-based environmental controls for clinics

General considerations for environmental control recommendations can be found in Table 3 for low-risk clinics and Table 4 for medium-risk clinics or those classified as having potential for ongoing TB transmission.

TABLE 3. **Environmental controls for low-risk clinics**

AREA	RECOMMENDATION	COMMENTS
General ventilation system	• Ventilation systems should ideally have MERV 8 filters (for supply air) or MERV 13 filters (for recirculated air), but if not feasible, use the most efficient filter compatible with the system that allows for the minimum airflow rate.[10,11,12,13] • Generally, a minimum airflow rate of outdoor air per occupant is 15 cubic feet per minute (CFM) or 2 air changes per hour (ACH) of outdoor air, whichever is greater.[14]	• MERV 13 filters remove >50% of infectious particles in the size range of *M. tuberculosis* infectious particles.[15]
General waiting rooms	• 12 ACH (including 2 ACH supplied from outdoor air) is recommended for this area.[3,13] • Use RACs with HEPA or other high-efficiency filters to increase effective ACH if needed.[3] • Ultraviolet-C (UVC) may also be used in this area to supplement ventilation systems.[3] • Air should flow from clean areas toward less clean areas.[3]	• In many waiting rooms, persons with potential TB disease have not yet been screened or diagnosed. Increasing the ACH will dilute potential infectious particles. • Airflow from staff areas (clean areas) toward areas that may be occupied by persons with TB (less clean areas) will help to protect clinic staff.
General exam rooms or interview rooms	• At least 6 ACH (including 2 ACH supplied from outdoor air) are recommended.[13] • Ventilation systems should ideally have MERV 8 filters (for supply air) or MERV 13 filters (for recirculated air), but if not feasible, use the most efficient filter compatible with the system that allows for the minimum airflow rate.[13] • Room should be at neutral or negative pressure relative to adjacent spaces.[13]	
Airborne infection isolation/exam room	• Probably not needed for low-risk facilities. The occasional person with presumptive or confirmed infectious TB can be masked and separated in a closed room with a RAC with HEPA or other high-efficiency filter or directed to a specified outdoor area.	
Sputum induction	• Fully enclosed, ventilated sputum-induction booth is preferred.[3] • If a sputum-induction booth is unavailable, any room used for sputum induction should meet all recommendations for an AIIR, including negative pressure, at least 12 ACH, and air exhausted directly outside or HEPA-filtered.[3] • Negative pressure of the sputum-induction booth and room should be checked daily when in use.[3]	• CDC guidelines recommend a medium-risk category for facilities performing sputum induction on presumptive or confirmed persons with TB.[3]

TABLE 4. **Environmental controls for medium-risk clinics and clinics with potential ongoing transmission**

AREA	RECOMMENDATION	COMMENTS
General ventilation system	• Ventilation systems should ideally have MERV 8 filters (for supply air) or MERV 13 filters (for recirculated air), but if not feasible, use the most efficient filter compatible with the system that allows for the minimum airflow rate.[10,11,12,13] • Generally, a minimum airflow rate of outdoor air per occupant is 15 CFM or 2 air changes per hour (ACH) of outdoor air, whichever is greater.[14]	• MERV 13 filters remove about >50% of infectious particles in the size range of *M. tuberculosis* infectious particles.[15]
General waiting rooms	• 12 ACH (including 2 ACH supplied from outdoor air) is recommended for this area.[3,13] • Use RACs with HEPA or other high-efficiency filters to increase effective ACH if needed.[3] • Ultraviolet-C (UVC) may also be used in this area to supplement ventilation systems.[3] • Air should flow from clean areas toward less clean areas.[3]	• In many waiting rooms, persons with potential TB disease have not yet been screened or diagnosed. Increasing the ACH will dilute potential infectious particles. • Airflow from staff areas (clean areas) toward areas that may be occupied by persons with TB (less clean areas) will help to protect clinic staff.
Medium-risk waiting areas such as those in radiology or pulmonary Clinics	• 12 ACH (including 2 ACH supplied from outdoor air) is recommended for this area.[13] • Use RACs with HEPA or other high-efficiency filters to increase effective ACH if needed.[3] • UVC may also be used in this area to supplement ventilation systems.[3] • Air should flow from clean areas toward less clean areas.[3] • Room should be at negative pressure relative to adjacent spaces.[13] • Air from this room should be exhausted or HEPA-filtered before recirculation.[3]	
General exam rooms or interview rooms	• At least 6 ACH (including 2 ACH supplied from outdoor air) are recommended.[13] • Ventilation systems should ideally have MERV 8 filters (for supply air) or MERV 13 filters (for recirculated air), but if not feasible, use the most efficient filter compatible with the system that allows for the minimum airflow rate.[13] • Room should be at neutral or negative pressure relative to adjacent spaces.[13]	

TABLE CONTINUES ›

TABLE CONTINUES

AREA	RECOMMENDATION	COMMENTS
Airborne infection isolation/ exam room (AIIR)	• Recommended for medium-risk clinics. • At least 12 ACH with 2 ACH of outdoor air recommended.[13] • Air should be properly discharged outdoors or HEPA-filtered before recirculation.[3] • Room should be under negative pressure.[3] • Monitor negative pressure at least monthly, and daily when room is in use.[3]	• 12 ACH is the minimum ventilation rate recommended by CDC for new or renovated AIIRs. CDC allows 6 ACH for existing pre-1994 AIIRs but recommends that this be increased to 12 ACH "where feasible." Note: 6 ACH may not satisfy local requirements.
Sputum induction	• Fully enclosed, ventilated sputum-induction booth is preferred.[3] • If a sputum-induction booth is unavailable, any room used for sputum induction should meet all recommendations for an AIIR, including negative pressure, at least 12 ACH, and air exhausted directly outdoors or HEPA-filtered.[3] • Check negative pressure of the sputum-induction booth and room daily when in use.[3]	• CDC guidelines recommend a medium-risk category for facilities performing sputum induction on persons with presumptive or confirmed TB.[3]

Environmental controls for high-risk procedures

Some clinics may provide services that include sputum induction or other cough-inducing procedures that are considered high-risk for aerosolization of *M. tuberculosis*. Use special precautions to prevent occupational exposure when these procedures are performed on a person with potential or confirmed infectious TB.

The clinic IPC plan should specify which special precautions are used to prevent and minimize occupational exposure when high-risk procedures are performed on persons with presumed or confirmed infectious TB. Table 5 lists the types of precautions that could be applied. A version of this table with descriptive language adjusted to reflect the circumstances and technical configuration of the specific clinic system can be included within the IPC plan.

TABLE 5. **IPC precautions for high-risk procedures for persons with presumptive or confirmed infectious TB**

HIGH-RISK PROCEDURES	IPC PRECAUTIONS
Sputum induction or sputum collection **Aerosol breathing treatments**	**Procedure(s) performed within:** › Sputum-induction booth or tent with local exhaust ventilation; or › AIIR with 12 air changes per hour (ACH)* exhausted directly outdoors away from operable windows, doors, and air intake grilles; otherwise, the exhausted air should be filtered; or › Outdoors (sputum collection only) if booth/tent or AIIR not available.
Bronchoscopy, endoscopy **Airway suctioning or intubation**	› AIIR with 12 ACH* exhausted directly outdoors away from operable windows, doors, and air intake vents; otherwise, the exhausted air should be filtered using HEPA or higher efficiency filtration.
HCP assisting with high-risk procedures will wear N-95 or equivalent respirators.	

* 6 ACH for existing pre-1994 facilities

Respiratory protection for clinics

The third level of the TB control hierarchy is the use of personal protective equipment (PPE). Since the onset of the SARS-CoV2 pandemic in 2020, there has been a greater understanding of the role of PPE, including both N95 respirators and surgical (procedure) masks, as an adjunct IPC measure to administrative and environmental controls. Most healthcare clinics have respiratory PPE policies in place for use in circumstances in which airborne infectious disease transmission is of concern.

For more details on the use of PPE as a means of TB respiratory protection, see Chapter 3, *Personal Protective Equipment*.

Surgical masks: Surgical masks are designed to reduce the spread of infectious particles exhaled by the persons wearing them. A person with presumptive or confirmed infectious TB should be given a surgical mask to wear (when outside of an AIIR) and educated on proper use.

Respirators: Clinic employees are required to wear NIOSH-certified N-95 or equivalent respirators that have been designed to filter out infectious particles as the wearer inhales. Use respirators when:

- In the presence of a person with presumptive or confirmed infectious TB disease (or other potential airborne infectious disease).

- Entering a room, including an AIIR, which has been occupied by an unmasked person with presumptive or confirmed infectious TB, prior to the time required for 99% of the airborne contaminants to be removed from the room. See Chapter 2, *Environmental Controls: Part 1 – Ventilation*, Appendix A, *Room Clearance Time Calculation Worksheet*.
- Transporting or accompanying a person with presumptive or confirmed infectious TB to other areas for tests or traveling together within an enclosed vehicle, even if that person is wearing a surgical mask.
- Performing high-risk procedures (e.g., sputum induction).

Respiratory protection program: If respirator use is required at the facility per the IPC plan, the facility must have a respiratory protection program with written standard operating procedures. Include information such as the types and sizes of respirators available, fit-testing policy, employee training plan, and program evaluation plan.

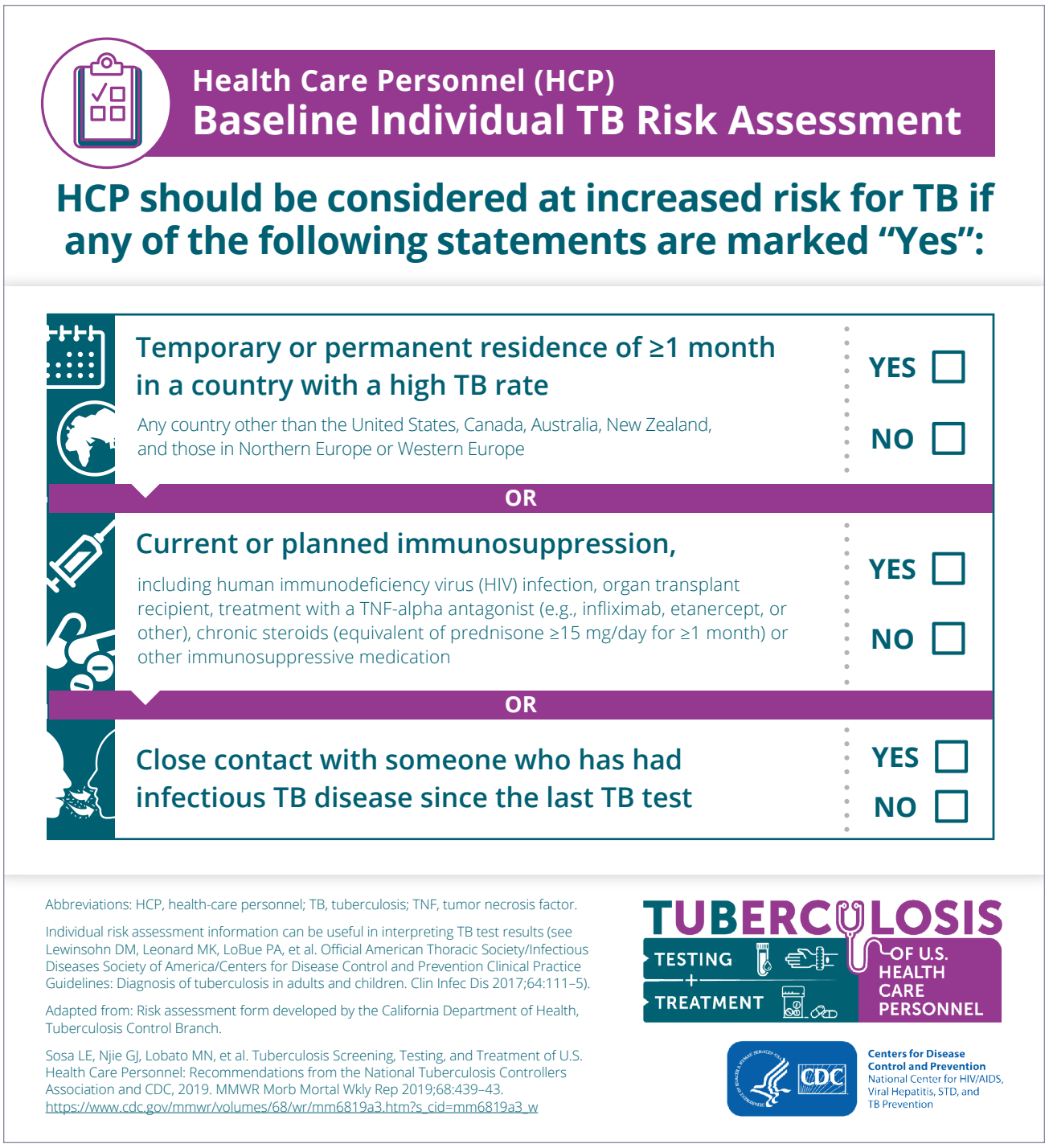
- HCP should be fit-tested to determine which respirator model and size fits the wearer best. Retesting is warranted if the HCP has significant changes in facial features (e.g., large shifts in weight or changes in facial hair) that may affect the respirator seal.

See *Resources* for websites that contain additional information and assistance for writing a respiratory protection program plan.


Source: iStock

APPENDIX A:

CDC Healthcare Personnel (HCP): Baseline Individual TB Risk Assessment



https://www.cdc.gov/tb/topic/infectioncontrol/pdf/healthCareSettings-assessment.pdf

Resources

Administrative controls

General resources

- *Cover Your Cough* signage in multiple languages – Centers for Disease Control and Prevention (CDC)
  https://www.cdc.gov/flu/prevent/actions-prevent-flu.htm
- State and local regulations – Occupational Safety and Health Administration (OSHA) offices by state
  https://www.osha.gov/html/RAmap.html
- List of state, big city, and territory TB program contacts – National TB Coalition of America (NTCA)
  https://www.tbcontrollers.org/community/statecityterritory/
- TB data and statistics – CDC
  https://www.cdc.gov/tb/statistics/default.htm
- Guidelines and resources for infection preventionists – Association for Professionals in Infection Control and Epidemiology (APIC), Sierra Chapter
  https://community.apic.org/sierra/resources/overview
- Infection prevention and control resources – The Joint Commission
  https://www.jointcommission.org/resources/patient-safety-topics/infection-prevention-and-control/

TB facility risk assessment and classification

- Comprehensive resource for conducting a TB risk assessment – CDC *Guidelines for Preventing the Transmission of Mycobacterium tuberculosis in Health-Care Settings, 2005*
  https://www.cdc.gov/mmwr/preview/mmwrhtml/rr5417a1.htm
  - TB risk assessment worksheet for healthcare and non-traditional facility-based settings (Appendix B)
    https://www.cdc.gov/tb-healthcare-settings/hcp/facility-risk-assessment/index.html
    - Updates to CDC 2005 Appendix B based on CDC/NTCA 2019 TB screening, testing, and treatment recommendations provided in 2020 companion document, Appendix 1, from the American College of Occupational and Environmental Medicine and the National Tuberculosis Controllers Association
      https://links.lww.com/JOM/A780

TB screening, evaluation, infectiousness, and isolation

- General: TB in healthcare settings resource page – CDC https://www.cdc.gov/tb-healthcare-settings/index.html
- Concise coverage of principles of infectiousness, detection and diagnosis of TB disease, and discontinuation of airborne isolation within overview of TB IPC – CDC, *Core Curriculum on Tuberculosis: What the Clinician Should Know, 7th edition,* 2021, *Chapter 6: Tuberculosis Infection Control* https://www.cdc.gov/tb/hcp/education/core-curriculum-on-tuberculosis-continuing-education.html
- TB screening and testing of healthcare personnel – CDC https://www.cdc.gov/tb-healthcare-settings/hcp/screening-testing/
- *Tuberculosis Screening, Testing, and Treatment of U.S. Health Care Personnel: Recommendations from the National Tuberculosis Controllers Association and CDC, 2019* https://www.cdc.gov/mmwr/volumes/68/wr/pdfs/mm6819a3-H.pdf
  - Companion implementation document: *Tuberculosis Screening, Testing, and Treatment of US Health Care Personnel: ACOEM and NTCA Joint Task Force on Implementation of the 2019 MMWR Recommendations* – American College of Occupational and Environmental Medicine, July 2020 https://acoem.org/acoem/media/PDF-Library/Publications/Tuberculosis_Screening,_Testing,_and_Treatment.pdf
- *Updated Guidelines for Using Interferon Gamma Release Assays to Detect Mycobacterium tuberculosis Infection – United States, 2010* – CDC https://www.cdc.gov/mmwr/preview/mmwrhtml/rr5905a1.htm
- *Consensus Statement on the Use of Cepheid Xpert MTB/RIF® Assay in Making Decisions to Discontinue Airborne Infection Isolation in Healthcare Settings;* 2016 – NTCA and Association of Public Health Laboratories http://www.tbcontrollers.org/docs/resources/NTCA_APHL_GeneXpert_Consensus_Statement_Final.pdf
- Shorter LTBI regimens – CDC *Treatment Regimens for Latent TB Infection* https://www.cdc.gov/tb/topic/treatment/ltbi.htm
- Basic review of estimating the infectiousness of a person with TB and use of TST within the context of guidelines for TB IPC – CDC *Guidelines for Preventing the Transmission of Mycobacterium tuberculosis in Health-Care Settings, 2005*. (Refer to other resources listed for updated information on the use of IGRAs, general diagnostic and treatment principles, and release from isolation.) https://www.cdc.gov/mmwr/preview/mmwrhtml/rr5417a1.htm
- Updates on isolation policy guidance – NTCA https://academic.oup.com/cid/advance-article/doi/10.1093/cid/ciae199/7649400
- TB training, education, and medical consultation – CDC-supported TB Centers of Excellence https://www.cdc.gov/tb-programs/php/about/tb-coe.html

Respiratory protection

Information and assistance for writing a respiratory protection program plan

- *Respiratory Protection in the Workplace: A Guide for Employers*; revised 2021 – California Department of Industrial Relations, Cal/OSHA http://www.dir.ca.gov/dosh/dosh_publications/respiratory.pdf
- *Respiratory Protection eTool* – OSHA http://www.osha.gov/SLTC/etools/respiratory/oshafiles/writtenprogram1.html

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Homeless Shelters

Background and needs overview

Homeless shelters vary considerably in the types of services they provide, the people they serve, and the types of buildings in which they are housed.

- Housing providers classify housing in various ways, including emergency shelters, transitional shelters, rapid re-housing, and permanent supportive housing.
- Some shelters provide food and shelter, but no other services. Other facilities provide a range of services on-site, including case management and chemical dependency recovery services.
- Some shelters serve a different group of clients every night on a first-come, first-served basis. Other shelters allow clients to stay for up to 6 months.
- Structures used as shelters may vary from a converted warehouse or tents sleeping 600 people to a self-contained trailer for 4 clients. Use of shared living spaces (e.g., kitchen, bathroom, indoor recreation room) may vary.
- Many shelters serve only adult male clients. A smaller number serve women, families, or teenagers.
- Documentation and record keeping across shelters varies from non-existent to paper-based systems to electronic information management systems.

Because of these factors, the likelihood that TB will spread varies from shelter to shelter.

Since the onset of the COVID-19 pandemic in 2020, a renewed focus on improving infection prevention and control (IPC) interventions within shelters and other congregate settings has resulted in greater awareness and updated national guidance.[1]

Challenges in implementing strong IPC intervention with shelters, particularly for TB, have been long-standing. During 1996-1998, a mechanical engineer conducted on-site consultations at 19 California homeless shelters. These consultations included an evaluation of how ventilation, filters, and UV (when present) helped

reduce the risk of TB transmission. Consultations also included conversations with shelter managers and other staff to determine their knowledge and skills regarding TB control measures.[2]

The most common problems found with environmental control systems at homeless shelters included:

- Rooms without ventilation
- Broken ventilation equipment
- Heating, ventilation and air-conditioning (HVAC) systems operating below design capacity because the equipment needed cleaning or other routine upkeep
- Inadequate or improperly-sized air filters in central HVAC systems
- Inappropriate design and installation of germicidal ultraviolet C (UVC) light, also referred to as Ultraviolet Germicidal Irradiation (UVGI) lamps

The following barriers to more effective use of ventilation, filters, and UVC were identified:

- Limited knowledge among shelter staff and administrators about TB and how TB is spread
- Limited knowledge of the role of ventilation, filters, and UVC in reducing TB transmission risk
- High staff turnover rate and overworked staff
- Limited maintenance staff and budgets
- Older buildings and mechanical HVAC systems in need of repairs
- Limited funds to improve TB control through the use of ventilation, filters, and UVC

Following each consultation, the facility received a report recommending ways to reduce the likelihood of TB transmission in the shelter. Recommendations ranged from immediate no-cost steps, such as opening windows and doors, to suggested modifications of the shelter's ventilation equipment.

This chapter describes the challenges faced by shelter management and ways to reduce the risk of TB transmission in these settings.


Source: iStock/Shironosov

Why TB is a problem in homeless shelters

TB is likely to spread in shelters. If a shelter client has infectious TB, it can place shelter staff and clients at risk. Shelters are especially vulnerable because:

- People experiencing homelessness are more likely to have TB than others in the general population.
- The congregate shelter environment often increases the chances that if a person with TB is present, TB will be spread.

In 2022, approximately 4.8% of reported TB cases in the United States were people who were experiencing homelessness at some time during the year before their TB was diagnosed.[3] Over the past two decades, TB incidence was more than 10 times higher among people experiencing homelessness than those not experiencing homelessness.[4] People experiencing homelessness are more likely than the general population to have TB because they have more risk factors for TB.[5] The risk factors include:

- Contact with other people who are experiencing homelessness who have TB
- Poor access to on-site or referral to healthcare services
- Barriers to adherence to follow-up visits and prescribed treatment for latent TB infection (LTBI)
- Lack of permanent housing arrangement (e.g., movement between shelters or other temporary situations)
- Substance use, especially injection drugs and alcohol
- Limited access to HIV education and prevention measures, increasing the risk of poorly-controlled HIV infection among people experiencing homelessness

TB disease develops more quickly among people who are co-infected with TB and HIV. Because persons experiencing homelessness are at higher risk for HIV infection than the general population, TB can also develop among persons experiencing

homelessness more quickly and spread to others before it is detected. For persons experiencing homelessness, food, shelter, and personal safety may be higher priorities than TB and HIV prevention.

Characteristics of shelter environments often increase the chances that TB will spread. For example, building ventilation is often inadequate, and clients are crowded into close quarters, typically for 8 to 12 hours per night.

The most important factor that contributes to TB transmission is that many shelters do not screen clients for TB symptoms. Without this screening, a client with symptoms of TB will not be:

- Referred for medical care and treatment
- Separated from other clients or asked to use a face mask to lessen the chance that TB, if present, will spread

Reducing the risk of TB transmission in homeless shelters

Although the likelihood of TB transmission in shelters is high, shelter operators and others can take steps to significantly reduce this risk. **All shelters should have an IPC plan** to limit the spread of TB. There are three main areas to consider:

- Administrative and work practice control measures
- Environmental controls (ventilation, filters, and UVC)
- Appropriate use of respiratory protection by staff and clients

In general, administrative and work practice control measures have the greatest impact on preventing TB transmission, followed by the use of ventilation, filtration, and UVC. Use of respirators by shelter staff may be important in certain situations, such as when transporting clients suspected of having TB of the lungs or larynx or entering a room in which such clients have been placed temporarily to separate them from other clients and staff. The local TB control program can help a shelter facility to assess its risk and develop a plan.

Administrative controls

Homeless shelter management and staff should employ the following control measures:

- Assign a health “point person” within the agency to coordinate TB and other health-related activities. This person can order and display educational brochures and posters throughout the agency, provide instructional webinars on TB, conduct or schedule client health groups, attend TB and other health workshops in the community, share health resources, serve as a health resource to other staff and residents, and contact the health department, when appropriate.

- Conduct a TB risk assessment for the facility.
  - See *Resources* for a sample Centers for Disease Control and Prevention (CDC) risk assessment worksheet for healthcare facilities that can be modified and adapted.
- Develop a written IPC plan for the program that includes clear policies for client screening and what to do in case symptoms are identified:
  - Clients entering shelter housing should be systematically screened for TB symptoms (and other transmissible respiratory disease) upon entry. Offer information for all shelter clients about TB symptoms and how to access care if needed.
    - In areas of high TB incidence, and if resources allow, additional screening with TB testing upon entry may be beneficial. Ideally, screening will be linked to a program to help clients complete preventive treatment should LTBI be identified.
  - Identify clients who have a cough (lasting 3 weeks or longer) and one or more other symptoms of TB disease of the lungs or larynx including fever, chills, night sweats, weight loss, fatigue, chest pain, or coughing up blood. *Basic TB Facts: Signs and Symptoms* (CDC) offers more information on the signs and symptoms of TB.[6] See *Resources*.
  - Separate clients with symptoms of TB from other clients and staff by placing clients with symptoms in rooms by themselves until they can be medically evaluated.
    - Consider maintaining a cough log to document clients who are coughing, particularly at night, and their bed location.
  - Promptly refer clients with one or more symptoms of TB disease for medical care. Medical evaluation should take place as soon as possible, though is sometimes not feasible until the following day. Instruct clients to use masks over the nose and mouth to trap infectious particles and monitor clients to ensure they are wearing them.
  - Promptly report clients with potential or confirmed TB disease to the public health department. Keep contact information up to date and easily accessible for staff.
  - If possible, assist the local public health department in treating shelter clients for LTBI and TB disease. Examples include: providing transportation assistance and follow-up for healthcare appointments, providing incentives for clients to complete their full treatment, and helping clients cooperate with directly observed therapy (DOT) provided by the public health department to ensure TB treatment is taken as prescribed.
  - If a TB screening or formal clearance process is done, include client TB clearance records into the local electronic records system, e.g., the Department of Housing and Urban Development (HUD) Homeless Information Management Systems (HMIS), if available. Records should flag incomplete evaluations.

    - State and local guidance on TB screening for shelter clients can vary; consult with the local TB program and/or public health department. See *Resources* for a listing of TB program websites and contacts.
- Make tissues (or surgical masks) readily available to clients, instructing them to cover their noses and mouths when coughing and sneezing.
- Reinforce "cover your cough" behavior with signs and verbal reminders. Signage is available in multiple languages. See *Resources*.
- Place each bed as far from neighboring beds as possible, with beds arranged head-to-foot, instead of head-to-head.
- Maintain a guest log and bed map (ideal if searchable and in downloadable electronic format); these items are essential if the health department conducts contact tracing or investigation to follow-up a TB outbreak in a shelter.
- Educate staff and clients about TB. See *Resources* for sample training materials and basic TB information.
- Documentation of baseline TB screening is recommended for new employees and volunteers. CDC 2019 recommendations for TB screening of healthcare personnel (HCP) applies to clinics within shelters and may be considered for at-risk congregate settings. The need for repeat TB screening or testing is dependent on facility risk assessments and the prevalence of TB in the community.
    - For most circumstances, particularly if TB prevalence is low, annual TB testing of employees is not recommended.
    - For more information about general recommendations and resource links for HCP screening, see Chapter 5, *Clinics*, section, *TB screening program*.

Note: Shelters should not house clients who are being evaluated for, or known to have, active TB disease of the lungs or larynx until the clients are declared no longer infectious by the treating providers. This would not apply to a client who has a diagnosis of LTBI; i.e., has a history of a positive TB test (blood or skin test) with no TB symptoms and is not being considered for medical evaluation for TB disease. Consult with the local public health department to determine risk of infectiousness, or for assistance with alternative housing or transfer to an appropriate medical facility.

For additional administrative information and helpful links, see *Resources*.

- CDC's *Administrative Controls: TB Control in Overnight Homeless Facilities Quick Reference Guide*
- *Preventing Tuberculosis and other Aerosol Transmittable Diseases in Shelters: A Guide for Preventing and Controlling TB and other Aerosol Transmissible Diseases in Los Angeles County Facilities*
- Example of a simple and concise toolkit: *Tuberculosis Prevention and Control Recommendations for Homeless Shelters in Maine – Toolkit*

Environmental controls

These measures will reduce the chances that others will inhale air containing *M. tuberculosis*. For more details about each of these measures and how they help to prevent TB from spreading, see Chapter 2, *Environmental Controls*.

- **Ventilation** can reduce the spread of TB through dilution and removal by supplying outdoor air and exhausting room air to the outdoors. Ventilation is either natural (employing windows, doors, skylights, and/or fans) or mechanical (HVAC or other forced air systems).
- **Filtration of recirculated air** can remove particles from the recirculated air. Many different levels of filtration are available and HVAC systems may have only one filter or have two or more. Using a suitable filter with the HVAC system helps reduce further the risk of spreading TB.
- **Room air cleaners (RACs)** can supplement HVAC systems by filtering or inactivating *M. tuberculosis* in the air. These are generally stand-alone systems.
- **UVC** uses a type of radiation that has been shown to kill or inactivate *M. tuberculosis* in the air. It is used in TB control either as in-duct UVC (using UVC lamps inside the duct of an HVAC system), in a RAC, or as upper-room UVC (mounting UVC lamps in the upper part of a room).

Evaluate the shelter's current system for effectiveness and modify as needed. The following information will help to determine if any changes are needed in a facility.

Natural ventilation

If rooms in a building are not served by a central HVAC system, see Chapter 2, *Environmental Controls: Part 1 – Ventilation* (sections on *Using directional airflow to reduce TB transmission*; *Natural ventilation*; and *Using fans with natural ventilation*) to learn how to check and improve natural ventilation, how to use exhaust and freestanding fans more effectively, and to learn about the advantages and disadvantages of natural ventilation and fans as compared to other types of ventilation.

Methods that help improve natural ventilation in the shelter include:

- Providing fresh outdoor air to all occupied rooms in homeless shelters.
- Keeping doors, windows, and skylights open as often as possible, and checking that they are easy to open. If possible, aim for keeping these at least 10% open on opposing walls.
- Adding fans to increase air mixing and directional airflow, placing them so air movement can be observed in all occupied parts of the room, and keeping them running as much as possible. In some cases (e.g., heating season), drafts might not be acceptable.
- Providing extra blankets to clients who complain of drafts so that ventilation can be used when the space is occupied.
- Increasing ventilation at times when the space is unoccupied if ventilation and fans cannot be used when the space is occupied because they are too noisy

or cause unacceptable drafts. For example, many shelters are closed during part of the day. This provides an opportunity to open windows and doors while running fans at high speed to "air out" dormitories.

Natural ventilation can be unpredictable and may not be practical in cold climates. If this is the case, consider adding a central HVAC system.

To learn how one homeless shelter director improved the natural ventilation in her building, see Chapter 2, *Environmental Controls: Part 1 – Ventilation*, section, *Case study: Natural ventilation and exhaust fans*.

Central HVAC systems

If rooms in the building have an existing central HVAC system, see Chapter 2, *Environmental Controls: Part 1 – Ventilation*, section, *HVAC systems*, to learn about the various parts of the central HVAC system, how they help control TB transmission, what to check and how to make improvements, and the advantages and disadvantages of central ventilation.

If the design of a central HVAC system is being considered for a new or an existing building, see Chapter 2, *Environmental Controls: Part 1 – Ventilation*, sections, *Recommendations for existing HVAC systems* and *Recommendations for the design of new HVAC systems*.

Methods that improve existing central HVAC systems in the shelter may include:

- Using higher-efficiency (e.g., pleated) filters while maintaining the intended design airflow rate
- Providing outdoor air intakes
- Setting outdoor air intakes to the fully open position
- Using thermostats and HVAC system controls that allow continuous fan operation whenever the building is occupied
- Providing natural ventilation to occupied rooms not served by HVAC systems and to all occupied spaces at times when HVAC systems are broken or otherwise not operating as designed
- Using in-duct UVC as a supplement to HVAC systems with filtration

In addition, perform regular checks of each HVAC system and the rooms that it serves, and conduct routine maintenance. See Chapter 2, *Environmental Controls: Part 1 – Ventilation*, section, *Checking an HVAC system* for more details if improvements to the central HVAC system are being considered and for a description of the checks to perform.

To learn how one homeless shelter director used these ideas and made immediate low-cost improvements to ventilation in his shelter, see Chapter 2, *Environmental Controls: Part 1 – Ventilation, Case study: HVAC systems*.

HVAC air filters

Three types of filters are used in central HVAC systems:

- Lint filter (removes large dust particles but does not remove particles as small as *M. tuberculosis*)
- Pleated filters (American Society of Heating, Refrigerating, and Air-Conditioning Engineers [ASHRAE]) minimum efficiency reporting value [MERV] 8 for supply air from outdoors, or MERV 13 for recirculated air
- High-efficiency particulate air (HEPA) or other high-efficiency filter (limited to specialized HVAC systems that are HEPA-friendly)

A pleated filter is the most suitable type of filter for many recirculating air systems, such as those in homeless shelters. Pleated filters are readily available from hardware stores in sizes that fit most HVAC systems. They are slightly more expensive than lint filters and cause more of an obstruction, which will reduce airflow slightly. To read more about filters, see Chapter 2, *Environmental Controls: Part 1 – Ventilation*, section, *Air filters*, and Table 3 for examples of ventilation filters and a comparison of filter efficiencies.

RAC air filters

RACs with HEPA or other high-efficiency filters allow the air quality in a room to improve rapidly. These units are useful in homeless shelters that may have inadequate or no HVAC system and limited funds for upgrades.

Ways to use RACs in your shelter:

- Provide portable RACs with HEPA or other high-efficiency filters for all poorly ventilated rooms frequented by clients.
- Place small RACs off the floor and next to staff so that the "clean air" they generate is delivered close to the breathing zone of the people that they are used to protect. For example, if clean air is exhausted from the front of a RAC, an ideal location is on a desk or on a file cabinet adjacent to a staff member. Consider the RACs primarily as a source of clean air and secondly as a removal device for contaminated air.
- Place units evenly throughout crowded rooms so that air movement can be observed in all parts of the room.
- Operate RACs continuously while rooms are occupied by clients and for approximately 1 hour after they leave.

To keep RACs operating efficiently, designate a staff person to be the in-house monitor of the units and to perform routine maintenance. This person should know the basic principles of RAC operation and should create a written schedule for changing the filters. To read more about RACs how to select suitable units, and their routine upkeep see Chapter 2, *Environmental Controls: Part 1 – Ventilation*, section, *RACs*.

UVC

Only an experienced professional, such as a UVC fixture manufacturer, should design and install UVC fixtures in a shelter. This type of installation (and the maintenance of such an installation) requires expertise and equipment that may be resource-intensive to acquire.

In-duct UVC is a useful option for a recirculating HVAC system that serves areas at high risk for TB transmission and areas without risk. The UVC lamps are installed inside an air duct. This type of UVC is usually less expensive to operate than a 100% outdoor air system. In-duct UVC is more useful when central HVAC systems cannot handle higher-efficiency filters. The usefulness of in-duct UVC goes down as the central HVAC filtration efficiency goes up. To read more about this type of UVC and advantages and disadvantages of in-duct UVC, see Chapter 2, *Environmental Controls: Part 2 – UVC*, section, *Irradiation of air in an HVAC system (In-duct UVC)*.

Upper-room UVC is a specialized technology that is particularly appropriate for homeless shelters but can only be used in certain rooms. UVC lamps are mounted high on walls or hung from the ceiling (at a height of at least 7 feet above the floor), resulting in disinfection of the upper-room air. UVC fixtures should not be installed in rooms with ceilings less than 8 feet high to avoid people looking into the lamps (safety risk) or bumping into them. In addition, bunk beds should not be used in rooms that have an upper-room UVC installation unless ceilings and placement of units are at a safe distance from the occupants of the upper bunks.

When using upper-room UVC, it is essential that the lamps and irradiation levels be checked on a regular basis.

- Have an expert use a radiometer with the appropriate UVC detector to check the irradiation levels in parts of the room where people are likely to be exposed. Irradiance levels should be below the recommended exposure limit (REL) set by the CDC/National Institute for Occupational Safety and Health (NIOSH).
- If irradiation levels are too high in any location, turn off the lamp or lamps causing the high irradiation levels. It may be necessary to add non-reflective paint to the ceiling and/or wall to adjust the “beam” of the UVC fixture and/or to relocate or replace the fixtures to correct the problem.
- Turn off lamps and check that lamps and fixtures are free of dust and lint.
- Check that the irradiation level at each fixture meets the lamp manufacturer’s recommendation. Protective clothing or special equipment may be needed to take these readings without overexposing the skin or eyes to the UVC irradiation. Replace the UVC bulbs if the irradiation levels are below the manufacturer’s recommended minimum levels.

To read more about upper-room UVC, how to determine whether a room is suitable, installation planning, routine upkeep, and the advantages and disadvantages of upper-room UVC, see Chapter 2, *Environmental Controls: Part 2 – UVC*, section, *Upper-room UVC*.

Respiratory protection

A CDC/NIOSH-approved respirator, e.g., N-95, fits over the nose and mouth of the user (i.e., HCP). In TB control, a respirator is designed to prevent the user from inhaling at least 90% of the infectious particles containing *M. tuberculosis*.

As described in Chapter 3, *Personal Protective Equipment*, CDC has specific recommendations, and the Occupational Safety and Health Administration (OSHA) has requirements for staff use of respirators.[7,8,9] See *Resources*.

While N-95 respirators need not be worn routinely by shelter staff, their availability for staff use in certain situations should be part of a respiratory protection program. Surgical masks should be available for clients presenting with respiratory symptoms. For example, if a client in a shelter becomes ill and is considered a potential TB case, a staff member attending to that person in close proximity should wear an N95 (or higher) respirator, if available, in the person's room while transport to a medical facility for evaluation is being arranged. Ensure the client wears a surgical mask and follows proper cough etiquette.

Contact Federal OSHA or the state OSHA for additional information. See *Resources*.

Source: iStock

Resources

Administrative controls

Centers for Disease Control and Prevention (CDC)

- Sample risk assessment worksheet for healthcare facilities that can be modified and adapted
  https://www.cdc.gov/tb-healthcare-settings/hcp/facility-risk-assessment/index.html
- Signs and Symptoms of Tuberculosis
  https://www.cdc.gov/tb/signs-symptoms/index.html
- Cover your cough signage
  English: https://www.cdc.gov/flu/pdf/protect/cdc_cough.pdf
  Multiple languages: https://www.health.state.mn.us/people/cyc/hcpposter.html

Los Angeles County Department of Public Health

- Preventing Tuberculosis and other Aerosol Transmittable Diseases in Shelters: A Guide for Preventing and Controlling TB and other Aerosol Transmissible Diseases in Los Angeles County Facilities
  http://ph.lacounty.gov/tb/docs/Shelterguidelines.pdf

The Maine Department of Health and Human Services, Bureau of Health

- Example of a simple and concise toolkit: Tuberculosis Prevention and Control Recommendations for Homeless Shelters in Maine – Toolkit
  https://www.maine.gov/dhhs/mecdc/infectious-disease/epi/tuberculosis/documents/shelter-tool-kit.pdf#:~:text=If%20your%20shelter%20serves%20%E2%80%9Chigh%20risk%E2%80%9D%20guests%20%28See,special%20training%20in%20administering%20and%20reading%20skin%20tests

National Tuberculosis Coalition of America (NTCA)

- State and local guidance on TB screening for shelter clients
  https://www.tbcontrollers.org/community/statecityterritory/

Respirators

Occupational Safety and Health Administration (OSHA)

- Requirements for staff use of respirators
  https://www.osha.gov/respiratory-protection/general#:~:text=General%20Respiratory%20Protection%20Guidance%20for%20Employers%20and%20Workers.,is%20needed%20for%20a%20respirator%20to%20provide%20protection.
- State plans
  https://www.osha.gov/stateplans

Additional resources

CDC

- TB and People Experiencing Homelessness
  https://www.cdc.gov/tb/risk-factors/homelessness.html
- Guidance on Management of COVID-19 in Homeless Service Sites and in Correctional and Detention Facilities
  https://archive.cdc.gov/#/results?q=https://www.cdc.gov/coronavirus/2019-ncov/community/homeless-correctional-settings.html&start=0&rows=10&url=https://www.cdc.gov/coronavirus/2019-ncov/community/homeless-correctional-settings.html

Curry International Tuberculosis Center/UCSF

- Homelessness and TB Toolkit (database of materials, resources, presentations)
  https://www.currytbcenter.ucsf.edu/products/view/homelessness-and-tb-toolkit
- Shelters and TB: What Staff Need to Know, Second Edition (viewer's guide)
  https://www.currytbcenter.ucsf.edu/sites/default/files/shelters_and_tb_viewers_guide.pdf

Public Health Reports, 2023 article

- Diagnosis, Treatment, and Prevention of Tuberculosis Among People Experiencing Homelessness in the United States: Current Recommendations
  https://journals.sagepub.com/doi/10.1177/00333549221148173

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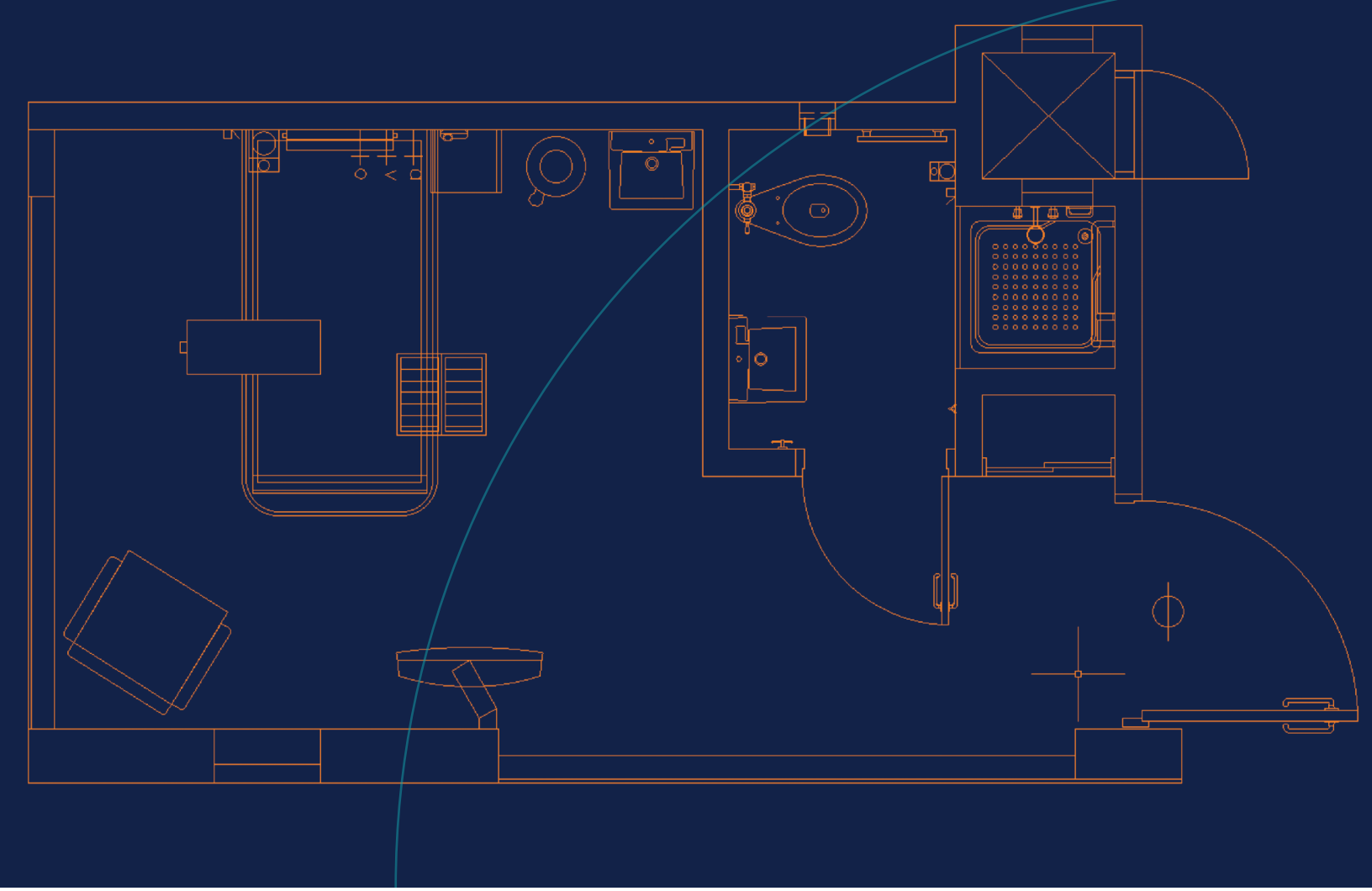

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