Using Ultraviolet Radiation and Ventilation to Control Tuberculosis

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PREFACE

This booklet was produced in response to a need expressed by many tuberculosis control officials for a technically oriented, practical guide to the use of ultraviolet light and ventilation to control tuberculosis transmission. Application of the techniques presented is best done as a collaborative effort among tuberculosis control personnel, environmental health and safety personnel, and physical plant management personnel.

A conscious attempt was made to make the information consistent with current occupational health and safety requirements applicable to these situations. However, the specifics of laws and regulations are constantly evolving. To assure legal compliance, the prudent course is to consult local occupational health officials.

Members of the California Tuberculosis Controllers Association, The American Biological Safety Association, the Center for Infectious Diseases and the National Institute for Occupational Safety and Health of the Centers for Disease Control reviewed the material in this booklet. Many individuals gave generously of their time in providing comments. The successful evolution of the "booklet project" from idea to the reality of this document results directly from the persistent and skilled efforts of three individuals: Janet Macher, Sc. D., M.P.H., Project Director, Leon Alevantis, P.E., M.S. from the California State Air Industrial Hygiene Laboratory and Stanley A. Morita, Associate Project Director, from the California State Tuberculosis Control and Refugee Health Programs Unit.

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The figures for this booklet were drawn by Hazel Anderholm.

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Contents

I. INTRODUCTION

Tuberculosis (TB) Infection and Disease remains a world-wide burden despite efforts to identify and treat cases. After many years of slow but steady decrease in the incidence of TB in the United States, this disease is making a comeback. It is a serious public health problem among the homeless, some groups of immigrants, inmates of correctional institutions, and people infected with or at high risk for infection with the human immunodeficiency virus (HIV). Concerns about the continued spread of TB infection have led to an increased interest in using environmental control measures to protect the above-mentioned groups of people, health care personnel, and the general public from TB infection and disease.

How Tuberculosis Spreads

TB is spread (transmitted) from person to person by tiny airborne particles containing tubercle bacilli. Particles, called "droplet nuclei," containing these bacteria are coughed up by persons with untreated or inadequately treated, clinically-active, pulmonary or laryngeal TB. Droplet nuclei are carried on air currents and disperse rapidly throughout a room. The longer that a susceptible (uninfected) person shares the same air space with someone who has active pulmonary or laryngeal TB, the greater the chance that the person will inhale airborne TB bacilli. Therefore, the goal of environmental infection control is to prevent the spread of TB by protecting susceptible people from inhaling airborne particles generated by infectious individuals.

Environmental Control Measures

Airborne infections such as TB can be prevented by killing the infectious microorganisms in the air with ultraviolet (UV) radiation. UV lamps are inexpensive, easy to install and maintain, and are effective at killing airborne microorganisms. Therefore, some health authorities recommend UV lamps for certain high risk environments.

Some frequently-asked questions about the use of UV radiation for reducing the spread of TB are answered in the first part of Section II, and a brief technical description of UV radiation is given in the second part of that section. The spread of airborne infections also can be reduced with proper ventilation, as discussed in Section III.

Although environmental control measures such as air disinfection and ventilation can decrease the transmission (i.e., airborne spread) of TB, they are only supplements to the usual control measures. Environmental controls cannot replace conventional interventions such as the prompt detection and treatment of cases, and tracing of contacts. However, if the identification and follow-up of TB cases is difficult, UV air disinfection and exhaust ventilation can provide an extra measure of protection.

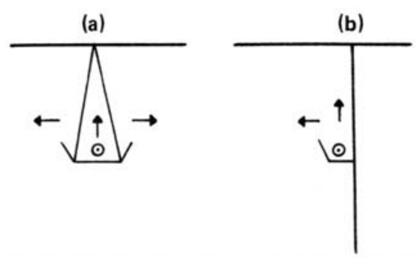
II. ULTRAVIOLET RADIATION

Questions and Answers on the Use of UV Radiation for TB Control

How are UV lamps used to disinfect the air?

Germicidal UV lamps (low-pressure mercury vapor lamps which emit radiation near 254 nanometers) can be used in ceiling fixtures suspended above the people in a room or within air ducts of recirculating systems. The first method is called overhead or upper air irradiation. The fixtures are shielded on the bottoms so that the radiation is directed only up toward the ceiling and out to the sides (see Figure 1). The bottoms of the fixtures should be at least 7 feet above the floor so that people will not bump into them or look directly at the bare tubes (1,2,16). Overhead UV lamps are most effective in rooms in which the ceilings are at least 9 feet high because this allows a significant portion of the air to be irradiated. Fixtures with adjustable louvers which control the direction of the UV rays may be used (with caution) in areas with lower ceilings.

Figure 1
Examples of shielded UV fixtures:
a) ceiling-mounted fixture
b) wall-mounted fixture
(the arrows indicate the direction of the radiation)



The air entering or leaving a room can be disinfected with UV lamps placed inside the ventilation system ducts, as illustrated in Figure 2. This method of air disinfection could be used, for example, in a TB clinic from which air is recirculated to other parts of the building, but in which overhead disinfection cannot be used because the ceiling is too low. UV lamps could be placed instead inside the exhaust duct to kill any microorganisms in the air leaving the clinic. Because people are not exposed to the UV radiation, very high levels can be used inside ducts.

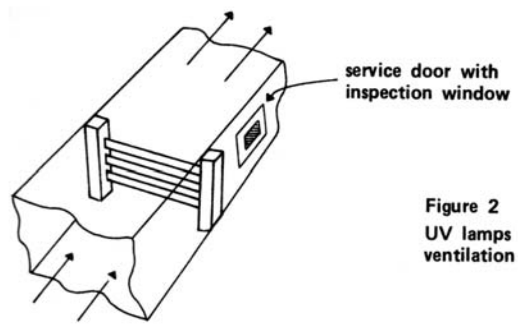


Figure 2
UV lamps located inside ventilation system duct

How effective is UV radiation at killing TB bacteria?

The following factors, which are discussed in detail below, play a part in determining whether or not exposure to UV radiation will kill a microorganism:

1) the type of microorganism,
2) the dose of radiation to which it is exposed, and
3) the amount of moisture in the air.

1) Type of microoroganism: UV radiation rapidly kills airborne bacteria and viruses, but it is less effective against airborne fungal and bacterial spores. The bacteria that cause TB are more resistant to UV than some others, but they are not as difficult to kill as spores. UV radiation does not penetrate well through matter, therefore, bacteria carried in large particles of dried sputum, for example, might be shielded from the disinfecting radiation. However, these larger particles do not remain suspended in the air for very long nor do they reach the lower lung if inhaled, and therefore do not pose as great a risk of infection as do smaller, more UV-sensitive particles.

2) **Radiation dose:** For air disinfection to be effective, the TB bacteria must receive a sufficient dose of UV radiation. This can be achieved by using lamps of the correct wavelength and intensity (wattage) and by exposing the bacteria for sufficiently long periods of time. There must be good mixing between the irradiated upper room air and the air lower in a room where people are. In this way, contaminated droplets are moved into the irradiated zone and the disinfected air dilutes the contaminated lower air. Portable or ceiling fans can be used to increase air circulation.

3) Moisture in the air: At typical indoor temperatures, relative humidities above 70% reduce the bactericidal efficiency of UV radiation. This level of moisture is not common in air-conditioned buildings (unless the air-conditioning equipment is not operating properly) or during the colder months of the year when airborne transmission is more likely. However, if excess humidity is a problem, air disinfection must exclusively rely on other forms of environmental control, such as increased ventilation or duct irradiation.

For what types of facilities should overhead UV radiation be considered as a means to reduce the transmission of infection?

Overhead UV lamps are useful in crowded and poorly-ventilated buildings where the conventional control methods are inadequate. Examples of such areas are:

Shelters for the homeless (3),
Correctional institutions (4),
Nursing homes,
Hospitals: emergency rooms, operating rooms, intensive care areas, laboratories,
TB clinics: sputum collection rooms, aerosol treatment areas, ronchoscopy rooms,
AIDS clinics, aerosol pentamidine treatment areas.(5)(17).

In such places, there occasionally are unidentified TB cases. UV lamps also might be appropriate in pediatricians' offices where the disinfecting radiation would help control the transmission of other airborne infections such as measles.

Is the airborne spread of TB in high risk settings best controlled by mechanical ventilation, air cleaners, or UV air disinfection?

The American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) recommends an outdoor air supply of 15 to 20 cubic feet of air per minute for each person in a room (15-20 cfm/person) for comfort purposes (6). However, this amount of ventilation would not significantly reduce the number of airborne TB bacteria that a highly infectious person could produce. It would take more than 100 cfm/person of outdoor air to reduce the number of airborne bacteria to the same level that a UV lamp could (1,2,16). Supplying that much outdoor air would be impractical in many situations, because it is very expensive to heat or cool such large quantities of outdoor air and to move it through a ventilation system.

Indoor air that might contain infectious particles cannot safely be recirculated back into a room unless the airborne microorganisms have been removed or inactivated. Filtering the air, installing UV lamps inside the air ducts, and other forms of air cleaning can effectively remove or kill bacteria and are suitable, or even necessary, in certain facilities. However, high-efficiency air cleaners are more expensive to install and maintain than overhead UV lamps, and generally are not practical for treating the air in large open rooms. See Section III of this booklet for more details on the use of general and local exhaust ventilation for the control of TB.

It is often best to design a ventilation system to provide at least 15 cfm/person for comfort, to use exhaust hoods and special booths to contain airborne particles produced by high risk procedures, and to consider using overhead UV radiation to further reduce the airborne spread of infectious particles.

Checklist of features to consider before recommending overhead UV air disinfection.

	Yes	No
A potentially high risk of TB transmission in population that cannot be controlled adequately by conventional interventions	( )	( )
Sufficiently high ceilings (at least 9 ft) that are relatively free of obstructions.	( )	( )
Relative humidity below 70%	( )	( )
The capability of maintaining and operating the UV lamps effectively and safely	( )	( )
A means of measuring the reduction in airborne infections among the occupants	( )	( )

If the answer to any of the above questions is "no," overhead UV disinfection might not be suitable for the proposed situation.

How are UV lamps used inside heating, ventilating, and airconditioning (HVAC) system ducts?

When duct irradiation is used, the lamps should be placed at right angles to the direction of airflow and installed at the center of the longest available run, as illustrated in Figure 2. Because the effectiveness of germicidal UV radiation is dependent on both the level of radiation and the exposure time, it is best, whenever possible, to install UV lamps where the velocity of the air is lowest.

The access door for servicing the lamps should have an inspection window (ordinary glass is sufficient to filter out the UV rays) through which the lamps periodically are checked and a sign in appropriate languages alerting maintenance personnel to the health hazard of looking directly at bare tubes. The lock for this door should have an electric switch so that the lamps turn off automatically whenever the door is opened.

How do I decide how many overhead UV lamps an area needs?

The number of fixtures needed depends on the size of the room, the height of the ceilings, and the location of the supply air diffusers. The higher the UV radiation intensity, the more rapidly microorganisms are inactivated. Threrefore, the more lamps the better so long as human exposure to UV is kept at safe levels. As a general rule of thumb, install the equivalent of one 30 watt fixture for every 200 ft'- of floor area or for every seven people in the room, whichever is greater. Using two 15 watt lamps instead of one 30 watt lamp might provide better irradiation of the upper room air and reduce the risk of exposing the occupants to unsafe levels of UV radiation. This amount of air disinfection is considered the equivalent of 20 room air changes per hour (ACH) or approximately 100 cfm/person (i,2). Ceiling fixtures should be oriented so that the radiation is directed into the longest part of a room (see Figure 3, below). If multiple fixtures are installed, they should be spaced evenly so that there is minimal overlap of irradiation.

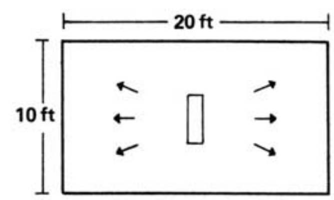


Figure 3a
- overhead view of a 200 ft^2 dormitory room, occupied by six people
- one ceiling fixture

(the arrows indicate the direction of the radiation)

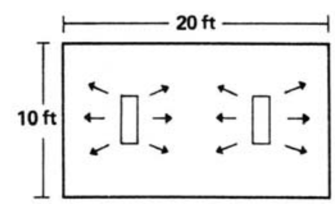


Figure 3b
- overhead view of a 200 ft^2 waiting room, occupied at times by more than seven people
- two ceiling fixtures

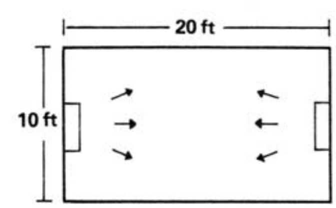


Figure 3c
- same room as in 3b
- two wall fixtures

Can upper air UV irradiation cause any problems?

UV radiation is divided into three regions. UV-A (long UV 400-320nm), and UV-B (midrange UV 320-290nm) that produce sunburn and tanning. Prolonged exposure can cause skin cancer and cataracts (7). Germicidal UV radiation is in the UV -C region of the spectrum (short UV, 290-100nm).UV C may cause reddening of the skin and conjunctivitis (a feeling of sand in the eyes), but not skin cancer or cataracts in humans (8). Because UV-C is absorbed in the outer layers of the skin and eyes, the irritation produced by overexposure is superficial. Although serious burns can be incapacitating at the time, the effects usually disappear within 24 hours without lasting effects (8).
Intense UV radiation can fade colored paints and fabrics, speed up the deterioration of plastics, and cause plants to wilt. Because prolonged exposure to UV radiation can damage skin and eyes, one should never look directly at the lighted tubes for more than a few seconds unless wearing appropriate safety goggles or a face shield. Also, one should wear a long-sleeved shirt and gloves if it is necessary to work near lighted lamps. Maintenance personnel should exercise appropriate precautions against breakage when replacing and disposing of these tubes. Modern UV lamps do not produce ozone.

It also must be remembered that UV lamps produce some visible violet light. While the color is scarcely noticeable during the day, at night it might disturb people who are trying to sleep. Nonetheless, the lamps should be operated whenever people occupy the controlled rooms. In buildings that are occupied all day, the UV lamps should be left on continuously. Frequent on-off cycling tends to shorten the life of some types of lamps.

A person should be assigned responsibility to maintain the UV fixtures, train in safety procedures and keep a maintenance log. A maintenance and safety log should include information on tube cleaning, baseline and periodic meter readings for irradiation areas (between lamp and ceiling) and for employee/client exposure areas, training, and complaints of eye or skin irritation. There is no substitute for on-site meter readings to assure that germicidal levels are attained between tubes and ceilings or walls while at the same time room occupants are not exposed to injurious levels. Employees should be trained on the hazards of exposure to UV radiation. This training should include:

1. Information as to the proper eye protection and protective clothing to be used.
2. Instructions on how to recognize the symptoms of eye and skin damage due to UV radiation.

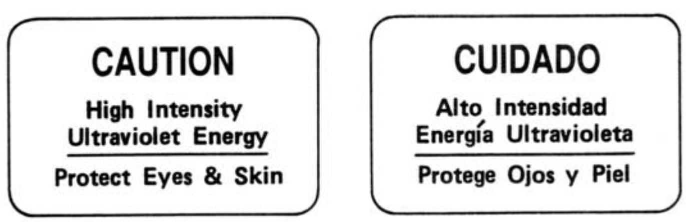
How can I be sure that new UV lamps have been installed safely?

When the lamps are installed, an experienced person should measure the level of UV radiation at the locations where people will be exposed. All readings must be below the American Conference of Government Industrial Hygienists' (ACGIH) limit, which for germicidal lamps is 0.2 microwatts per square centimeter ($\mu W/cm^2$) for an 8-hour period (8). If you plan on purchasing a UV radiometer, make certain that it can measure the necessary range of wave lengths and is sufficiently sensitive.

The exposure limit refers to **254-nm UV radiation** which is the predominant wave-length produced by germicidal lamps. The permitted exposure limit is 6 milli-Joules/cm= or 6000µW • seconds/cm^2. For an 8-hour day, the average exposure level limit is 0.2µW/cm^2. For 24 hour exposure, the limit would be 0.07µW/cm^2. To reduce UV exposure in the occupied portions of a room, install baffles to prevent people from looking directly at the tubes. If necessary, use paints containing titanium dioxide (Ti02) to reduce reflection from ceilings and walls, or otherwise treat them to reduce reflection. Once a room has been checked to assure that all occupied areas are below the NIOSH exposure limit, these measurements do not need to be repeated every time the lamps are changed.

If the UV lamp manufacturer or installer does not supply warning labels, make or purchase your own to identify the fixtures as dangerous for direct eye and prolonged skin exposure. Figure 4 is a sample warning label recommended by NIOSH (8). The NIOSH document also states that for this type of lamp, warning labels are required on the lamp and housing, but not in the work area. Make certain that the switches to turn the UV fixtures off for inspection, cleaning, and tube changing are accessible when needed but are out of the reach of unauthorized people so that the lamps cannot be turned on or off accidentally.

Figure 4
Warning labels



How often must the tubes be changed?

Unless a facility has an appropriate radiometer and a trained staff member who can check lamp output periodically, we recommend that the tubes be **replaced each year or at the end of their rated life if that is less than twelve months.**

How often must the lamps be cleaned?

The tubes and the fixture trough should be checked **periodically** (perhaps every three months) and cleaned **when needed.** We do not recommend frequent lamp readings or cleaning, unless performed by a properly trained and equipped person, because of the risk of accidents.

How much does it cost to use overhead UV air disinfection?

New UV fixtures cost between $100 and $500, depending on their design, and new lamps cost between $50 and $100 per tube. You can estimate how much it will cost to operate a lamp continuously for one year by multiplying the input wattage by the number of hours of use (8760 hours for one year) and the local cost of electricity (see the formula below). UV lamps should be purchased as they are needed, because prolonged storage results in a loss of UV intensity.

$$\frac{\text{input wattage}}{\text{1000W/Kilowatt}} \times \text{hours of use} \times \frac{\text{cost}}{\text{Kilowatt-hour}} = \text{operation cost}$$

Where can I find someone to install germicidal UV fixtures?

You may be able to locate suppliers by contacting your local health department, a hospital, or microbiology laboratory since these entities may already have experience of their own with UV fixtures. Prior to purchase and installation of tubes and/or fixtures, you should review the information in this booklet with your supplier and/or installer to ensure that appropriate fixtures are provided and properly installed. If your supplier/installer has not recently been involved in these types of installations, familiarization with the material in this booklet, especially as it pertains to safety, is all the more important.

The main recommendations of this section are summarized below.

Suggestions on the Proper Use of Upper Air UV Irradiation.

1. Use germicidal lamps that emit short wave (254 nm*)* ultraviolet radiation.

2. Install the equivalent of one 30W ceiling or wall fixture for every 200 ft^2 of floor area or for every seven people in a room, whichever is greater. Always check that your installation does not exceed safe exposure levels for workers or clients.

3. Position the lamps to irradiate the greatest area.

4. Place labels on the fixtures to warm people to avoid direct eye and prolonged skin exposure.

5. Check that the level of ultraviolet radiation where people will be exposed does not exceed 0.2$\mu W/cm^2$ (assumes an 8-hour exposure). Recheck whenever reflective surfaces or room contents are changed.

6. Change the tubes annually or when meter readings indicate tube failure.

7. Inform all employees of the potential hazards of overexposure to UV radiation and provide adequate personal protection to anyone who needs it

8. Delegate a person to maintain the lamps, to see that safety measures are followed and to keep a log of when the lamp are replaced

Technical Details About UV Radiation

As mentioned previously, UV radiation is divided into three regions by wavelength: long, middle, and short waves. UV radiation for the purpose of killing microorganisms is produced by lamps that emit radiation in the short wave region near 254 nanometers (there are 25 million nanometers in an inch), which is near the peak of bactericidal effectiveness. All UV wavelengths are shorter than visible light, therefore, UV rays are invisible to the human eye and should be referred to as UV radiation or UV energy, not as UV light. However, UV lamps also emit a small amount of visible violet-blue light.

Two important principles (the reciprocity and the inverse square laws), which are helpful in understanding how UV lamps can be used for air disinfection, are discussed below.

Reciprocity law: The dose of radiation to which microorganisms are exposed is equal to the intensity of the radiation times the duration of exposure. Equal doses of UV radiation have the same disinfecting action. Therefore, exposure to 100 microwatts per square centimeter ($\mu W/cm^2$) for 10 seconds has the same killing power as exposure to $50 \mu W/cm^2$ - for 20 seconds.

Inverse square law: As with visible light, the intensity of UV radiation diminishes as the square of the distance from a source. For example, two feet from a point source the intensity of the radiation would be only $(1/2)^2$ or 1/4 of what it was at one foot, and at four feet it would be $(1/4)^2$ or 1/16 of the level at one foot.

Distance from UV source (ft)	Measured UV intensity ($\mu W/cm^2$)
1	800
2	200
4	50

Because UV lamps are long narrow sources of radiation rather than point sources, it is difficult to predict the UV intensity at a given distance from a lamp. Therefore, it is more reliable to measure the actual exposure level with a sufficiently sensitive UV meter.

III. ULTRAVIOLET RADIATION

The concentrations of contaminants in a room can be controlled with mechanical ventilation in two ways. The first is called local exhaust ventilation. The second is referred to as dilution ventilation. These methods are described below.

Local Exhaust Ventilation

A local exhaust ventilation system removes airborne contaminants at or near their sources and can contain infectious aerosols very effectively. An example would be the safety hoods that laboratory workers use when handling specimens. Similar enclosures often are used for aerosol-generating activities such as sputum collection and aerosol therapy. Detailed information on the design of local exhaust systems is available in *Industrial Ventilation. A Manual of Recommended Practice (10).*

The major components of a local exhaust ventilation system are: 1) the hood or enclosure, 2) the ductwork through which the air moves, 3) an air cleaner, and 4) the fan (see Figure 5). An air cleaner, such as a high-efficiency air filter, a UV lamp, or an air incinerator, is needed when the contaminated air cannot be exhausted safely or is recirculated to a room.

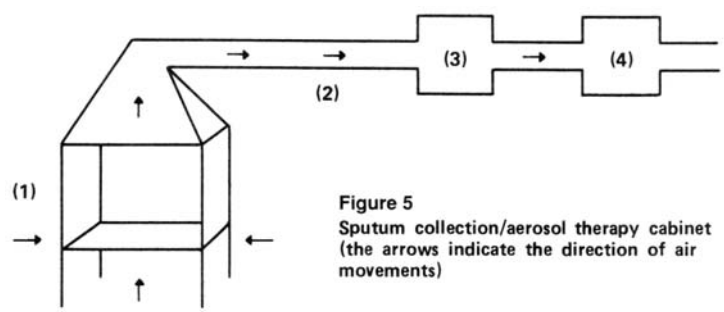


Figure 5
Sputum collection/aerosol therapy cabinet (the arrows indicate the direction of air movements)

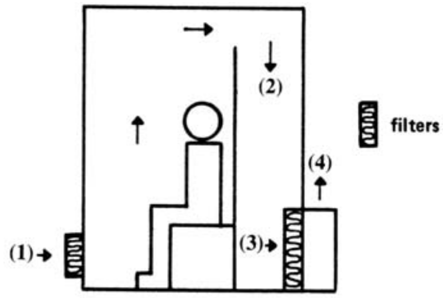


Figure 6
Side view of a sputum collection/aerosol therapy booth

The booth illustrated in Figure 6 is designed for use during sputum induction or aerosolized pentamidine treatment. Patients enter the booth through a door in the side and either sit or lie on a bench. Air is drawn into the chamber through a pre-filter (l) located in the front, then moves up past the patient and over the top of a back panel (2). The air is filtered through a HEPA (high efficiency particulate air) filter (3) before it is exhausted back into a room (4).

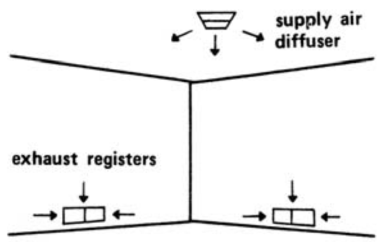
Also on the market are vinyl chambers that isolate the patient in an enclosure similar to an oxygen tent canopy. The canopy falls to within 2 inches from the floor. The air is drawn upward from the open area around the skirt and exhausted from the enclosure by a fan through a HEPA filter. The chamber is collapsible, conveniently sized so that it takes little space and is on wheels for increased mobility.

Dilution Ventilation

Dilution ventilation is a process of supplying pollutant-free air into a space to reduce the level of contamination. Some ventilation systems provide 100% outdoor air and exhaust all return air. Other systems, in the interest of energy conservation, recirculate part of the return air.

If a ventilation system is used to protect people from infectious particles, the system must draw the contaminated air away from the people in the room and carry it safely outside. The American Institute of Architects (AIA) has developed construction and operation guidelines for hospitals and medical facilities (11). A design that they recommend for reducing exposure to air contaminants generated by people is to place the air supply diffusers in the ceiling and the exhaust air grilles (also called registers) near the floor (see Figure 7). The idea behind this arrangement is that clean air enters above the occupants and contaminated air is removed at floor level. This design would not be appropriate if overhead UV lamps were being used because the contaminated air would be directed away from the lamps. When overhead UV lamps are used, the supply air diffusers should be near the floor, and the exhaust air grilles near or in the ceiling.

Figure 7
Typical ventilation system design for a hospital (the arrows indicate the direction of air movement)



Contaminated air removed from a room should not be recirculated back into the room or to other parts of a building unless it passes through a high efficiency filter, or an air incinerator, past a high intensity UV lamp, or is otherwise disinfected. Untreated exhaust air should be discharged well away (at least 25 ft) and downwind from the air intakes of any buildings (io). Air often is exhausted at the roof of a building so that any contaminants it contains are well diluted before they reach street level. Detailed guidelines for designing ventilation systems for infection control can be obtained from the AIA (11) and from the ASHRAE(6).

Room Air Distribution

Short circuiting of air. If a supply air diffuser is only a few feet away from a return air grille, part of the supply air will be exhausted before it mixes with the air in the room. This is called "short circuiting."

Air stagnation. Given average room air movement and the non-uniformity of natural convection currents, stagnant regions are formed in a room near the ceiling during cooling and near the floor during heating. The air in a stagnant region does not mix well with the air in the rest of the room.

Air mixing. The mixing of supply air with the air in a room is affected by:

1) the configuration of the supply air diffusers and the return air grilles,
2) the volume of air supplied to the room, and
3) the operating mode of the ventilation system, that is, whether it is heating or cooling the air.

Calculating the Number of Room Air Changes per Hour

Engineers sometimes express dilution ventilation in terms of the air change rate, which is measured as the number of room air changes per hour (ACH). An air change rate of 1 ACH means that an amount of air equal to the volume of the room is removed and replaced one every hour. Reference 17 cites the American Society of Heating, Refrigerating and Air-conditioning Engineers and the Health Resources and Services Administration (our reference 11) as recommending that acid-fast bacilli isolation rooms: **"...should have at least six total air changes per hour, including at least two outside air changes per hour..."** A facility could meet this recommendation by supplying 4 ACH of air recirculated from other parts of the building and 2 ACH of outdoor air. Reference 17 also gives ventilation recommendations for intensive care units and emergency and autopsy rooms, and discusses the use of personal respirators of patients while they are being transported and for health care providers while they are treating patients with suspected or confirmed infectious tuberculosis. Although an air change rate as high as 20 ACH may be desirable in high risk areas and has been recommended in earlier documents, we realize that this level of ventilation is impractical for many facilities and that the resultant air movement may cause drafts.

For a given air change rate and room size, the required amount of supply air in cubic feet per minute (cfm) can be calculated, as follows:

$$\frac{\text{(room volume in cubic feet)} \times \text{(number of ACH)}}{\text{60 min/hour}} = \text{CFM}$$

For example, a 20 ft by 10 ft room with a 10 ft ceiling would need 667 cfm of supply air to have an air change rate of 20 ACH:

$$\frac{(20\text{ft} \times 10\text{ft} \times 10\text{ft}) \times (20\text{ACH})}{\text{60 min/hour}} = 667$$

You can find out what the design airflow rates are for a given area by asking the build ing manager to check the original plans. The operator of your heating, ventilating, and air-conditioning (HVAC) system or a contractor can determine the actual supply airflow rate for a particular room by measuring it with special instruments.

As mentioned in the first part of Section II, ASHRAE recommends a ventilation rate of at least 15 cubic feet of outdoor air per minute per person (15 cfm/person) for comfort (6). The ASHRAE standard assumes that there are 10 persons/1000 ft^2 in hospital treatment rooms, and 30 persons/1000 ft^2 in lobby areas. In a well-designed facility, 15 cfm/person will sufficiently dilute the odors that people produce, but it should no be relied on to reduce exposure to highly infectious air contaminants.

Referring again to the 2000 ft^3 room used as an example above, when occupied by seven people, this room would need a supply of at least 105 cfm outdoor air (7 people x 15 c&n/person=105 cfin) to conform with the ASHRAE standard. However, this would supply only 3 air changes an hour [(105 cfin x 60 min/hr)/ 2000 ft^3 = 3 ACH]. This amount of dilution air would not be sufficient to control the spread of TB.
For comparison, if the 20 ACH that the CDC/ATS(13) recommends was supplied with outdoor air, the ventilation rate would have to be 95 cfm/person (667 cfm/7 people= 95 cfm/person), an impractically high ventilation rate for most facilities. However, the equivalent of this amount of TB-free air could be provided with upper air UV disinfection, as discussed in Section II.

Supplying Make-up Air

When an exhaust system is used, air must be supplied to the room to "make-up" for the volume removed through the ventilation system or the hood. If the ventilation system is balanced to provide less than the required amount of make-up air, the room will be under negative pressure. This vacuum will result in the movement of air from cleaner adjacent rooms into the contaminated room and not the reverse. The U. S. Public Health Service suggests an infiltration rate of 50 cfm for containment laboratories (14) or approximately 10% of the return air volumetric flowrate (15).

It is important that a building's air supply and exhaust systems be designed to accomodate the pressure changes caused by the opening and closing of doors, and by the movement of staff and patients. An instrument to measure air pressure (a manometer) with an audible alarm can be installed to warn people if room pressure changes.

Proper ventilation is an important determinant of a comfortable indoor environment. It also can provide a measure of protection against airborne infection. Periodic monitoring and maintenance of air supply and exhaust systems is necessary for effective operation. The main recommendations of Section III are summarized below.

Suggestions for Good Ventilation.

1. Use local exhaust ventilation (for example, cabinets or booths) to contain activities that generate infectious particles. Use general exhaust ventilation to remove contaminated air from a room, and to keep the room under negative pressure to other areas. Supply at least the minimum recommended amount of outdoor air.

2. Install supply air diffusers and general exhaust air grilles so that contaminated air moves away from the breathing zones of the people in a room. Make certain that short-circulating and stagnation of air are minimized.

3. Discharge the contaminated air outdoors at least 25 ft away and down wind from any outdoor air intakes. Install high efficiency air filters, UV lamps, or other disinfection units if the air must be exhausted closer than 25 ft to an air intake or if a large percentage of the potentially contaminated air will be recirculated to a building.

In order to prevent the transmission of TB and other respiratory infections in certain high risk settings, health care workers are paying increasing attention to environmental control measures. The references listed below provide additional details on the subject. For further information, contact your local health department or TB control officer; the Indoor Air Quality Program, Air & Industrial Hygiene Laboratory, California Department of Health Services, 2151 Berkeley Way, Berkeley, CA 947041011; of the Tuberculosis Control and Refugee Health Programs Units, Infectious Disease Branch, California Department of Health Services, 714/744 P Street, P.O. Box 942732, Sacramento, California 94234-7320.

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