

CHAPTER 9

HEALTH CARE FACILITIES

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CONTINUAL advances in medicine and technology necessitate constant reevaluation of the air-conditioning needs of hospitals and medical facilities. Medical evidence shows that air conditioning can affect certain clinical outcomes, and ventilation requirements exist to protect against harmful occupational exposures. Although the need for clean and conditioned air in health care facilities is high, the relatively high cost of air conditioning demands efficient design and operation to ensure economical energy management. It is a challenge to establish a balance between patient outcomes, safety, and higher operating costs. Often, there is little research or data to quantify the effect of the HVAC system on patient outcomes; whereas energy costs are relatively easy to quantify. The following is a suggested prioritization of the HVAC system design characteristics for a healthcare facility (Turpin 2013):

1. Performance (infection control, comfort, patient outcome)
2. Safety (fire, life safety, potential injuries)
3. Reliability
4. Maintenance cost
5. Energy cost
6. Adaptability

Health care occupancy classification, based on the latest occupancy guidelines from the National Fire Protection Association's (NFPA) *Life Safety Code*[®] and applicable building codes, should be considered early in project design. Health care facilities are unique in that there may be multiple, differing authorities having jurisdiction (AHJs) overseeing the design, construction, and operation of the facility. These different AHJs may use different standards or different versions of the same standards. Health care occupancy classification is important to determine for fire protection (smoke zones, smoke control) and for future adaptability of the HVAC system for a more restrictive occupancy.

Health care facilities are increasingly diversifying in response to a trend toward outpatient services. The term *clinic* may refer to any building from a residential doctor's office to a specialized cancer treatment center. Integrated regional health care organizations are becoming the model for medical care delivery as outpatient facilities take on more advanced care and increasingly serve as the entryway to the acute care hospital. These organizations, as well as long-established hospitals, are sometimes constructing buildings that look less like hospitals and more like luxury hotels and office buildings. However, when specific health care treatments in these facilities are medically consistent with hospital-based treatment activity, then the environmental design guidance applicable to the hospital-based treatment should also apply to the clinic's treatment environment.

For the purpose of this chapter, health care facilities are divided into the following categories:

- Hospital facilities

- Outpatient health care facilities
- Residential health care and support facilities

The general hospital provides a variety of services; its environmental conditions and design criteria apply to comparable areas in other health care facilities. The general acute care hospital has a core of patient care spaces, including rooms for operations, emergency treatment, delivery, patients, and a nursery. Usually, the functions of radiology, laboratory, central sterile, and pharmacy are located close to the critical care space. Inpatient nursing, including intensive care nursing, is also within the complex. The facility also incorporates a kitchen, dining and food service, morgue, and central housekeeping support.

Outpatient surgery is performed with the anticipation that the patient will not stay overnight. An outpatient facility may be part of an acute care facility, a freestanding unit, or part of another medical facility such as a medical office building.

Nursing facilities are addressed separately, because their fundamental requirements differ greatly from those of other medical facilities in regards to odor control and the average stay of patients.

Dental facilities are briefly discussed. Requirements for these facilities differ from those of other health care facilities because many procedures generate aerosols, dusts, and particulates.

1. REGULATION AND RESOURCES

The specific environmental conditions required by a particular medical facility may vary from those in this chapter, depending on the agency responsible for the environmental standard. ANSI/ASHRAE/ASHE *Standard 170* represents the minimum design standard for these facilities, and gives specific minimum requirements for space design temperatures and humidities as well as ventilation recommendations for comfort, asepsis, and odor control in spaces that directly affect patient care.

Standard 170 is in continuous maintenance by ASHRAE, with proposed addenda available for public review/comment and published addenda available for free download from www.ashrae.org. It is republished in whole approximately every four years with all published addenda incorporated. See Table 1 for an excerpt of requirements found in *ASHRAE Standard 170*.

Standard 170 is also included in its entirety in the Facility Guidelines Institute's *Guidelines for Design and Construction of Hospitals and Outpatient Facilities* and *Guidelines for Design and Construction of Residential Health, Care, and Support Facilities* (FGI 2014a, 2014b). The FGI Guidelines are adopted in more than 42 U.S. states by AHJs overseeing the planning, construction, and operation of health care facilities in those states.

Many outpatient facilities are B-occupancy, and may require compliance to ASHRAE/ANSI *Standard 90.1* or other energy regulations, which may also cover ventilation. *ASHRAE Guidelines 10*

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Table 1 Sample of ASHRAE *Standard 170* Design Parameters

Function of Space	Pressure Relationship to Adjacent Areas	Minimum Outdoor ach*	Minimum Total ach*	All Room Air Exhausted Directly to Outdoors	Air Recirculated by Room Units	Design Relative Humidity, %	Design Temp. °F
Operating room	Positive	4	20	NR*	No	20 to 60	68 to 75
Emergency department public waiting area	Negative	2	12	Yes	NR*	max. 65	70 to 75
All rooms	Negative	2	12	Yes	No	max. 60	70 to 75
Patient room	NR*	2	4	NR*	NR*	max. 60	70 to 75

*ach = air changes per hour, NR = no requirement.

and 29 may be especially applicable to the design of health care facilities. The *HVAC Design Manual for Hospitals and Clinics* (ASHRAE 2013) presents enhanced design practice approaches to health care facility design and greatly supplements the information in this chapter. The ASHRAE Learning Institute (ALI) provides many applicable courses, including *Designing High Performing Health Care HVAC Systems* and *Health Care Facilities: Best Practice Design and Applications*.

ASHRAE *Standard 188-2015* requires health care buildings to establish a water management program to control growth of *Legionella*. The program must include a systematic analysis of building water systems, including the locations of end-point uses of potable and nonpotable water systems; the location of water processing equipment and components, and how water is received and processed, including how it is conditioned, stored, heated, cooled, recirculated, and delivered to end-point uses. A process flow diagram is required to graphically describe the step-by-step detail of where building water systems are at risk of harboring or promoting *Legionella* growth and dissemination. Those areas so identified must have control measures and limits established to allow monitoring of conditions and corrective actions to ensure the system is operating as designed.

NFPA *Standard 99*, which has been adopted by many jurisdictions, provides requirements for ventilation of medical gas storage and transfilling spaces. It also has requirements for heating, cooling, and ventilating the emergency power system room.

American Society for Healthcare Engineering's (ASHE) monographs and interpretation tools are an important resource to help integrate facility management considerations into the built environment. The American Conference of Governmental Industrial Hygienists' (ACGIH 2013) *Industrial Ventilation: A Manual of Recommended Practice for Design* includes guidance on source control of contaminants.

Agencies that may have standards and guidelines applicable to medical facilities include state and local health agencies, the U.S. Department of Health and Human Services (including the Centers for Disease Control and Prevention [CDC], Indian Health Service, Food and Drug Administration [FDA], U.S. Public Health Service, and Medicare/Medicaid), U.S. Department of Defense, U.S. Department of Veterans Affairs, and The Joint Commission's Hospital Accreditation Program.

Other medically concerned organizations with design and/or operational standards and guidelines that may be applicable to health care facility design include the United States Pharmacopeia (USP), American Association of Operating Room Nurses (AAORN), and Association for the Advancement of Medical Instrumentation (AAMI).

FGI (2014a, 2014b) requires the owner to provide an infection control risk assessment (ICRA) and prepare infection control risk mitigation recommendations (ICRMR) that are intended to pre-identify and control infection risks arising from facility construction activities. The ICRMR and ICRA are then to be incorporated in the contract documents by the design professional. Therefore, it is essential to discuss infection control objectives with the hospital's infection control committee.

International standards for health care ventilation sometimes contain suggestions that differ significantly from those in this chapter. International standards include the following:

- Canada's CSA Group's *Standard Z317.2*
- Australasian Health Facility Guidelines (AusHFG), available at www.healthfacilityguidelines.com.au
- U.K. Department of Health and Social Care's *Healthcare Technical Memorandum 03-01 premises*
- German Institute for Standardization's (DIN) *Standard 1946-4 Ventilation and air conditioning—Part 4*
- Spain's AENOR/UNE *Standard 100713:2005*
- Department of Health—Abu Dhabi (HAAD) *Health Facility Guidelines*, available at www.healthdesign.com.au/haad.hfg/
- World Health Organization's (WHO) *Natural Ventilation for Infection Control in Health-Care Settings*

ASHRAE international associate societies (e.g., India's ISHRAE) may have health care resources specific to the local culture and climate; see www.ashrae.org/members.html for a list of associate organizations.

Along with HVAC requirements for normal operation, many health care facilities are considered essential facilities and have programmatic requirements to remain operational after earthquakes or other naturally occurring events. Building code importance factor designation and application can require structural and restraint features not normally included in other types of facilities. Many health care facilities have on-site diesel engine generated electric power, which can necessitate EPA fuel storage permitting, security requirements, and potentially air permitting issues.

1.1 AIR CONDITIONING IN DISEASE PREVENTION AND TREATMENT

In hospitals, air conditioning can play a role beyond the promotion of comfort. In many cases, proper air conditioning is a factor in patient therapy. Patients in well-controlled environments generally show more rapid physical improvement than those in poorly controlled environments. Examples of HVAC considerations for various patients include the following:

- Patients exhibiting thyrotoxicosis (related to hyperthyroidism) may be more sensitive to hot, humid conditions or heat waves (Pearce 2006).
- Extreme ambient heat is a public health threat, especially for the elderly and persons with preexisting health conditions (Richard et al. 2011).
- Cardiac patients are often unable to maintain the circulation necessary to ensure normal heat loss. Air conditioning cardiac wards and rooms of cardiac patients, particularly those with congestive heart failure, is necessary and considered therapeutic (Burch and Pasquale 1962).
- Individuals subjected to operations and those with barbiturate poisoning may be susceptible to hypothermia (Belani et al. 2013). HVAC systems may reduce this risk.

- Symptoms of rheumatoid arthritis are correlated to humidity of the environment (Patberg and Rasker 2004). Some have suggested the benefit of dry environments (less than 35% rh).
- Dry air increases the difficulty in terminally cleaning spaces and causes particles to remain airborne for longer periods of time. Pathogen transmission through the air is greater when the air is dry, and infectious particles travel deeper into the lungs when they are small. Cilia in the respiratory system, which are responsible for clearing particulates out of the bronchial tubes, have reduced function in dry conditions. Dry air also leads to cracks in the skin and increased cortisol production.
- Clinical areas devoted to upper respiratory disease treatment and acute care are often maintained at a minimum of 30% rh. The foundation and associated clinical benefit of this practice have recently come under question, so the designer is encouraged to closely consult the latest design guidance and the facility owner when establishing this design criterion.
- Exposure to dry environments may have a negative impact. Taylor (2016) found an increase in the number of healthcare associated infections in patients in a medical-surgery wing and in an oncology wing when the relative humidity dropped below 40% rh.
- Patients with chronic pulmonary disease often have viscous respiratory tract secretions. As these secretions accumulate and increase in viscosity, the patient's exchange of heat and water dwindles. Under these circumstances, inspiration of warm, humidified air is essential to prevent dehydration (Walker and Wells 1961).
- Patients needing oxygen therapy, those with tracheotomies, and other mechanically ventilated patients require warm, humidified air (Jackson 1996). Cold, dry oxygen or bypassing the nasopharyngeal mucosa presents an extreme situation. Rebreathing techniques for anesthesia and enclosure in an incubator are special means of addressing impaired heat loss in therapeutic environments.
- Warm, moist air has been shown to be beneficial in treatment of burn patients (Liljedahl et al. 1979; Zhou et al. 1998). A ward for severe burn victims should have temperature controls (and compatible architectural design and construction) that allow room temperatures up to 90°F db and relative humidity up to 95%.

Reducing **hospital-acquired infections (HAIs; also called nosocomial infections)** is a focus of the health care industry. It is difficult to draw any general conclusions about HVAC's contributions or ability to affect infections (DeRoos et al. 1978; Jacob et al. 2013). True airborne infection is somewhat rare (5 to 15%), compared to the direct route of infection (Short and Al-Maiyah 2009), although there is evidence that too little ventilation increases risk of infection (Atkinson 2009). The exact ventilation rates needed to control infectious agents in hospitals are not known (Li et al. 2007; Memarzadeh 2013). It was previously believed that 100% exhaust or 100% outdoor air was necessary. ASHRAE research project RP-312 found that recirculation of most hospital air is appropriate (Chaddock 1983).

HVAC engineering controls, such as required differential pressure relationships between spaces, directional airflow, methods of air delivery, air filtration, overall building pressurization, etc., directly contribute to maintaining asepsis. Well-designed HVAC systems also affect indoor environmental quality and asepsis integrity through specifically HVAC related factors (e.g., thermal comfort, acoustics, odor control). Therefore, HVAC system effectiveness can also lead to an improved healing environment for the patient, contributing to shorter patient stays and thereby minimizing the risk of HAIs. ASHE (2011) provides an engineering perspective on the topic with many additional references.

1.2 SUSTAINABILITY

Health care is an energy intensive, energy-dependent enterprise. Hospital facilities are different from other structures in that they

operate 24 hours a day and year round, require sophisticated back up systems in case of utility shutdowns, use large quantities of outdoor air to combat odors and to dilute microorganisms, and must deal with problems of infection and solid waste disposal. Similarly, large quantities of energy are required to power diagnostic, therapeutic, and monitoring equipment, and to support services such as food storage, preparation, and service and laundry facilities. Control strategies such as supply air temperature reset on variable-air-volume systems and hydronic reheat supply water temperature reset on variable pumping systems can often be applied with good results, but should be applied with care: undesired impacts on temperature and (especially) humidity can result. Resources to help ensure efficient, economical energy management and reduce energy consumption in hospital facilities include ASHRAE *Standard* 90.1 and the *Advanced Energy Design Guides* on hospitals (ASHRAE 2009, 2012). ASHRAE *Standard* 189.3 provides guidance for design, construction, and operation of high-performance, green health care facilities.

Hospitals can conserve energy in various ways, such as using individual zoning control with advanced control strategies and energy conversion devices that transfer energy from building exhaust air to incoming outdoor air. The critical nature of the health care environment requires design and operational precautions to minimize the chances of heat exchangers becoming a source of contaminants in the supply air stream. Use of heat pipes, runaround loops, enthalpy wheels, and other forms of heat recovery is increasing; ASHRAE *Standard* 170 addresses their use. Large health care campuses use central plant systems, which may include thermal storage, hydronic economizers, primary/secondary pumping, cogeneration, heat recovery boilers, and heat recovery incinerators. Integrating building waste heat into systems and using renewable energy sources (e.g., solar under some climatic conditions) provide substantial savings (Setty 1976).

Selecting building and system components for cost effective energy measures requires careful planning and design. Life-cycle cost analysis can show the full effect of design decisions, considering fuel and labor costs, maintenance costs, desired performance (comfort and air quality), replacement costs, cost of downtime, and the value of investment dollars over time.

2. HOSPITAL FACILITIES

Although proper air conditioning is helpful in preventing and treating disease, application of air conditioning to health care facilities presents many problems not encountered in usual comfort conditioning design.

The basic differences between air conditioning for hospitals (and related health care facilities) and that for other building types stem from the (1) need to restrict air movement in and between departments; (2) specific requirements for ventilation and filtration to dilute and remove contamination (odor, airborne microorganisms and viruses, hazardous chemicals, and radioactive substances); (3) different temperature and humidity requirements for various areas; and (4) design sophistication needed for accurate control of environmental conditions.

2.1 AIR QUALITY

Systems should provide air virtually free of dust, dirt, odor, and chemical and radioactive pollutants. In some cases, untreated outdoor air is hazardous to patients suffering from cardiopulmonary, respiratory, or pulmonary conditions. In such instances, consider treatment of outdoor air as discussed in ASHRAE *Standard* 62.1.

Infection Sources

Bacterial Infection. *Mycobacterium tuberculosis* and *Legionella pneumophila* (Legionnaires' disease) are examples of bacteria that are highly infectious and transported in air (or air and water

mixtures). Wells (1934) showed that droplets or infectious agents of 5 μm or less in size can remain airborne indefinitely.

Viral Infection. Examples of viruses that are transported by, and virulent within, air are *Varicella* (chicken pox/shingles), *Rubella* (German measles), and *Rubeola* (regular measles). Research indicates that many airborne viruses that transmit infection are originally submicron in size, though in air they are often attached to larger aerosol and/or as conglomerates of multiple viruses, which may be more easily filtered from the airstream.

Molds. Evidence indicates that some molds such as *Aspergillus* can be fatal to advanced leukemia, bone marrow transplant, and other immunocompromised patients.

Chemicals. Hospitals use various chemicals as disinfectants, which may require control measures for worker or patient safety. Many pharmaceuticals are powerful chemical agents.

Control Measures

Outdoor Air Ventilation. If outdoor air intakes are properly located and areas adjacent to the intakes are properly maintained, outdoor air is virtually free of infectious bacteria and viruses compared to room air. Infection control problems frequently involve a bacterial or viral source within the hospital. Ventilation air dilutes indoor viral and bacterial contamination. If ventilation systems are properly designed, constructed, and maintained to preserve correct pressure relations between functional areas, they control the between-area spread of airborne infectious agents and enable proper containment and removal of pathogens from the hospital environment.

Filtration. Some authorities recommend using high-efficiency particulate air (HEPA) filters with test filtering efficiencies of 99.97% in certain areas. Although there is no known method to effectively eliminate 100% of the viable particles, HEPA and/or ultralow-penetration (ULPA) filters provide the greatest air-cleaning efficiency currently available.

Pressure Differential. Directional airflow created by differential pressures, which result from controlling the HVAC system in a particular manner, is a common control measure to help prevent dispersal of contaminants between adjoining spaces.

Anterooms. Isolation rooms and isolation anterooms with appropriate ventilation/pressure relationships are a primary means used to prevent the spread of airborne contaminants from space to space in the health care environment. The addition of the anteroom allows for the dilution and control of air that passes from one space to another every time a door is opened and closed.

Contaminant Source Control. Certain aerosol-generating activities may also benefit from local control techniques to minimize virus dissemination and other contaminants. Exhausted enclosures (e.g., biological safety cabinets, chemical fume hoods, benchtop enclosures) and localized collection methods (e.g., snorkels, direct equipment connections) are typical control measures. Physical locations of supply air diffusers and return/exhaust grilles in a space can be designed to help control contaminant dispersal within the room.

Temperature and Humidity. These conditions can inhibit or promote the growth of bacteria, and activate or deactivate viruses. Some bacteria, such as *Legionella pneumophila*, are basically waterborne and survive more readily in a humid environment. Codes and guidelines specify temperature and humidity range criteria in some hospital areas for infection control as well as comfort. Historical use of flammable anesthetics also influenced the minimum relative humidity requirements of various governing documents. Where flammable anesthetics have been phased out, there is considerable interest in lowering minimum humidity requirements because of the humidification systems' increased energy usage and operational and maintenance challenges. Medical equipment static electricity concerns and transmission and growth of various

potential contaminants in differing humidity environments have also been examined, and led to a relaxation of some minimum relative humidity requirements in ASHRAE *Standard 170*. Specialized patient care areas, including organ transplant and burn units, should have additional ventilation provisions for air quality control as may be appropriate.

Ultraviolet Light, Ionization and Chemicals. ASHRAE guidance on the use of ultraviolet energy as an adjunct infection control measure may be found in Chapter 60 of the 2015 *ASHRAE Handbook—HVAC Applications* and Chapter 17 of the 2016 *ASHRAE Handbook—HVAC Systems and Equipment*. Current guidance from the U.S. Centers for Disease Control and Prevention can be found in CDC (2005) and NIOSH (2009). Ionization devices and/or chemical fogging/mists are not recommended in occupied environments and should only be considered for terminal cleaning applications in unoccupied spaces.

Increasing Air Changes. Whether achieved by introducing clean fresh air or filtration, increasing a room's air change rate reduces its airborne burden of microorganisms, thus reducing opportunities for airborne exposures. Table 2 notes the theoretical time to remove particles from a room being flushed with clean, filtered air, assuming perfect mixing/perfect ventilation effectiveness in the space (ASHRAE 2013).

Outdoor Air Intakes. These intakes should be located as far as is practical (on directionally different [i.e., compass directions] exposures whenever possible), but not less than 25 ft, from combustion equipment stack exhaust outlets, ventilation exhaust outlets from the hospital or adjoining buildings, medical/surgical vacuum systems, cooling towers, plumbing vent stacks, smoke control exhaust outlets, and areas that may collect vehicular exhaust and other noxious fumes. Air intakes should be located at least 30 ft from any Class 4 air exhaust discharges as defined in *Standard 62.1-2010*. The bottom of outdoor air intakes serving central systems should be located as high as practical (minimum of 12 ft recommended) but not less than 6 ft above ground level or, if installed above the roof, 3 ft above the roof level.

Exhaust Air Outlets. These exhausts should be located a minimum of 10 ft above ground level and away from doors, occupied areas, and operable windows. Preferred location for exhaust outlets is at roof level projecting upward or horizontally away from outdoor air intakes. Care must be taken in locating highly contaminated exhausts (e.g., from engines, fume hoods, biological safety cabinets, kitchen hoods, paint booths). Prevailing winds, adjacent buildings, and discharge velocities must be taken into account (see Chapter 24 of the 2017 *ASHRAE Handbook—Fundamentals*). In critical or complicated applications, wind tunnel studies or computer modeling may be appropriate. ASHRAE *Standard 170* contains additional minimum requirements for certain exhaust discharges.

Air Filters. The purpose of filters is to remove contaminants from the air. While there is no generally accepted ratio of organic to

Table 2 Effect of Air Change Rates on Particle Removal

Air Changes per Hour, ach	Time Required for Removal Efficiency of 99%, min	Time Required for Removal Efficiency of 99.9%, min
2	138	207
4	69	104
6	46	69
8	35	52
10	28	41
12	23	35
15	18	28
20	14	21
50	6	8

Source: CDC (2003).

inorganic particles, it is generally accepted that the presence of more airborne particles correlates to a greater number of airborne microorganisms that cause surgical site infections (Birgand et al. 2015). As with most HVAC design considerations, the engineer must guide the owner to make the best choice of filters, considering life cycle cost and efficacy for each air handler and space.

As described in 2017 *ASHRAE Handbook—Fundamentals* Chapter 11, air contaminants are generally classified as

- Particles: These may be aerosols or particulate matter. Particles may be organic, inorganic, viable, or non-viable. Particles of interest are often 0.1 to 10 µm.
- Gases: These include gases and vapors considered at the molecular level. Chapters 10 and 12 in the 2017 *ASHRAE Handbook—Fundamentals* discuss techniques to manage odors.

HVAC filters, which may include prefilters, second-stage filters, and final-stage filters, should be tested in accordance with *ASHRAE Standard 52.2*. This standard is written for testing filters under controlled conditions (laboratory environment) and establishes the minimum efficiency reporting value (MERV) of an air filter. Filters are classified as MERV 1 to 16. Tests are based on removal efficiency (%) in three particle size ranges: 0.3 to 1 µm, 1 to 3 µm, and 3 to 10 µm. The higher the MERV rating, the better the overall removal. *ASHRAE Standard 145.2* is written for testing gaseous air contaminant filters under controlled conditions (laboratory environment) and establishes efficiency ratings for contaminants that represent broad classes of organic chemicals and ozone.

Air filters necessitate a comprehensive management program, including installation, monitoring, replacement, and disposal. Typically, the priorities for selecting an air filter are

1. Contaminant removal efficiency (MERV, MERV-A)
2. Initial and operating cost (Total cost of ownership)
3. Structural integrity

Some filters exhibit different behavior under field conditions. *ISO Standard 29462* describes testing of HVAC filters for removal efficiency in field conditions. See Chapter 29 of the 2016 *ASHRAE Handbook—HVAC Systems and Equipment*. All central ventilation or air-conditioning systems should be equipped with filters having efficiencies no lower than those indicated in *ASHRAE Standard 170*. Appropriate precautions should be observed to prevent wetting the filter media by uncontrolled condensation or free moisture from humidifiers. The filter system should be designed and equipped to allow safe removal, disposal, and replacement of contaminated filters.

Guidelines for filter installations are as follows:

- HEPA filters are required by *Standard 170* only for protective-environment rooms. These rooms are used for patients with a high susceptibility to infection due to leukemia, burns, bone marrow transplant, chemotherapy, organ transplant, or human immunodeficiency virus (HIV). HEPA filters should also be considered for discharge air from fume hoods or biological safety cabinets in which infectious, highly toxic, or radioactive materials are processed. Some hospitals choose to use HEPA filters on exhaust originating from airborne infectious isolation rooms and on supply air to very sensitive patients, such as those in orthopedic surgery. Filter seals or gaskets should be installed to prevent leakage between filter segments and between the filter bed and its supporting frame. A small leak that allows any contaminated air to escape through the filter significantly reduces performance. Leakage can occur due to poor gaskets, warping of the rack, or holes in the rack. Ensure that the rack is designed to withstand high lateral pressure. Diagonal supports may be necessary to maintain the integrity of the filter rack. Maintaining the rated filtration efficiency over the entire installed service life of the filter should be

considered, particularly if the initial removal efficiency is based on an electrostatic charge on the filter.

- High-efficiency filters should be installed in the system, with adequate facilities provided for maintenance and in situ performance testing without introducing contamination into the delivery system or the area served. Also keep in mind maintenance workers' safety. High-efficiency filters are expensive. Energy costs associated with the pressure drop can be 70% of the total cost of ownership. Consider filter life, first cost, energy cost, and maintenance (installation, removal, and disposal). Provide a local manometer to measure pressure drop across each filter bank. Be sure the gauge range is appropriate (usually 0 to 2 in. of water). Mark the gage with the manufacture's recommended initial and final pressure drops. In addition, BAS control sequences to monitor and alarm, including ability to normalize or benchmark pressure drops and associated airflows, indicate when replacement is necessary even when air handlers operate at less than full flow. Filter system life-cycle costs can be calculated and various scenarios compared for overall optimization (Eurovent/CECOMAF 2005). Installing a lower-efficiency prefilter upstream of the high-efficiency filter keeps coils cleaner and extend the life of the high-efficiency final filter.
- During construction, openings in ductwork and diffusers should be sealed in accordance with *ASHRAE Standard 170* to prevent intrusion of dust, dirt, and hazardous materials. Such contamination is often permanent and provides a medium for growth of infectious agents. Existing or new filters as well as coils may rapidly become contaminated by construction dust. The final filter should be installed downstream of all the chilled-water coil.

Air Movement

Table 3 illustrates the degree to which contamination can be dispersed into the air by routine patient care activities. The bacterial counts in the hallway clearly indicate the spread of this contamination.

Because of the bacteria dispersal from such necessary activities, air-handling systems should provide air movement patterns that minimize spread of contamination. Undesirable airflow between rooms and floors is often difficult to control because of open doors, movement of staff and patients, temperature differentials, and stack effect, which is accentuated by vertical openings such as chutes, elevator shafts, stairwells, and mechanical shafts. Although some of these factors are beyond practical control, the effect of others may be minimized by terminating shaft openings in enclosed rooms and by designing and balancing air systems to create positive or negative air pressure in certain rooms and areas.

Pressure differential causes air to flow in or out of a room through various leakage areas (e.g., perimeter of doors and windows, utility/fixture penetrations, cracks). A level of differential air pressure (0.01 in. of water) can be efficiently maintained only in a tightly sealed room. Therefore, it is important to obtain a reasonably close

Table 3 Influence of Bedmaking on Airborne Bacterial Count in Hospitals

Item	Count per Cubic Foot	
	Inside Patient Room	Hallway near Patient Room
Background	34	30
During bedmaking	140	64
10 min after	60	40
30 min after	36	27
Background	16	
Normal bedmaking	100	
Vigorous bedmaking	172	

Source: Greene et al. (1960).

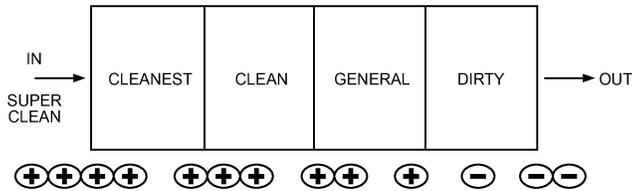


Fig. 1 Controlling Air Movement through Pressurization
(ASHRAE 2013)

fit of all doors and seal all walls and floors, including penetrations between pressurized areas. Opening a door between two areas immediately reduces any existing pressure differential between them, effectively nullifying the pressure difference. When such openings occur, a natural interchange of air takes place between the two rooms because of turbulence created by the door opening and closing and personnel ingress/egress. For critical areas requiring both maintenance of pressure differentials to adjacent spaces and personnel movement between the critical and adjacent areas, consider using anterooms. The purpose of differential pressurization is to inhibit movement of potentially infectious particles from dirty areas to clean ones. Figure 1 illustrates controlling airflow through pressurization. More air is supplied to the cleanest areas, with less air supplied to less clean areas, and air is exhausted from dirty areas.

In general, outlets supplying air to sensitive ultraclean areas should be located on the ceiling, and several perimeter exhaust outlets should be near the floor. This arrangement provides downward movement of clean air through the breathing and working zones to the floor area for exhaust.

Airborne infectious isolation (AII) rooms should locate the exhaust outlets over the patient bed or on the wall behind the bed. Supply air may be located above and near the doorway and/or near the exterior window with ceiling-mounted supply outlets. This arrangement controls the flow of clean air first to parts of the room where workers or visitors are likely to be, and then across the infected source into the exhaust. Because of the relatively low air exchange rates and minimal influence of the exhaust outlet, this arrangement's ability to achieve directional airflow is limited. The supply diffusers must be carefully selected and located such that primary air throw does not induce bedroom air to enter the corridor or anteroom (if provided) or overly disturb the function of the exhaust to remove contaminants (Memarzadeh and Xu 2011).

The laminar airflow concepts developed for industrial cleanroom and pharmaceutical use have applications in **surgical suites**. There are advocates of both vertical and horizontal laminar airflow systems, with and without fixed or movable walls around the surgical team (Pfof 1981), as well as air curtain concepts. Vertical laminar airflow in surgical operating rooms is predominantly unidirectional where not obstructed by extensive quantities of ceiling-mounted swing-arm booms.

Ventilation system design must, as much as possible, provide air movement from clean to less clean areas. In critical-care areas, use constant-volume systems to ensure proper pressure relationships and ventilation. In noncritical patient care areas and staff rooms, variable-air-volume (VAV) systems may be considered for energy conservation; if VAV is used, take special care to ensure that minimum ventilation rates as required by codes are maintained, and that pressure relationships between various spaces are maintained. With VAV systems, a method such as air volume tracking between supply, return, and exhaust could be used to control pressure relationships (Lewis 1988).

Smoke Control

As the ventilation design is developed, a proper smoke control strategy must be considered. Both passive and active smoke control

systems are in use. Passive systems rely on fan shutdown, smoke and fire barriers, and proper treatment of duct penetrations. Active smoke control systems use the ventilation system to create areas of positive and negative pressures that, along with fire and smoke partitions, limit the spread of smoke. The ventilation system may be used in a smoke removal mode in which combustion products are exhausted by mechanical means. NFPA *Standard 99* has specific guidance on smoke control and other safety provisions, which have changed in each edition. The engineer and code authority should carefully plan system operation and configuration with regards to smoke control. Refer to Chapter 53 and NFPA *Standards 90A, 92A, and 101* as enforced by the AHJ.

2.2 FACILITY DESIGN AND OPERATION

Zoning

Zoning (using separate air systems for different departments) may be indicated to (1) compensate for exposures caused by orientation or for other conditions imposed by a particular building configuration, (2) minimize recirculation between departments, (3) provide flexibility of operation, (4) simplify provisions for operation on emergency power, and (5) conserve energy.

Ducting the air supply from several air-handling units into a manifold gives central systems some standby capacity. When one unit is shut down, air is diverted from noncritical or intermittently operated areas to accommodate critical areas, which must operate continuously. This, or another means of standby protection, is essential if the air supply is not to be interrupted by routine maintenance or component failure.

Separating supply, return, and exhaust systems by department is often desirable, particularly for surgical, obstetrical, pathological, and laboratory departments. The desired relative balance in critical areas should be maintained by interlocking supply and exhaust fans. Thus, exhaust should cease when supply airflow is stopped in areas otherwise maintained at positive or neutral pressure relative to adjacent spaces. Likewise, supply air should be deactivated when exhaust airflow is stopped in spaces maintained at a negative pressure.

Heating and Hot Water Standby Service

When one boiler breaks down or is temporarily taken out of service for routine maintenance, the remaining boilers should still be able to provide hot water for clinical, dietary, and patient use; steam for sterilization and dietary purposes; and heating for operating, delivery, birthing, labor, recovery, intensive care, nursery, and general inpatient rooms. Some codes or authorities do not require reserve capacity in climates where a design dry-bulb temperature of 25°F is equaled or exceeded for 99.6% of the total hours in any one heating period, as noted in the tables in Chapter 14 of the 2017 *ASHRAE Handbook—Fundamentals*.

Boiler feed, heat circulation, condensate return, and fuel oil pumps should be connected and installed to provide both normal and standby service. Supply and return mains and risers for cooling, heating, and process steam systems should be valved to isolate the various sections. Each piece of equipment should be valved at the supply and return ends.

Some supply and exhaust systems for delivery and operating room suites should be designed to be independent of other fan systems and to operate from the hospital emergency power system in the event of power failure. Operating and delivery room suites should be ventilated such that the hospital retains some surgical and delivery capability in cases of ventilating system failure.

Boiler steam is often treated with chemicals that may be released into the air-handling systems serving critical areas where patients may be more susceptible to respiratory irritation and its complications. In this case, a clean steam system could be considered for

humidification. ASHRAE *Standard 170* provides minimum requirements for steam treatment additives where direct injection steam is used.

Mechanical Cooling

Carefully consider the source of mechanical cooling for clinical and patient areas. The preferred method is to use an indirect refrigerating system using chilled water. When using direct refrigerating systems, consult codes for specific limitations and prohibitions, and refer to ASHRAE *Standard 15*. Until recently, it has been difficult to maintain desired temperatures and humidity with direct expansion (DX) systems. Newer technology has provided additional means of maintaining temperature and humidity in spaces. Use care when selecting DX equipment.

Insulation

Linings in air ducts and equipment must meet the erosion test method described in Underwriters Laboratories *Standard 181*. These linings (including coatings, adhesives, and insulation on exterior surfaces of pipes and ducts in building spaces used as air supply plenums) should have a flame spread rating of 25 or less and a smoke developed rating of 50 or less, as determined by an independent testing laboratory, per ASTM *Standard E84*.

ASHRAE *Standard 170* does not allow duct lining to be used downstream of the second filter bank (final filter). Duct lining with an impervious cover may be allowed in terminal units, sound attenuators, and air distribution devices downstream of the second filter bank. This lining and cover will be factory installed. Internal insulation of terminal units may be encapsulated with approved materials, but metal lining is preferable. Duct lining should be avoided except where necessary for acoustical improvement; for thermal purposes, external insulation should be used. The use of acoustical materials as duct interior linings, exposed to air movement, should be carefully reviewed for the application and regulatory standards in effect. Duct-mounted sound traps, where necessary, should be of the packless type or have polymer film linings over acoustical fill.

Testing, Adjusting, and Balancing (TAB) and Commissioning

For existing systems, testing before beginning remodeling construction (preferably before design completion) is usually a good investment. This early effort provides the designer with information on actual system performance and whether components are suitable for intended modifications, as well as discloses additional necessary modifications.

The importance of TAB for modified and new systems before patient occupancy cannot be overemphasized. Health care facilities require validation and documentation of system performance characteristics. Often, combining TAB with commissioning satisfies this requirement. See Chapters 39 and 44 for information on TAB and commissioning.

Operations and Maintenance

Without routine inspection and maintenance of HVAC system components, systems might operate outside of their optimum performance parameters. This variance can affect delivered system performance. Often, manufacturers' maintenance information applies only to their components, not the entire system. ASHRAE *Standard 180* addresses the often inconsistent practices for inspecting and maintaining HVAC systems in health care buildings where the public may be exposed to the indoor environment. The standard establishes minimum HVAC inspection and maintenance requirements to preserve a system's ability to achieve acceptable thermal comfort, energy efficiency, and indoor air quality.

The American Society for Healthcare Engineering (ASHE) (of the American Hospital Association [AHA]) and the International

Facility Management Association (IFMA) jointly published *O&M Benchmarks for Health Care Facilities* (ASHE/IFMA 2000). Health care facility management professionals at 150 different health care facilities, representing a broad cross section of the field, were surveyed for the report, which discusses facility age and location, utility costs and practices, maintenance costs and staffing, environmental services, waste streams, linen services, and operational costs. In addition to common facility benchmarks (e.g., cost per area, cost per worker), the report's analysis also includes metrics that hospital leaders recognize, such as adjusted patient days and adjusted discharges.

ASHRAE *Standard 170* provides recommended operations and maintenance procedures for certain health care specific rooms in its Informative Appendix A. Chapter 40 of this volume also discussed operation and maintenance.

A common cause of operational problems is the control system. Often, sensors are out of calibration. Maintenance and/or controls personnel often alter set points and sequences to provide short-term fixes. Training and persistent commissioning are necessary to keep the systems operating correctly.

Planning. *Standard 170* requires that an operational facility plan be established to ensure that the number and arrangements of system components can best support the owner's operational goals. The plan should take into account the age and reliability of the HVAC equipment, capabilities of different areas of the facility and their criticality to the facility mission, and available personnel resources. This plan typically examines loss of normal power scenarios, loss of certain pieces of HVAC equipment, back-up fuel sources, redundant systems, temporary measures, and abnormal events. In the event of power loss, inpatient areas should allow for potential 24 h operation and nonambulatory patients who may not be able to be relocated. The capital outlay for imaging and treatment equipment and their associated operating personnel can be balanced against additional potential outlays for redundant cooling or other features as adjusted for the risk of failure.

2.3 SPECIFIC DESIGN CRITERIA

There are seven principal divisions of an acute care general hospital: (1) surgery and critical care, (2) nursing, (3) ancillary, (4) administration, (5) diagnostic and treatment, (6) sterilizing and supply, and (7) service. Environmental requirements of each department/space in these divisions differ according to their function and procedures carried out in them. This section describes the functions of these departments/spaces. ASHRAE *Standard 170* provides details of HVAC design requirements for spaces in the hospital that directly affect patient care. If additional regulatory or organizational criteria must be met, refer to those criteria for specific space requirements. Close coordination with health care planners and medical equipment specialists in mechanical design and construction of health facilities is essential to achieve the desired conditions.

Surgery and Critical Care

No area of the hospital requires more careful control of aseptic environmental conditions than the surgical suite. Systems serving operating rooms, including cystoscopy and fracture rooms, require careful design to minimize concentrations of airborne organisms.

The greatest amount of bacteria found in the operating room comes from the surgical team and is a result of their activities during surgery. During an operation, most members of the surgical team are near the operating table, creating the undesirable situation of concentrating contamination in this highly sensitive area.

Operating Rooms. Past studies of operating room air distribution devices (e.g., Memarzadeh and Manning [2002]) and observation of installations in industrial cleanrooms indicate that delivering air from the ceiling, with a downward movement to several exhaust/return openings located low on opposite walls, is the

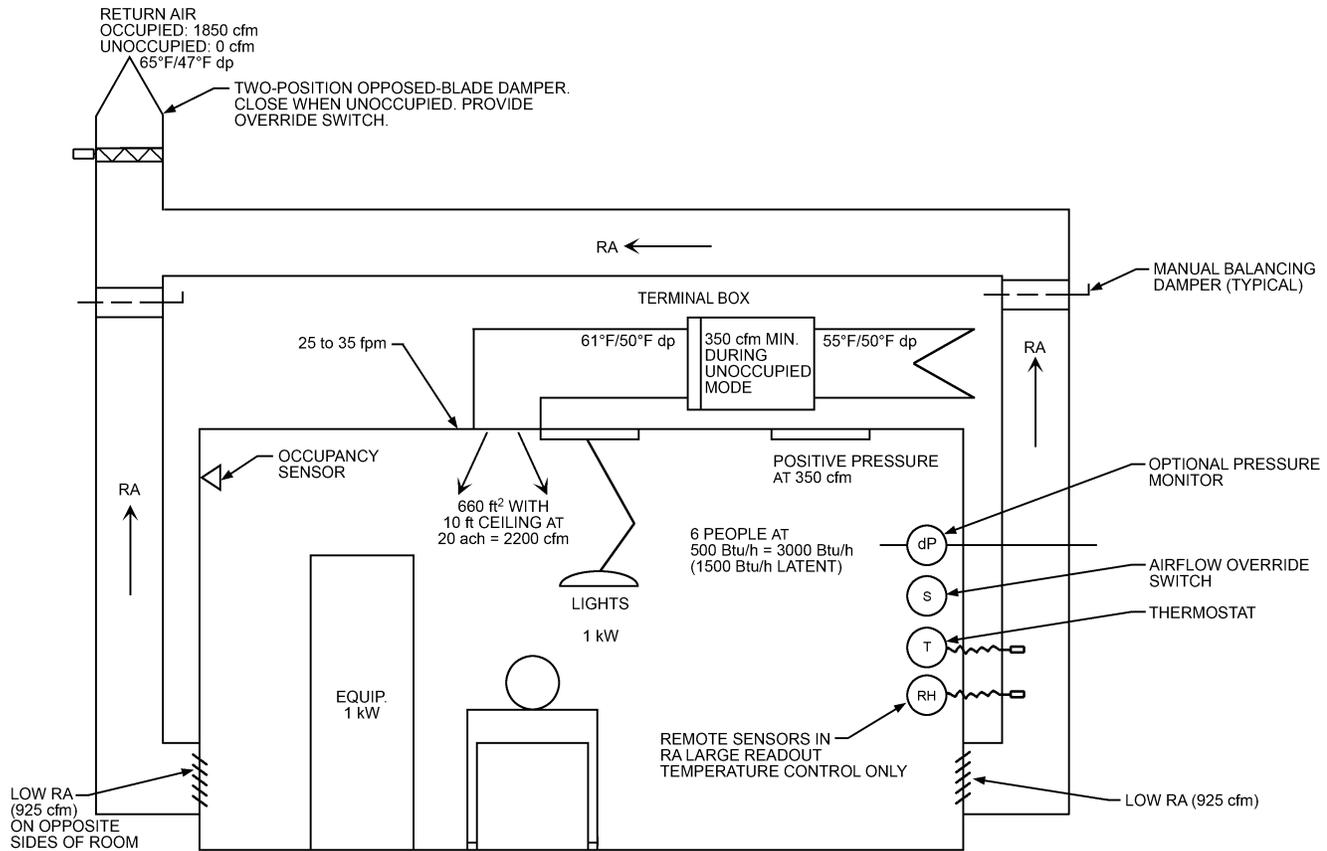


Fig. 2 Operating Room Layout
(ASHRAE 2013)

most effective (and current code requirement for) air movement pattern to minimize contamination of the surgical field. Completely perforated ceilings, partially perforated ceilings, and ceiling-mounted diffusers have been applied successfully (Pfof 1981). Memarzadeh and Manning (2002) found that a mixture of low and high exhaust opening locations may work slightly better than either all-low or all-high locations, with supply air furnished at average velocities of 25 to 35 fpm from a unidirectional laminar-flow ceiling array. It appears that the main factor in the design of the ventilation system is the control of the central region of the operating room (surgical or sterile field). The laminar flow concept generally represents the best option for an operating room in terms of contamination control, as it results in the smallest percentage of particles impacting the surgical site. Figure 6 shows a typical operating room layout.

Operating room setback (night setback or unoccupied setback) is a proven energy saving strategy in all climates. Love (2011) details these strategies. Operating room suites are typically used no more than 8 to 12 h per day (except trauma centers and emergency departments). Temperature is typically allowed to drift during setback. Lowering the set point during unoccupied times reduces reheat energy; however, positive space pressure must be maintained. Design of the setback solution should consider local climate, facility type, user needs, existing conditions (where applicable), relevant code requirements, and cost. There are several approaches to setback. Each has trade-offs between the level of control, complexity, and cost. Common approaches include

- Two-position supply with shutoff dampers in return/exhaust
- Pressure-independent valves on supply and return

- Modulating control damper or terminal box on return

If a return terminal box is used, consider adding a filter upstream of the terminal box to protect the airflow sensor.

A separate anesthesia waste gas disposal vacuum system should be provided for removal of trace gases (NFPA *Standard 99*). One or more outlets may be located in each operating room to connect the anesthetic machine scavenger hose.

Although good results have been reported from air disinfection of operating rooms by irradiation, this method is seldom used. The reluctance to use irradiation may be attributed to the need for special designs for installation, protective measures for patients and personnel, constant monitoring of lamp efficiency, and maintenance. Ultraviolet germicidal irradiation (UVGI) air and surface treatments have emerging applications in health care facilities; see Chapter 60 for general information on their application.

The following conditions are recommended for operating, catheterization, and cystoscopy rooms:

- Temperature set points should be adjustable to suit the surgical staff, and relative humidity should be maintained within the required range. Systems should be able to maintain the programmed space temperature and temperature rates of change for specialized procedures such as cardiac surgery. Tolerable temperature ranges are not intended to be dynamic control ranges. Special or supplemental cooling equipment should be considered if this lower temperature negatively affects energy use for surrounding areas.
- Air pressure should be kept positive with respect to any adjoining rooms. A differential-pressure-indicating device should be installed to help monitor air pressure readings in the rooms.

Thorough sealing of all wall, ceiling, and floor penetrations are essential to maintaining pressure differential.

- Humidity and temperature indicators should be located for easy observation. Occupant control of temperature may result in an unintended change in relative humidity.
- Filter efficiencies should be in accordance with ASHRAE *Standard* 170 and the user's requirements. Supply air HEPA filtration has been applied for some orthopedic surgical suites where long procedures with large open wound sites and significant generation of aerosols caused by use of surgical tools may occur. HEPA filtration has also been applied for high-air-change-rate recirculation systems where required by the surgical team.
- Air should be supplied at the ceiling with exhaust/return from at least two locations near the floor spaced approximately half of the room apart. Endoscopic, laparoscopic, or thoracoscopic surgery procedures aided by camera, and robotic or robot-assisted surgery procedures, require heat-producing equipment in the operating room. Exhaust/return openings located above this equipment can capture the more buoyant heated air and prevent it from being re-entrained in the ceiling supply airstream. The bottom of low openings should be at least 3 in. above the floor. Supply diffusers should be unidirectional (laminar-flow), located over the patient and the surgical team. High-induction ceiling or sidewall diffusers should be avoided.
- Total air exchange rates should address lights and equipment (e.g., blanket and blood warmers, fiber-optic equipment, robotic consoles) as well as the peak occupancy of the space and the potentially lower temperature required.
- Generally, all humidification should be done at the air handler. Where there is an unusual requirement for different humidity levels in different ORs, then sufficient lengths of straight, watertight, drained stainless steel or aluminum duct should be installed downstream of humidification equipment to ensure complete evaporation of water vapor before air is discharged into the room. Consider also providing a viewing window in the ductwork to allow easy verification of system performance.

Obstetrical Areas. The pressure in the obstetrical department should be positive or equal to that in other areas.

Delivery (Caesarean) Rooms. The delivery room design should conform to the requirements of operating rooms.

Recovery Rooms. Because the smell of residual anesthesia sometimes creates odor problems in recovery rooms, ventilation is important, and a balanced air pressure relative to that of adjoining areas should be provided.

Intensive Care Units. These units serve seriously ill patients, such as postoperative and coronary patients. HVAC is similar to general inpatient rooms unless used for wound (burn) intensive care.

Nursery Suites. Air movement patterns in nurseries should be carefully designed to reduce the possibility of drafts. Some codes or jurisdictions require that air be removed near floor level, with the bottoms of exhaust openings at least 3 in. above the floor; the relative efficacy of this exhaust arrangement has been questioned by some experts, because exhaust air outlets have a minimal effect on room air movement at the relatively low air exchange rates involved. Finned-tube radiation and other forms of convection heating should not be used in nurseries.

Full-Term Nurseries. The nursery should have a positive air pressure relative to the work space and examination room, and any rooms located between the nurseries and the corridor should be similarly pressurized relative to the corridor.

Special-Care Nurseries. This type of nursery is usually equipped with individual incubators to regulate temperature and humidity. It is desirable to maintain these same conditions in the nursery proper to accommodate both infants removed from the incubators and

those not placed in incubators. Pressurization of special-care nurseries should correspond to that of full-term nurseries.

Observation Nurseries. Temperature and humidity requirements for observation nurseries are similar to those for full-term nurseries. Because infants in these nurseries have unusual clinical symptoms, air from this area should not enter other nurseries. A negative air pressure relative to that of the workroom should be maintained in the nursery. The workroom, usually located between the nursery and the corridor, should be pressurized relative to the corridor.

Emergency Rooms. Emergency rooms are typically the most highly contaminated areas in the hospital because of the condition of many arriving patients and the large number of persons accompanying them. Waiting rooms and triage areas require special consideration due to the potential to house undiagnosed patients with communicable airborne infectious diseases. Clean-to-dirty directional airflow and zone pressurization techniques should be maintained, to reduce the potential of airborne exposure for health care personnel assigned to the emergency room reception stations.

Trauma Rooms. Emergency trauma rooms located with the emergency department should have the same temperature, humidity, and ventilation requirements as those of other applicable operating rooms.

Anesthesia Storage Rooms. Anesthesia storage rooms must be mechanically ventilated in conformance with several detailed requirements in NFPA *Standard* 99. Building codes may impose additional requirements on the storage of compressed gases.

Nursing

Patient Rooms. Each patient room should have individual temperature control. Air pressure in general patient suites can be neutral in relation to other areas. Most governmental design criteria and codes require that all air from toilet rooms be exhausted directly outdoors. The requirement appears to be based on odor control, though recent research has documented the ability of toilets to generate droplets and aerosols (Johnson et al. 2013). Where recirculating room unit systems are used within patient rooms, it is common practice to exhaust through the adjoining toilet room an amount of air equal to the amount of outdoor air brought in for ventilation. Ventilation of toilets, bedpan closets, bathrooms, and all interior rooms should conform to applicable codes.

HVAC energy consumption by patient rooms can be a major contributor to a hospital's overall HVAC energy usage because they are constantly occupied. This high occupancy rate, along with the space's minimum air change requirements, should be a focus of methods to minimize energy use. Design requirements for minimum air changes may result in excessive reheating of supply air from central air-handling units in certain climate zones and building exposures.

Protective Environment Isolation Units. Immunosuppressed patients (including bone marrow or organ transplant, leukemia, burn, and AIDS patients) are highly susceptible to diseases. Some physicians prefer an isolated laminar airflow unit to protect the patient; others feel that the conditions of the laminar cell have a psychologically harmful effect on the patient and prefer flushing out the room and reducing pathogens in the air. An air distribution of 12 air changes per hour (ach) supplied through a nonspiraling diffuser is often recommended. With this arrangement, the clean air is drawn across the patient and removed at or near the door to the room. Protective environment rooms are sometimes treated as clean spaces with design considerations such as an anteroom, supply air HEPA filtration, and particle count testing evaluated during design.

In cases where the patient is immunosuppressed but not contagious, positive pressure must be maintained between the patient room and adjacent area. Some jurisdictions may require an anteroom, maintenance of differential pressure, and local pressure monitoring or alarming. Exam and treatment rooms for these patients

should be controlled in the same manner. Positive pressure should also be maintained between the entire unit and adjacent areas to preserve clean conditions.

Exceptions to normally established negative and positive pressure conditions include operating rooms where highly infectious patients may be treated (e.g., operating rooms in which bronchoscopy or lung surgery is performed) and infectious isolation rooms that house immunosuppressed patients with airborne infectious diseases such as tuberculosis (TB). When a patient is both immunosuppressed and potentially contagious, **combination airborne infectious isolation/protective environment (combination AII/PE)** rooms are provided. These rooms require an anteroom, which must be either positive or negative to both the AII/PE room and the corridor or common space. Either of these anteroom pressurization techniques minimizes cross contamination between the patient area and surrounding areas, and may be used depending on local fire smoke management regulations. Pressure controls in the adjacent area or anteroom must maintain the correct pressure relationship relative to the other adjacent room(s) and areas. A separate, dedicated air-handling system to serve the protective isolation unit simplifies pressure control and air quality (Murray et al. 1988). Figure 3 shows a typical protective environment room arrangement. The differential pressure (DP) sensor measures the differential pressure between the patient room and the corridor. If the patient room becomes negative with respect to the corridor, alarm lights are triggered to alert staff of the change in pressurization.

Airborne Infection Isolation Unit. The airborne infection isolation (AII) room protects the rest of the hospital from patients' airborne infectious diseases. Multidrug-resistant strains of tuberculosis have increased the importance of pressurization, air change rates, filtration, and air distribution design in these rooms (Rousseau and Rhodes 1993). Temperatures and humidities should correspond to those specified for patient rooms.

The designer should work closely with health care planners and the code authority to determine the appropriate isolation room design. It may be desirable to provide more complete control, with a separate anteroom used as an air lock to minimize the potential that aerosol from the patients' area reach adjacent areas. Design approaches to airborne infection isolation may also be found in CDC (2005). AII room exhaust may include HEPA filtration where there is a concern over recirculation of the exhaust air into nearby building air intakes or due to concern of the location of where maintenance workers may be working. Figure 4 shows a typical AII room arrangement with an anteroom. The differential pressure (DP) sensor measures the differential pressure between the patient room and

the corridor. If the AII patient room becomes positive with respect to the corridor, alarm lights are triggered to alert staff.

Some facilities have switchable isolation rooms (rooms that can be set to function with either positive or negative pressure). CDC (2005) and FGI (2014a) have, respectively, recommended against and prohibited this approach. The two drawbacks of this approach are that (1) it is difficult to maintain the mechanical dampers and controls required to accurately provide the required pressures, and (2) it provides a false sense of security to staff who think that this provision is all that is required to change a room between protective isolation and infectious isolation, to the exclusion of other sanitizing procedures.

Biocontainment Treatment Areas (BTAs). These patient treatment areas (also called biocontainment patient care units) are of increasing interest and should possibly adopt the previously discussed clean-to-dirty zoning and airflow paradigm. BTAs are special and often isolated clinical and supporting areas specifically designed to minimize nosocomial transmission during treatment of patients with suspected or confirmed highly contagious and hazardous illnesses. The design focus for these areas is to protect both the hospital and attending healthcare workers, while providing an environment conducive to patient treatment and recovery. This is partially achieved by following protective engineering and design principles similar to those used in biosafety level 3 and 4 laboratory facilities (Smith et al. 2006). Exact design features for BTAs can vary depending on illness, modes of disease transmission, and available resources, and BTAs may be designed as disease-specific treatment (or triage) areas or for an all-hazards infectious disease approach. The spectrum of care may be very broad, ranging from basic medical observation to intensive clinical care. The most protective BTA design features include a clean-to-dirty single-pass airflow design that augments an established clean-to-dirty human and material workflow. This approach often incorporates separate entry and exit points from the patient room. Anterooms at the entry point can be used for donning personal protective equipment (PPE) as well as clean observation areas for use by unexposed observers. Patient rooms within the BTA should be under negative pressure and may benefit from being AII rooms. Key system redundancies (i.e., power, HVAC, exhaust) should be considered and incorporated if integral to the effectiveness of the BTA's functional intent. Due to the significant PPE requirements and their corresponding influence on worker heat stress, the patient room conditioning capacity should allow for room temperatures below those commonly used for inpatient treatment.

BTA patient rooms should ideally have private bathrooms with self-closing doors, toilets with fully closing toilet lids (as allowed by local code and the AHJ), and hands-free electronic faucets. Negative

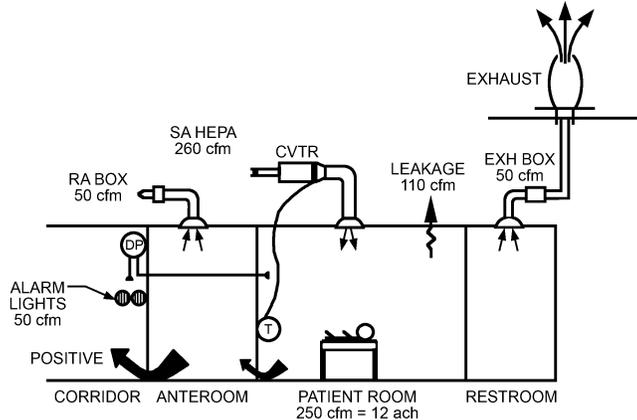


Fig. 3 Protective Environment Room Arrangement (ASHRAE 2013)

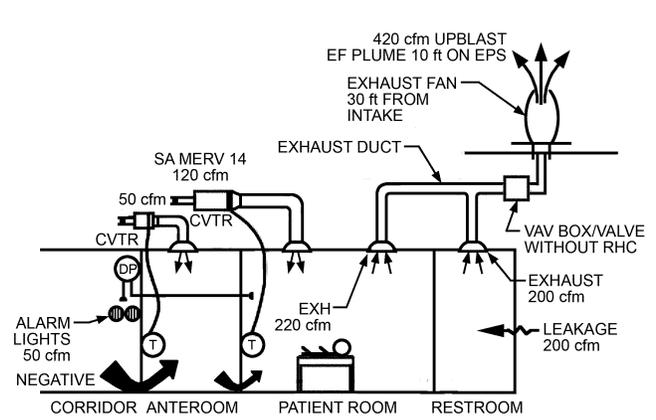


Fig. 4 Airborne Infection Isolation Room (ASHRAE 2013)

air pressure, enhanced exhaust airflow volumes, and strategic exhaust louver placement to facilitate capture and removal of toilet plume aerosols are appropriate considerations for such patient bathrooms. Exit points and pathways from the patient room should consider issues such as worker/material decontamination and PPE doffing, sufficient temporary storage for hazardous medical waste, and exit path routing of wastes and laboratory samples.

A dedicated laboratory capacity may also be incorporated into the BTA and should be placed in a location that is compatible with the clean-to-dirty paradigm. Facilities considering more than one patient room in their BTA may want to consider incorporating a shared exit-path anteroom to accommodate many of these functions while optimizing usage of space. Depending on the scope, size, and capacity of the BTA, dedicated BTA worker restrooms, decontamination showers, changing rooms, PPE storage, and break areas may be appropriate. Facilities that specialize in pediatric patients may also consider special observation and/or interactive capabilities (e.g., specialized glove ports built into wall of clean observation area) that allow for safe familial interaction with pediatric patients. Figure 5 contains a sample layout of a biocontainment unit.

Floor Pantry. Ventilation requirements for this area depend upon the type of food service used by the hospital. Where bulk food is dispensed and dishwashing facilities are provided in the pantry, using hoods above equipment with exhaust to the outdoors is

recommended. Small pantries used for between-meal feedings require no special ventilation. Air pressure of the pantry should be in balance with that of adjoining areas to reduce air movement in either direction.

Labor/Delivery/Recovery/Postpartum (LDRP). The procedures for normal childbirth are considered noninvasive, and rooms are controlled similarly to patient rooms. Some jurisdictions may require higher air change rates than in a typical patient room. It is expected that invasive procedures such as cesarean section are performed in a nearby operating room.

Ancillary

Radiology Department. Factors affecting ventilation system design in these areas include odors from certain clinical treatments and the special construction designed to prevent radiation leakage. Fluoroscopic, radiographic, therapy, and darkroom areas require special attention.

Fluoroscopic, Radiographic, and Deep Therapy Rooms. These rooms may require a temperature from 78 to 80°F and a relative humidity from 40 to 50%. This relative humidity range control often requires dedicated room equipment and control. Depending on the location of air supply outlets and exhaust intakes, lead lining may be required in supply and return ducts at points of entry to various clinical areas to prevent radiation leakage to other occupied areas.

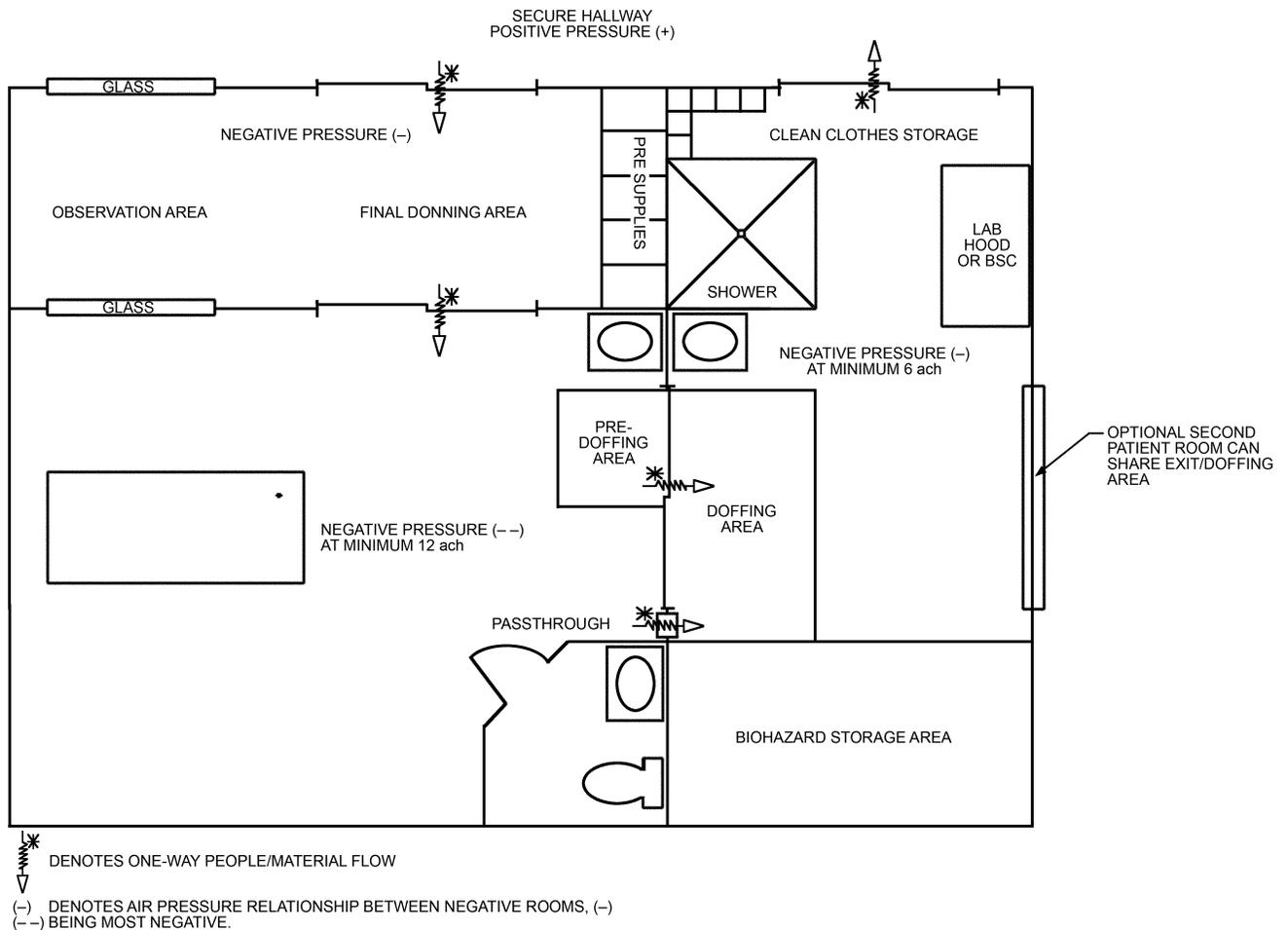


Fig. 5 Biocontainment Treatment Areas
(ASHRAE 2013)

Darkroom. The darkroom is normally in use for longer periods than x-ray rooms and should have an exhaust system to discharge air to the outdoors. Exhaust from the film processor should be connected into the darkroom exhaust system.

Laboratories. Air conditioning is necessary in laboratories for the comfort and safety of the technicians (Degenhardt and Pfost 1983). Chemical fumes, odors, vapors, heat from equipment, and the undesirability of open windows all contribute to this need. Pay particular attention to the size and type of equipment used in the various laboratories, because equipment heat gain usually constitutes a major portion of the cooling load; see Table 7 in Chapter 18 of the 2013 *ASHRAE Handbook—Fundamentals* for examples.

The general air distribution and exhaust systems should be constructed of conventional materials following standard designs for the type of systems used. Exhaust systems serving hoods in which radioactive materials, volatile solvents, and strong oxidizing agents (e.g., perchloric acid) are used should be made of stainless steel. Washdown facilities and dedicated exhaust fans should be provided for hoods and ducts handling perchloric acid.

Hood use may dictate other duct materials. Hoods in which radioactive, carcinogenic, or infectious materials are to be used should be equipped with high-efficiency (HEPA) filters for the exhaust and have a procedure and equipment for safe removal and replacement of contaminated filters. Exhaust duct routing should be as short as possible with minimal horizontal offsets and, when possible, duct portions with contaminated air should be maintained under negative pressure (e.g., locate fan on clean side of filter). This applies especially to perchloric acid hoods because of the extremely hazardous, explosive nature of this material. Hood exhaust fans should be located at the discharge end of the duct system to prevent exhaust products entering the building. The hood exhaust system should not shut off if the supply air system fails. Chemical storage rooms must have a constantly operating exhaust air system. For further information on laboratory air conditioning and hood exhaust systems, see AIHA *Standard Z9.5*, Hagopian and Hoyle (1984), NFPA *Standard 45*, and Chapter 16 of this volume.

Exhaust air from hoods in biochemistry, histology, cytology, pathology, glass washing/sterilizing, and serology-bacteriology units should be discharged to the outdoors with no recirculation. Use care in designing the exhaust outlet locations and arrangements: exhaust should not be reentrained in the building through outdoor air intakes or other building openings. Separation from outdoor air intake sources, wind direction and velocity, building geometry, and exhaust outlet height and velocity are important. In many laboratory exhaust systems, exhaust fans discharge vertically at a minimum of 10 ft above the roof at velocities up to 4000 fpm. The entire laboratory area should be under slight negative pressure to reduce the spread of odors or contamination to other hospital areas. Temperatures and humidities should be within the comfort range.

Bacteriology Laboratories. These units should not have undue air movement; limit air velocities to a minimum. The sterile transfer room, which may be within or adjoining the bacteriology laboratory, is where sterile media are distributed and where specimens are transferred to culture media. To maintain a sterile environment, a HEPA filter should be installed in the supply air duct near the point of entry to the room. The media room should be ventilated to remove odors and steam.

Infectious Disease and Virus Laboratories. These laboratories, found only in large hospitals, require special treatment. A minimum ventilation rate of 6 ach or makeup approximately equal to hood exhaust volume is recommended for these laboratories, which should have a negative air pressure relative to adjacent areas to help prevent exfiltration of airborne contaminants. Exhaust air from fume hoods or safety cabinets must be sterilized before being

exhausted to the outdoors. This may be accomplished by using electric or gas-fired heaters placed in series in the exhaust systems and designed to heat the exhaust air to 600°F. A more common and less expensive method of sterilizing the exhaust is to use HEPA filters in the system.

Nuclear Medicine Laboratories. Such laboratories administer radioisotopes to patients orally, intravenously, or by inhalation to facilitate diagnosis and treatment of disease. There is little opportunity in most cases for airborne contamination of the internal environment, but exceptions warrant special consideration. One important exception involves the use of iodine-131 solution in capsules or vials to diagnose thyroid disorders. Another involves use of xenon-133 gas via inhalation to study patients with reduced lung function.

Capsules of iodine-131 occasionally leak part of their contents before use. Vials emit airborne contaminants when opened for preparation of a dose. It is common practice for vials to be opened and handled in a standard laboratory fume hood; a minimum face velocity of 100 fpm should be adequate for this purpose. This recommendation applies only where small quantities are handled in simple operations. Other circumstances may warrant use of a glove box or similar confinement. Diagnostic use of xenon-133 involves a special instrument that allows the patient to inhale the gas and to exhale back into the instrument. The exhaled gas is passed through a charcoal trap mounted in lead, and is often vented outdoors. The process suggests some potential for escape of the gas into the internal environment.

Because of the specialized nature of these operations and of the equipment involved, it is recommended that system designers determine the specific instrument to be used and contact the manufacturer for guidance. Other guidance is available in U.S. Nuclear Regulatory Commission *Regulatory Guide* 10.8 (NRC 1980). In particular, emergency procedures in case of accidental release of xenon-133 should include temporary evacuation of the area and/or increasing the ventilation rate of the area. Recommendations for pressure relationships, supply air filtration, supply air volume, airborne particle counts, recirculation, and other attributes of supply and discharge systems for histology, pathology, pharmacy, and cytology laboratories are also relevant to nuclear medicine laboratories. The NRC does, however, impose some special ventilation system requirements where radioactive materials are used. For example, NRC (1980) provides a computational procedure to estimate the airflow necessary to maintain xenon-133 gas concentration at or below specified levels. It also contains specific requirements as to the amount of radioactivity that may be vented to the atmosphere; the disposal method of choice is adsorption onto charcoal traps.

Autopsy Rooms. Susceptible to heavy bacterial contamination (e.g., tuberculosis) and odor, autopsy rooms must maintain a negative air pressure relative to adjoining rooms or the corridor to help prevent the spread of contamination (Murray et al. 1988). Autopsy rooms are part of the hospital's pathology department and require special attention (CDC 2005). Exhaust intakes should be located both at the ceiling and in the low sidewall. Where large quantities of formaldehyde are used, special exhaust systems can effectively control concentrations below legal exposure limits. A combination of localized exhaust and ventilation systems with downdraft or side-draft tables has been shown to effectively control concentrations while using smaller exhaust volumes than those required by dilution ventilation (Gressel and Hughes 1992). In smaller hospitals where the autopsy room is used infrequently, local control of the ventilation system and an odor control system with either activated charcoal or potassium permanganate-impregnated activated alumina may be sufficient.

Animal Quarters. Principally because of odor, animal quarters (found only in larger research hospitals) require a mechanical exhaust system that discharges contaminated air above the hospital roof and maintains a negative air pressure relative to adjoining areas to

help prevent the spread of odor, allergens, or other contaminants. Chapter 16 has further information on animal room air conditioning.

Pharmacies. Design and ventilation requirements for pharmacies can vary greatly according to the type of compounding performed within the space. Pharmacies handling hazardous drugs and/or involved in sterile compounding activities have special requirements for incorporating primary engineering controls (PECs) such as horizontal or vertical laminar-airflow workbenches (LAFW), biological safety cabinets (BSC), and compounding (barrier) isolators. Room air distribution and filtration must be coordinated with any PECs that may be needed. See Chapters 16 and 18 for more information.

Sterile Compounding. Sterile pharmaceutical compounding requirements are prescribed by USP (2008). USP Chapter 797 is enforceable under the U.S. Food and Drug Administration, is adopted in whole or in part by many state boards of pharmacy, and may be incorporated into the inspection programs of health care accreditation organizations. The Joint Commission recognized USP 797 as a consensus-based safe practice guideline for sterile compounding; however, they do not require its direct implementation as a condition of accreditation. End users, owners, architects, and engineers should consult the most recent release of USP 797, which is under continuous maintenance, as well as applicable sterile compounding design guidance adopted by their state boards of pharmacy.

USP 797 prescribes that all sterile pharmaceutical preparations to be administered more than 1 h after preparation must be compounded entirely within a critical work zone protected by a unidirectional, HEPA-filtered airflow of ISO class 5 (former class 100 under withdrawn *Federal Standard 209E*; see Chapter 18 for class definitions) or better air quality. This ISO class 5 environment is generally provided using a primary engineering control (PEC) such as a LAFW, BSC, or compounding isolator. USP 797 also requires that the ISO class 5 critical work zone be placed within a buffer area (also called a buffer room or cleanroom) (the air quality of which must meet a minimum of ISO class 7) and contain air-conditioning and humidity controls. Adjacent to the buffer area, the sterile compounding pharmacy design must incorporate an ante area for storage, hand washing, nonsterile preparation activities, donning and doffing of protective overgarments, etc. The air cleanliness in the ante area must be a minimum of ISO class 8 (exception: see the following Hazardous Drugs section). The ante area and buffer area constitute secondary engineering controls. Low-risk preparations that are nonhazardous and destined for administration within 12 h of compounding are granted an exemption from these secondary engineering controls if they are prepared within an ISO class 5 PEC and the compounding area is segregated from noncompounding areas. Pharmacy designers should note that the ISO class 5, 7, and 8 air cleanliness requirements are specified for dynamic conditions (USP 2008). Although ASHRAE *Standard 170* does not prescribe a design temperature for health care pharmacies, USP 797 recommends a maximum temperature of 68°F because of the increased thermal insulation that results from wearing protective clothing and the adverse sterility conditions that could arise from uncomfortably warm and/or sweaty pharmacy workers.

Beyond air quality requirements, the physical design features separating the buffer area from the ante area are based on the pharmacy's **compounded sterile preparation (CSP)** risk level (low, medium, or high) for microbial, chemical, and physical contamination. USP 797 instructs pharmacy professionals on how to determine their pharmacy's CSP risk level based on purity and packaging of source materials, quantity and type of pharmaceuticals, time until its administration, and various other factors. The desired CSP risk level capability should be identified before designing the pharmacy design layout. Pharmacies intended for compounding high-risk-level CSPs require a physical barrier with a door to separate the buffer room from the anteroom, and the buffer room must be maintained at a

minimum positive pressure differential of 0.02 in. of water. For medium- and low-risk level CSPs, the buffer area and ante area can be in the same room, with an obvious line of demarcation separating the two areas and with the demonstrable use of displacement airflow, flowing from the buffer area towards the ante area. Depending on the affected cross-sectional area and the moderately high velocity required to maintain the displacement uniformity (typically 40 fpm or greater), designers may find the physical barrier design to be a more energy friendly approach. USP further prescribes areas to receive a minimum of 30 ach (with up to 15 of these provided by the PEC) if the area is designated to be ISO class 7. There is no minimum ventilation requirement prescribed for ISO class 8 ante areas (USP 2008).

Selecting pharmacy PECs can be a delicate task. Class II BSCs are currently certified following the construction and performance guidelines developed by the National Sanitation Foundation (NSF) and adopted by the American National Standards Institute (ANSI/NSF *Standard 49-2014*). However, no such national certification program exists for compounding isolators. USP 797 addresses this shortcoming by referencing isolator testing and performance guidelines developed by the Controlled Environment Testing Association (CETA 2006).

Hazardous Drugs. Compounding hazardous drugs is another pharmaceutical operation that requires special design considerations. NIOSH (2004) warned of the dangers of occupational exposures to hazardous drugs, over 130 of which were defined and identified; roughly 90 of these drugs were antineoplastic agents primarily used during cancer treatments. Several of NIOSH's recommended protective measures can affect a pharmacy's ventilation design and physical layout. These recommendations include the following:

- Prepare hazardous drugs in an area devoted to that purpose alone and restricted to authorized personnel.
- Prepare hazardous drugs inside a ventilated cabinet designed to prevent hazardous drugs from being released into the work environment.
- Use a high-efficiency particulate air (HEPA) filter for exhaust from ventilated cabinets and, where feasible, exhaust 100% of the filtered air to the outdoors, away from outdoor air intakes or other points of entry.
- Place fans downstream of HEPA filters so that contaminated ducts and plenums are maintained under negative pressure.
- Design the exhaust system such that negative pressure is maintained in the cabinet in the event of fan failure.
- Do not use ventilated cabinets (BSCs or compounding aseptic containment isolators [CACIs]) that recirculate air inside the cabinet or that exhaust air back into the pharmacy unless the hazardous drug(s) in use will not volatilize (evaporate or sublimate) while they are being handled or after they are captured by the HEPA filter. (*Note:* This recommendation is a shift from traditional pharmacy design practice and involves knowledge of the physical properties of drugs within the current drug formulary as well as future new drugs that might be compounded within the cabinet. Within-cabinet recirculation [e.g., BSC class II Type A2 or B1] is allowed when airstream has zero or only minute vapor drug contaminant.)
- Store hazardous drugs separately from other drugs, in an area with sufficient general exhaust ventilation to dilute and remove any airborne contaminants. Depending on the physical nature and quantity of the stored drugs, consider installing a separate, high-volume, emergency exhaust fan capable of quickly purging airborne contaminants from the storage room in the event of a spill, to prevent airborne migration into adjacent areas.

The American Society of Health Systems Pharmacists' *Guidelines on Handling Hazardous Drugs* (ASHP 2006) adopted NIOSH's (2004) protective equipment recommendations, and added the

specification that hazardous drug compounding should be done in a contained, negative-pressure environment or one that is protected by an airlock or anteroom.

Often, hazardous drugs also require sterile compounding. If so, pharmacies must have an environment suitable for both product sterility and worker protection. ASHP (2006), NIOSH (2004), and USP (2008) all address these dual objectives by recommending the use of BSCs or compounding aseptic containment isolators. The precautionary recommendations regarding in-cabinet recirculation and cabinet-to-room recirculation of air potentially contaminated with hazardous drugs still apply. In addition, USP 797 requires hazardous drug sterile compounding to be conducted in a negative-pressure compounding area and to be stored in dedicated storage areas with a minimum of 12 ach of general exhaust. When CACIs are used outside of an ISO 7 buffer area, the compounding area must maintain a negative pressure of 0.01 in. of water and also have a minimum of 12 ach. Anterooms adjacent to an ISO 7 buffer area must also be ISO 7, since there will be air leakage from the anteroom into the negative pressure hazardous drug buffer area.

Table 4 provides a matrix of design and equipment decision logic based on USP 797 and NIOSH (2004).

In February 2016, USP published a new pharmaceutical standard identified as general chapter 800: Hazardous Drugs—Handling in Healthcare Settings. The new chapter applies to all hazardous drug compounding, whereas the previously published guidance in USP 797 was only applicable to sterile compounding. As a USP chapter numbered less than 1000, it is federally enforceable, as well as adoptable (in whole or in part) by individual state boards of pharmacy. Although published in 2016, USP 800 has an official implementation date of December 1, 2019 to allow health care facilities sufficient time to implement necessary engineering design requirements. The USP 800 chapter applies to all health care facilities (including veterinary facilities) where hazardous drugs are handled, manipulated, stored, or distributed. Most of the guidance for hazardous drug sterile compounding carries over from USP 797, but there are two major changes: (1) the low-volume exemption mentioned in Table 3 no longer applies, and (2) USP 800 allows low-to-medium risk sterile compounding to occur in an ISO 5 PEC placed in a nonclassified area (segregated compounding area) in accordance with USP 797 use limitations. The USP 800 chapter adopts a reception-through-administration approach to protecting health care workers from hazardous drug exposures and provides specified requirements for receiving, storing, mixing, preparing, compounding, dispensing, and administering hazardous drugs. Most of these requirements include an engineering and/or architectural design component are summarized in Table 5.

Administration

This department includes the main lobby and admitting, medical records, and business offices. Admissions and waiting rooms may harbor patients with undiagnosed airborne infectious diseases, so

consider using local exhaust systems that move air toward the admitting patient. A separate air-handling system is considered desirable to segregate this area from the hospital proper, because it is usually unoccupied at night and thus a good candidate for energy savings control solutions. Open-water features are strongly discouraged inside health care occupancies; if closed water features are proposed, provide water treatment and other administrative and engineering controls to protect occupants from infectious or irritating aerosols. Refer to ASHRAE *Standard* 188-2015 and *Guideline* 12 for further guidance.

Diagnostic and Treatment

Bronchoscopy, Sputum Collection, and Pentamidine Administration Procedures. These procedures have a high potential for discharges of potentially infectious droplet nuclei into the room air via coughing. Bronchoscopy procedures can release airborne aerosols into the room from a patient who could possibly be diagnosed with tuberculosis, and nontherapeutic exposures to pentamidine are an additional exposure concern. The procedures and patient recovery period (when excessive coughing may occur) are best suited for an **airborne infectious isolation (AII)** room. ASHRAE *Standard* 170 requires local capture exhaust (enclosed administration booth, enclosing hood or tent) near the bronchoscopy procedure site along with exhaust and pressurization similar to an AII room.

Magnetic Resonance Imaging (MRI) Rooms. These rooms should be treated as exam rooms in terms of temperature, humidity, and ventilation. However, special attention is required in the control room because of the high heat release of computer equipment, and in the exam room because of the cryogenics used to cool the magnet. Nonferrous material requirements and shielding penetrations should be in accordance with the specific manufacturer's requirements.

Heat Gains from Medical Equipment. Table 6 in Chapter 18 of the 2017 *ASHRAE Handbook—Fundamentals* tabulates typical heat gain from many types of smaller mobile medical equipment. ASHRAE research project RP-1343 (Koenigshofer et al. 2009) developed methods to test heat gain from large, fixed medical imaging equipment systems at both idle and peak outputs during operational cycles. Tables 6 and 7 present results for some of the equipment tested in RP-1343. Medical equipment heat outputs can vary widely among different manufacturers, even for equipment that performs a similar function, and the medical equipment field is rapidly advancing. The functional program should identify specific manufacturers and models for the HVAC designer's use early in the design process.

Treatment Rooms. Patients are brought to these rooms for special treatments (e.g., hyperbaric oxygen therapy) that cannot be conveniently administered in patient rooms. To accommodate the patient, the rooms should have independent temperature and humidity control. Temperatures and humidities should correspond to those specified for patients' rooms.

Table 4 Minimum Environmental Control Guidance for Pharmacies

Compounding Scenario	Hazardous Drug (HD) (Requires separate area)	Nonhazardous Drug
Sterile compounding to be administered within 12 h	ISO 5 CACI or BSC within negative-pressure ISO 7 buffer + ISO 7 ante areas	If immediate use and low risk: no environmental requirements if administered <12 h + ISO 5 PEC within segregated compounding area
Sterile compounding to be administered after 12 h or more	ISO 5 CACI or BSC within negative-pressure ISO 7 buffer + ISO 7 ante areas	ISO 5 PEC + ISO 7 buffer + ISO 8 ante areas - High-risk compounding requires physical barrier with min. positive pressure (0.02 in. of water) in buffer room relative to anteroom - Medium- and low-risk compounding may use physical barrier (as per high risk) or a clearly identified line of demarcation between buffer and ante areas with uniform displacement airflow (min. of 40 fpm recommended) in direction of buffer to ante areas
Nonsterile compounding	Needs compounding containment isolator or BSC	No sterility or occupational exposure controls required

*For facilities that prepare a low volume of hazardous drugs and use two tiers of containment (e.g., CSTD within CACI or BSC), a negative-pressure buffer area is not required.

Table 5 Engineering Requirements for Receiving, Storing, and Manipulating Hazardous Drugs

Activity	Minimum Engineering Requirements
Hazardous drug receipt/unpacking	Segregated area at negative or neutral pressure to surrounding areas
Hazardous drug storage*	Segregated area, externally vented, (0.01 in. of water) negative pressure, 12 ach
Nonsterile HD compounding	Containment, primary engineering control (C-PEC): externally vented (preferred) or redundant HEPA filtered. Containment, secondary engineering control (C-SEC): externally vented, (0.01 in. of water) negative pressure, 12 ach
Sterile HD compounding (two allowable configurations):	
Buffer room configuration	C-PEC: ISO 5 direct compounding area, externally vented [e.g. Class II (Types A2, B1 or B2), Class III BSC or CACI] C-SEC: externally vented, ISO 7 buffer area, (0.01 in. of water) negative pressure, 30 ach plus ISO 7 anteroom, (0.02 in. of water) positive pressure relative to all adjacent unclassified areas, 30 ach
Segregated compounding area configuration (for low- and medium-risk compounding use only; see USP 797 for compounding risk determinations)	Nonclassified air cleanliness, 12 ach, 0.01 in. of water negative pressure

*Non-antineoplastic-reproductive risk only, and final dosage forms of antineoplastic HDs may be stored with other inventory if permitted by entity policy.

Table 6 Summary of Heat Gain to Air from Imaging Systems

System	Maximum 60 min Time-Weighted Average, Btu/h	Calculated Idle, Btu/h	Manufacturer's Design Information, Btu/h
MRI #1	83,331	75,873	—
MRI #2	80,475	65,323	—
X-ray	4,258	3,692	4,604
Fluoroscopy #1	41,384	31,322	24,946
Fluoroscopy #2	17,100	15,105	20,123
CT-64 slice	24,085	22,437	65,450
PET/CT	43,008	33,438	—
Nuclear camera	3,790	3,620	—
Linear accelerator	111,238	67,807	31,249
Ultrasound (portable)	2,927	1,692	—
Cyberknife	45,720	35,440	—

Physical Therapy Department. The cooling load of the electrotherapy section is affected by the shortwave diathermy, infrared, and ultraviolet equipment used in this area.

Hydrotherapy Section. This section, with its various water treatment baths, is generally maintained at temperatures up to 80°F. The potential latent heat load in this area should not be overlooked. The exercise section requires no special treatment; temperatures and humidities should be within the comfort zone. Air may be recirculated within the areas, and an odor control system is suggested.

Occupational Therapy Department. In this department, spaces for activities such as weaving, braiding, artwork, and sewing require no special ventilation treatment. Air recirculation in these areas using medium-grade filters in the system is permissible. Larger hospitals and those specializing in rehabilitation may offer patients a greater diversity of skills to learn and craft activities, including carpentry, metalwork, plastics, photography, ceramics, and painting. The air-conditioning and ventilation requirements of the various sections should conform to normal practice for such areas and to the codes relating to them. Temperatures and humidities should be maintained within comfort levels.

Inhalation Therapy Department. This department treats pulmonary and other respiratory disorders. The air must be very clean, and the area should have a positive pressure relative to adjacent areas, except when the patient may also be airborne infectious or when the treatment regimen uses hazardous drug therapies. Local exhaust ventilation controls (e.g., administration booth, enclosing hood or tent) should be provided to control exposure of staff to hazardous drug therapies.

Table 7 Summary of Heat Gain to Air

Equipment	Calculated Idle, Btu/h	High, Btu/h
Dialysis machine	1356	2342
Film processor	1367	1427
Pharmacy freezer	2478	2787
Pharmacy refrigerator	1653	1997

Workrooms. Clean workrooms serve as storage and distribution centers for clean supplies and should be maintained at a positive pressure relative to the corridor. Soiled workrooms serve primarily as collection points for soiled utensils and materials. They are considered contaminated rooms and should have a negative air pressure relative to adjoining areas. Temperatures and humidities should be in the comfort range and account for protective clothing requirements required for the room occupants.

Decontamination, High-Level Disinfection, Sterilization and Supply

Used and contaminated utensils, instruments, and equipment are brought to this unit for decontamination and high level disinfection or sterilization before reuse. The central sterile processing unit usually consists of a decontamination area, a sterile prep area, a sterilizing area, and a sterile storage area where supplies are kept until requisitioned. The decontamination area must be physically separated from the sterile prep and sterilization areas. A dedicated endoscope reprocessing area may support the inpatient endoscopy suite. Although AAMI allows for decontamination and high level disinfection to be located in the same space, a clear line of demarcation between soiled cleaning activities and the clean manual or automated disinfection activities. Air should flow from the clean disinfection area toward the contaminated cleaning area (ANSI/AAMI *Standard* 58:2013). Air pressure relationships should conform to those indicated in ASHRAE *Standard* 170. Temperature and humidity should be within the comfort range. Pay special attention to equipment used in these areas (gaps in disinfection/cleaning equipment and piping penetrations between decontamination and clean rooms) to maintain pressurization requirements.

The following guidelines are important in the central sterilizing and supply unit:

- Insulate sterilizers to reduce heat load.
- Amply ventilate sterilizer equipment closets to remove excess heat.
- Where ethylene oxide (ETO) gas sterilizers are used, provide a separate exhaust system with terminal fan (Samuals and Eastin

1980). Provide adequate exhaust capture velocity in the vicinity of sources of ETO leakage. Install an exhaust at sterilizer doors and over the sterilizer drain, and exhaust flammable storage cabinets and sterilant cylinder supply cabinets. Exhaust aerator and service rooms. Sterilizers should be equipped with automatic aeration functionality. Audible and visual ETO alarm sensors and exhaust flow sensors should also be provided and monitored. ETO sterilizers should be located in dedicated unoccupied rooms that have a highly negative pressure relative to adjacent spaces and 10 ach. Many jurisdictions require that ETO exhaust systems have equipment to remove ETO from exhaust air (see OSHA *Standard 29 CFR 1910.1047*).

- Similar provisions for monitoring and alarms should be considered for hydrogen peroxide sterilizers.
- Maintain storage areas for sterile supplies at a relative humidity of no more than 50%.

Service

Service areas include dietary, housekeeping, biohazardous waste storage, mechanical, and employee facilities. Whether these areas are conditioned or not, adequate ventilation is important to provide sanitation and a wholesome environment. Ventilation of these areas cannot be limited to exhaust systems only; provision for supply air must be incorporated into the design. Such air must be filtered and delivered at controlled temperatures. The best designed exhaust system may prove ineffective without an adequate air supply. Experience shows that relying on open windows results only in dissatisfaction, particularly during the heating season. Air-to-air heat exchangers in the general ventilation system offer possibilities for sustainable operation in these areas.

Dietary Facilities. These areas usually include the main kitchen, bakery, dietitian's office, dishwashing room, and dining space. Because of the various conditions encountered (i.e., high heat and moisture production, cooking odors), special attention in design is needed to provide an acceptable environment. See Chapter 34 for information on kitchen facilities.

The dietitian's office is often located within the main kitchen or immediately adjacent to it. It is usually completely enclosed for privacy and noise reduction. Air conditioning is recommended for maintaining normal comfort conditions.

The dishwashing room should be enclosed and minimally ventilated to equal the dishwasher hood exhaust. It is not uncommon for the dishwashing area to be divided into a soiled area and a clean area. In such cases, the soiled area should be kept at a negative pressure relative to the clean area.

Ventilation of the dining space should conform to local codes. The reuse of dining space air for ventilation and cooling of food preparation areas in the hospital is suggested, provided the reused air is passed through filters with a filtration efficiency of MERV 13 or better. Where cafeteria service is provided, serving areas and steam tables are usually hooded. The air-handling capacities of these hoods should be sized to accommodate exhaust flow rates (see Table 6 in Chapter 34). Ventilation systems for food preparation and adjacent areas should include an interface with hood exhaust controls to assist in maintaining pressure relationships.

Kitchen Compressor/Condenser Spaces. Ventilation of these spaces should conform to all codes, with the following additional considerations: (1) 350 cfm of ventilating air per compressor horsepower should be used for units located in the kitchen; (2) condensing units should operate optimally at 90°F maximum ambient temperature; and (3) where air temperature or air circulation is marginal, specify combination air- and water-cooled condensing units. It is often worthwhile to use condenser water coolers or remote condensers. Consider using heat recovery from water-cooled condensers.

Laundry and Linen Facilities. Of these facilities, only the soiled linen storage room, soiled linen sorting room, soiled utility

room, and laundry processing area require special attention. The room for storing soiled linen before pickup by commercial laundry is odorous and contaminated, and should be well ventilated, exhausted, and maintained at a negative air pressure. The soiled utility room is provided for inpatient services and is normally contaminated with noxious odors. This room should be mechanically exhausted directly outdoors.

In the laundry processing area, equipment such as washers, flatwork ironers, and tumblers should have direct overhead exhaust to reduce humidity. Such equipment should be insulated or shielded whenever possible to reduce the high radiant heat effects. A canopy over the flatwork ironer and exhaust air outlets near other heat-producing equipment capture and remove heat best. Air supply inlets should be located to move air through the processing area toward the heat-producing equipment. The exhaust system from flatwork ironers and tumblers should be independent of the general exhaust system and equipped with lint filters. Air should exhaust above the roof or where it will not be obnoxious to occupants of other areas. Heat reclamation from the laundry exhaust air may be desirable and practicable.

Where air conditioning is contemplated, a separate supplementary air supply, similar to that recommended for kitchen hoods, may be located near the exhaust canopy over the ironer. Alternatively, consider spot cooling for personnel confined to specific areas.

Mechanical Facilities. The air supply to boiler rooms should provide both comfortable working conditions and the air quantities required for maximum combustion of the particular fuel used. Boiler and burner ratings establish maximum combustion rates, so the air quantities can be computed according to the type of fuel. Sufficient air must be supplied to the boiler room to supply the exhaust fans as well as the boilers.

At workstations, the ventilation system should limit temperatures to 90°F effective temperature. When ambient outdoor air temperature is higher, indoor temperature may be that of the outdoor air up to a maximum of 97°F to protect motors from excessive heat.

Maintenance Shops. Carpentry, machine, electrical, and plumbing shops present no unusual ventilation requirements. Proper ventilation of paint shops and paint storage areas is important because of fire hazard and should conform to all applicable codes. Maintenance shops where welding occurs should have exhaust ventilation.

3. OUTPATIENT HEALTH CARE FACILITIES

An outpatient health care facility may be a free-standing unit, part of an acute care facility, or part of a medical facility such as a medical office building (clinic). Any outpatient surgery is performed without anticipation of overnight stay by patients (i.e., the facility operates 8 to 10 h per day).

If physically connected to a hospital and served by the hospital's HVAC systems, spaces within the outpatient health care facility should conform to requirements in the section on Hospital Facilities. Outpatient health care facilities that are totally detached and have their own HVAC systems may be categorized as diagnostic clinics, treatment clinics, or both. Many types of outpatient health care facilities have been built with many combinations of different programmed uses occurring in a single building structure. Some of the more common types include primary care facilities, freestanding emergency facilities, freestanding outpatient diagnostic and treatment facilities, freestanding urgent care facilities, freestanding cancer treatment facilities, outpatient surgical facilities, gastrointestinal endoscopy facilities, renal dialysis centers, outpatient psychiatric

centers, outpatient rehabilitation facilities, freestanding birth centers, and dental centers.

When specific treatments in these outpatient facilities are medically consistent with hospital-based treatments, then environmental design guidance for hospitals should also apply to the outpatient treatment location. Information under the Hospital Facilities part of this chapter may also be applicable to outpatient occupancies performing a similar activity. Outpatient and clinic facilities should generally be designed according to criteria shown in ASHRAE *Standard 170*, unless those criteria conflict with local or state requirements.

3.1 DIAGNOSTIC AND TREATMENT CLINICS

A diagnostic clinic is a facility where ambulatory patients are regularly seen for diagnostic services or minor treatment, but where major treatment requiring general anesthesia or surgery is not performed. Diagnostic clinics may use specialized medical imaging equipment, which may be portable cart-mounted items or large permanently mounted pieces with adjoining control rooms and equipment rooms. The equipment may require a minimum relative humidity for proper operation. Heat gains from equipment can be large; see Table 5 and the equipment manufacturer's recommendations.

A treatment clinic is a facility where major or minor procedures are performed on an outpatient basis. These procedures may render patients temporarily incapable of taking action for self-preservation under emergency conditions without assistance from others (NFPA *Code 101*).

Design Criteria

See the following subsections under Hospital Facilities:

- Infection Sources
- Control Measures
- Air Quality
- Air Movement
- Temperature and Humidity
- Smoke Control

An outpatient recovery area may not need to be considered a sensitive area, depending on the patients' treatments. Infection control concerns are the same as in an acute care hospital. Minimum ventilation rates, desired pressure relationships and relative humidity, and design temperature ranges are similar to the requirements for hospitals in ASHRAE *Standard 170*.

The following departments in an outpatient treatment clinic have design criteria similar to those in hospitals:

- Surgical: operating, recovery, and anesthesia storage rooms
- Ancillary
- Diagnostic and treatment
- Decontamination, high-level disinfection, sterilization, and supply
- Service: soiled workrooms, mechanical facilities, and locker rooms

3.2 DENTAL CARE FACILITIES

Institutional dental facilities include reception and waiting areas, treatment rooms (called operatories), and workrooms where supplies are stored and instruments are cleaned and sterilized; they may include laboratories where restorations are fabricated or repaired.

Many common dental procedures generate aerosols, dusts, and particulates (Ninomura and Byrns 1998). The aerosols/dusts may contain microorganisms (both pathogenic and benign), metals (e.g., mercury fumes), and other substances (e.g., silicone dusts, latex allergens). Some measurements indicate that levels of bioaerosols

during and immediately following a procedure can be extremely high (Earnest and Loesche 1991). Lab procedures have been shown to generate dusts and aerosols containing metals. At this time, only limited information and research are available on the level, nature, or persistence of bioaerosol and particulate contamination in dental facilities. Consider using local exhaust ventilation (possibly recirculating with HEPA filtration) to help capture and control these aerosols, because dental care providers and patients are often close together.

Nitrous oxide is used as an analgesic/anesthetic gas in many facilities. The design for controlling nitrous oxide should consider that nitrous oxide (1) is heavier than air and may accumulate near the floor if air mixing is inefficient, and (2) should be exhausted directly outdoors. Use active waste gas scavenging to prevent accumulation of waste gases during dental procedures; passive scavenging through an open window or a vent in the wall should not be used.

3.3 CONTINUITY OF SERVICE AND ENERGY CONCEPTS

Some owners may desire standby or emergency service capability for the heating, air-conditioning, and service hot-water systems and that these systems be able to function after a natural disaster.

To reduce utility costs, use energy-conserving measures such as recovery devices, variable air volume, load shedding, or devices to shut down or reduce ventilation of certain areas when unoccupied. Mechanical ventilation should take advantage of outdoor air by using an economizer cycle (when appropriate) to reduce heating and cooling loads.

The section on Facility Design and Operation includes information on zoning and insulation that applies to outpatient facilities as well.

4. RESIDENTIAL HEALTH, CARE, AND SUPPORT FACILITIES

FGI's (2014b) *Guidelines for Design and Construction of Residential Health, Care, and Support Facilities* discusses requirements for nursing homes, hospice facilities, assisted living facilities, independent living settings, adult day care facilities, wellness centers, and outpatient rehabilitation centers. HVAC design requirements for these spaces, and consequently applicability of ASHRAE standards to their design, can vary greatly. ASHRAE *Standard 170* addresses assisted living, hospice, and nursing facilities. ASHRAE *Standard 62.1* or *62.2* may be applicable to other types of commercial space design, if they are nontransient and residential in nature.

Nursing Facilities

Nursing facilities may be classified as follows:

Extended care facilities are for recuperation by hospital patients who no longer require hospital facilities but do require the therapeutic and rehabilitative services of skilled nurses. This type of facility is either a direct hospital adjunct or a separate facility with close ties with the hospital. Clientele may be of any age, usually stay from 35 to 40 days, and usually have only one diagnostic problem.

Skilled nursing homes care for people who require assistance in daily activities; many of them are incontinent and nonambulatory, and some are disoriented. Residents may come directly from their homes or from residential care homes, are generally elderly (with an average age of 80), stay an average of 47 months, and frequently have multiple diagnostic problems.

Residential care homes are generally for elderly people who are unable to cope with regular housekeeping chores but have no acute ailments and are able to care for all their personal needs, lead normal

lives, and move freely in and out of the home and the community. These homes may or may not offer skilled nursing care. The average length of stay is four years or more.

Functionally, these buildings have five types of areas that are of concern to the HVAC designer: (1) administrative and support areas inhabited by staff, (2) patient areas that provide direct normal daily services, (3) treatment areas that provide special medical services, (4) clean workrooms for storing and distributing clean supplies, and (5) soiled workrooms for collecting soiled and contaminated supplies and for sanitizing nonlaundry items.

4.1 DESIGN CONCEPTS AND CRITERIA

Nursing homes occupants are usually frail, and many are incontinent. Though some occupants are ambulatory, others are bedridden, suffering from advanced illnesses. The selected HVAC and air distribution system must dilute and control odors and should not cause drafts. Local climatic conditions, costs, and designer judgment determine the extent and degree of air conditioning and humidification. Odor may be controlled with large volumes of outdoor air and heat recovery. To conserve energy, odor may be controlled with activated carbon or potassium permanganate-impregnated activated alumina filters instead.

Temperature control should be on an individual room basis. In geographical areas with severe climates, patient rooms may have supplementary heat along exposed walls. In moderate climates (i.e., where outdoor winter design conditions are 30°F or above), overhead heating may be used.

Controlling airborne pathogen levels in nursing homes is not as critical as it is in acute care hospitals. Nevertheless, the designer should be aware of the necessity for odor control, filtration, and airflow control between certain areas.

ASHRAE *Standard 170* lists recommended filter efficiencies for air systems serving specific nursing home areas, as well as recommended minimum ventilation rates and desired pressure relationships. Recommended interior winter design temperature is 75°F for areas occupied by patients and 70°F for nonpatient areas. Provisions for maintenance of minimum humidity levels in winter depend on the severity of the climate and are best left to the designer's judgment. Where air conditioning is provided, the recommended interior summer design temperature and humidity is 75°F, and a maximum of 60% rh.

The general design criteria in the hospital sections on Heating and Hot Water Standby Service, Insulation, and Sustainability apply to nursing home facilities as well.

STANDARDS

AENOR/UNE <i>Standard 100713:2005</i>	Air Conditioning in Hospitals
ANSI/AAMI <i>Standard 58:2013</i>	Chemical Sterilization and High-level Disinfection in Health Care Facilities
ANSI/AIHA <i>Standard Z9.5-2012</i>	Laboratory Ventilation
ANSI/ASHRAE <i>Standard 15-2013</i> 52.2-2012	Safety Code for Mechanical Refrigeration Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size
62.1-2013	Ventilation for Acceptable Indoor Air Quality
ANSI/ASHRAE/IES <i>Standard 90.1-2013</i>	Energy Standard for Buildings Except Low-Rise Residential Buildings
ANSI/ASHRAE/ASHE <i>Standard 170-2017</i>	Ventilation of Health Care Facilities
ANSI/ASHRAE/ACCA <i>Standard 180-2012</i>	Standard Practice for Inspection and Maintenance of Commercial Building HVAC Systems

ASHRAE

<i>Standard 145.2-2016</i>	Laboratory Test Method for Assessing the Performance of Gas-Phase Air-cleaning Systems: Air-cleaning Devices
188-2018	Building Water Systems
189.3-2017	Design, Construction, and Operation of Sustainable, High-Performance Health Care Facilities
<i>Guideline 10-2011</i>	Interactions Affecting the Achievement of Acceptable Indoor Environments
12-2000	Minimizing the Risk of Legionellosis Associated with Building Water Systems
26-2012	Guideline for Field Testing of General Ventilation Filtration Devices and Systems for Removal Efficiency in-situ by Particle Size and Resistance to Airflow
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ANSI/ASTM

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