CHAPTER 9. HEALTH CARE FACILITIES

CONTINUAL advances in patient and resident care, medicine, and technology require health care facilities to constantly re-evaluate their HVAC needs. Ventilation and air conditioning can affect certain patient and staff outcomes, and good air quality helps protect occupants against harmful exposures. However, there is limited research that quantifies or describes the methods or causes of these effects (Lautzet al. 2019). There are significant requirements for clean, conditioned air for inpatient health care facilities, resulting in high energy use and operating cost compared to other types of buildings. The challenge is establishing the balance between patient outcomes, safety, and facility construction and operating costs. This demands knowledge and understanding of the unique needs and requirements of these type of facilities and a command of HVAC fundamentals and applications.

Health care institutions and organizations are increasingly diversifying how they deliver health and wellness services. 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. As health care delivery models evolve and real estate and facility needs change, HVAC design practices, codes, and standards need to keep pace, while maintaining the high standard for the indoor environment.

Key areas to consider during HVAC system design for health care facilities:

1. Indoor Environmental Quality (IEQ)
2. Life Safety
3. Reliability
4. Maintainability
5. Energy Use and Efficiency
6. Adaptability

The author who originally developed the list used the word *performance* instead of *indoor environmental quality* to cover infection control, indoor air quality, thermal comfort, and acoustics. These topics have been presented in the ASHRAE Learning Institute (ALI) course, Designing High Performing Health Care HVAC Systems and Health Care Facilities: Best Practice Design and Applications (Koenigshofer 2015). The author suggests that the list is in the order of priority. Within ASHRAE Technical Committee (TC) 9.6, which is responsible for this chapter, there is no consensus that the list represents their priority; however, all agree there is no higher priority than IEQ.

1. HEALTH CARE FACILITY CATEGORIES

Buildings where health care services are provided are commonly categorized into one of three major facility classifications: (1) hospitals or inpatient, (2) ambulatory or outpatient, or (3) residential or senior living. Since facility and clinical terminology can vary regionally, a brief description is provided to help define these terms as used in this chapter. There are critical distinctions between these categories that result in significant differences in their design and operation.

1.1 HOSPITAL, INPATIENT

There are many ways to refer to and classify hospitals depending on context. Not all of these impact the design of the facilities. The following is a nonexhaustive list of common classifications of hospitals:

Federal	Maintained for federal beneficiaries, such as military personnel, and veterans.
Not-for-profit	Privately owned but operated on a not-for-profit, tax-exempt basis.
Short-stay	Average length of stay is less than 30 days.
Long-term care	Length of stay exceeds 30 days; referred to as long-term-care hospitals.
General acute-care	Provide a variety of services, including general and specialized medicine to meet the needs of the community.
Specialty	Specific focus of medicine or patients (e.g., orthopedic hospital, children's hospital).

Community	Nonfederal, short-stay, acute-care general or specialty facilities available to the public.
Noncommunity	Federally operated, prison hospitals, college infirmaries, and long-term-care are examples.
Academic	Teaching with approved residency programs for physicians.
Critical-access	Rural limited-service with special designation under the Medicare Rural Hospital Flexibility Program.

Although classifying hospitals by size is not standardized, below is the common reference:

Small	Fewer than 100 beds.
Medium	100 to under 500 beds.
Large	More than 500 beds.

Common program elements of hospital facilities can include areas such as patient wings, diagnostic and treatment rooms, surgical suites, airborne infection isolation rooms (AII), protective environment rooms (PE), emergency departments, labor and delivery suites (LDR), intensive care units (ICU), behavioral health, general support areas such as materials and waste management, and environmental services. Other support services needed for patient care can include physical therapy, laboratory functions, central sterile services and pharmacies, dispensing or compounding types.

Given the life-saving work done in hospitals, HVAC systems must address not only patient and staff comfort but also life safety systems. Design considerations should include criteria such as required supply, return, and exhaust air change rates; space pressurizations (positive/negative/neutral); air quality filtration levels; and space humidity levels. In in the event of utility (e.g., power, natural gas, water) failures, adverse weather, fire (internal and external), and other emergency events, central utility plants for heating, cooling, and exhaust systems need to consider continuity of service for these facilities. This may include redundant equipment arrangements to allow maintenance or repairs while systems remain active. HVAC designers need to understand and communicate to their project teams the minimum code requirements and recommended good practice measures.

Some unique design considerations for hospitals and inpatient facilities include

- Specific requirements aimed at providing adequate and safe air quality
- Unique life safety, operations, maintenance, and emergency considerations impacting HVAC system design
- Temperature and humidity control requirements for some areas
- HVAC system zoning considerations, including the following factors:
  - The level the air systems can support the life safety smoke compartments and defend-in-place fire/smoke emergency response
  - Minimizing recirculation between departments that generate a significant source of contaminants with those that are highly sensitive to them
  - Increasing reliability by simplifying design and control sequences
  - Providing flexibility of operation
  - Conserving energy and save operating costs

1.2 AMBULATORY, OUTPATIENT

Health care institutions or organizations are increasingly diversifying in response to a trend toward ambulatory and outpatient services that do not require overnight or >23 h stays. 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 an acute care hospital. These organizations and long-established hospitals sometimes construct buildings that look less like hospitals and more like luxury hotels and office buildings. However, when specific treatments in these facilities are medically consistent with hospital-based treatment, then the environmental design guidance applicable to the hospital-based treatment should apply to the clinic’s treatment environment.

Common clinical areas or departments that can be found in an ambulatory or outpatient facility includes

- General and specialty medical
- Imaging
- Birth centers
- Urgent care
- Infusion

- Surgery
- Freestanding emergency department
- Endoscopy
- Renal dialysis
- Psychiatric
- Rehabilitation therapy
- Mobile/transportable medical units
- Dental

Many of these facilities may fall under a different set of building codes, standards, and guidelines from hospital and inpatient facilities. It is imperative that the HVAC designer understand and communicate the minimum legal HVAC requirements and what good design practices are being implemented based on relevant codes, standards, guidelines, manuals, and handbooks. Many outpatient facilities are classified according to the building code as B-occupancy and may not be required by code to follow the Facilities Guidelines Institute (FGI 2018a) publication *Guidelines for Design and Construction of Outpatient Facilities* or ASHRAE *Standard* 170. Typically, the design of these facilities follows ASHRAE *Standard* 62.1 for ventilation. If not required by code, the design team and health care organization need to determine if and what portions of FGI (2018a) are required. The design team needs to outline the differences, including cost and benefits. HVAC designers should understand the acoustical, commissioning, and ventilation requirements in the FGI guidelines.

Outpatient health care facilities commonly have combinations of various programmed uses occurring in a single building. If the HVAC systems serve multiple programs and are physically connected or located in the same area of a building as inpatient and hospital services, the systems should conform to the requirements of a hospital facility. This is often required by code and may depend on the medical licensure under which the services fall. HVAC designers must understand the codes being enforced and which agencies will be inspecting and enforcing them. Some procedures may render patients temporarily incapable of self-preservation under emergency conditions. Outpatient surgery and freestanding emergency departments are examples where life safety codes like an inpatient facility are required.

1.3 RESIDENTIAL FACILITIES

Residential/senior community facilities are addressed separately because their fundamental requirements differ greatly from those of other medical facilities. Facilities may be classified as follows:

Extended care or **institutional long-term care** is for 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 to the hospital. Clientele may be any age, usually stay from 35 to 40 days, and often have only one diagnostic problem.

Skilled nursing includes 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.

Independent living centers are often referred to as **retirement communities**, **congregate living**, or **senior apartments** and are designed specifically for independent senior adults who are able to live on their own but desire the security and conveniences of community living.

Assisted living facilities are best described as "a long-term care alternative that involves the delivery of professionally managed personal and healthcare services in a group setting that is residential in character and appearance in ways that optimizes the physical and psychological independence of residents" (Regnier 1994).

Residential care homes are generally for elderly people who are unable to cope with regular housekeeping chores but have no acute ailments and can 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.

Continuing care retirement communities are residential campuses that provide a continuum of care, from private units to assisted living and skilled nursing care, all in one location.

Memory care/Alzheimer's disease/dementia care provides specialized care and housing tailored to the needs of individuals with Alzheimer's disease and other related memory disorders or dementia.

Functionally, these facilities commonly have five areas that are of concern to the HVAC designer: (1) administrative and support areas inhabited by staff, (2) patient areas that provide direct 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.

Throughout all these facilities, residents may be frail and potentially 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 not cause drafts. Local climatic conditions, costs, and designer judgment determine the degree of air conditioning and humidification. 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 need for odor and airflow control, and filtration between certain areas. Odor may be controlled with large volumes of outdoor air and heat recovery. Additionally, to conserve energy, odor may be controlled with activated carbon or potassium permanganate-impregnated activated alumina filters.

FGI's (2018b) *Guidelines for Design and Construction of Residential Health, Care, and Support Facilities* has requirements for nursing homes, hospice facilities, assisted living facilities, independent living settings, adult day care facilities, wellness centers, and outpatient rehabilitation centers. In many U.S. states, this guideline is adopted as a code. The 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 non-transient and residential.

ASHRAE *Standard* 170 lists recommended filter efficiencies for air systems serving specific nursing home areas and recommended minimum ventilation rates and desired pressure relationships. Recommended interior winter design temperature is 75°F24°C for areas occupied by patients and 70°F21°C for nonpatient areas. Provisions to maintain 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°F24°C and a maximum of 60% relative humidity. Temperature should be controlled in individual rooms. In 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–1°C or above), overhead heating may be used.

1.4 REGULATION AND RESOURCES

Health care facility design is heavily regulated primarily for patient and staff safety. HVAC system design and implementation are covered by these regulations. In the United States, typically the **authorities having jurisdiction (AHJ)** for new construction and significant renovations are individual states' health departments, local building officials, and the state or local fire marshall. For health care organizations that accept federal government reimbursements for patient care, the facility is required to comply with the latest Centers for Medicare and Medicaid Services (CMMS) regulations, The Joint Commission (TJC), and the United States Pharmacopeia (USP).

In response to the recent COVID-19 global pandemic caused by the SARS-CoV-2 virus, ASHRAE, American Society for Health Care Engineering (ASHE), and the U.S. Centers for Disease Control (CDC) all have guidance posted and accessible on their websites. They contain both general and specific suggestions and recommendations for health care facilities, which are evolving and changing rapidly.

In addition to local and state building codes, other codes impacting HVAC systems when they are adopted include

- ANSI/ASHRAE/ASHE *Standard* 170, Ventilation of Healthcare Facilities
- NFPA *Standard* 90A, Standard for the Installation of Air-Conditioning and Ventilating Systems
- NFPA *Standard* 99, Healthcare Facilities
- NFPA *Standard* 101, Life Safety Code
- NFPA *Standard* 110, Standard for Emergency and Standby Power Systems
- *Facilities Guidelines Institute for the Design and Construction of Healthcare Facilities* (FGI 2018a)
- Individual state and local jurisdictional building code mandates

Refer to the individual state and local code mandates for the year of code adoption.

Health care facilities are unique in that there may be multiple, differing AHJs overseeing the design, construction, and operation of the facility. Each AHJ may use different standards or different versions of the same standards. NFPA *Standard* 101 defines inpatient hospitals to be occupancy type I-2 institutional facilities. As described previously, various hospital types are referred to in various ways. The 2018 FGI defines many of these and provides the architectural and engineering guidelines that many states have adopted as code minimum requirements.

The building occupants' ability to act for self-preservation during an emergency condition plays a big role in regulations. NFPA *Standards* 99 and 110, adopted by many jurisdictions, provide requirements for ventilation of medical gas storage and transfilling spaces. It also has requirements for heating, cooling, and ventilating the emergency room power system.

ANSI/ASHRAE/ASHE *Standard* 170 is written in code-enforceable language and represents the minimum design ventilation and related HVAC system requirements. *Standard* 170 is continually reviewed 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 its entirety approximately every four years.

Standard 170 is organized into three major categories of health care facilities: hospitals, outpatient, and residential care. It provides specific room design requirements for relative air pressure relationships, air exchanges, outdoor ventilation, air recirculation limitations, air filtration level, room temperature and humidity ranges. Table 1 presents some of the requirements found in ASHRAE *Standard* 170.

Since the 2010 FGI guidelines edition, FGI and ASHRAE have coordinated to provide a single document that addresses architectural and mechanical and electrical (MEP) requirements.

Table 1 Sample of ASHRAE Standard 170 -2021 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	Unoccupied Turndown	Minimum Filter Efficiencies	Design Relative Humidity,%	Design Temp., °C
Operating room	Positive	4	20	NR*	No	Yes	MERV-16	20 to 60	20 to 24
Emergency department public waiting area	Negative	2	12	Yes	NR*	Yes	MERV-8	max. 65	21 to 24
AII rooms	Negative	2	12	Yes	No	Yes	MERV-14	max. 60	21 to 24
Protective environment room	Positive	2	12	NR*	No	No	HEPA	max. 60	21 to 24
Patient room	NR*	2	4	NR*	NR*	Yes	MERV-14	max. 60	21 to 24

* ACH = air changes per hour. NR = no requirement.

Many outpatient facilities are classified according to the building code as B-occupancy where neither the FGI guidelines nor ASHRAE *Standard* 170 is adopted. Typically, the HVAC design of these facilities follow design practices and codes common to other commercial buildings, including ASHRAE *Standards* 62.1 and 62.2 for ventilation. Areas or rooms in hospitals that are not covered in *Standard* 170 also follow *Standards* 62.1 and 62.2. For systems serving a combination of rooms following the two different standards, the most stringent jurisdictional requirements should be considered. Determine the ventilation requirements for the ventilation systems using both standards and use the greater of the two ventilation values.

ASHRAE *Guideline* 10, Interactions Affecting the Achievement of Acceptable Indoor Environments, and ASHRAE *Guideline* 29, Guideline for the Risk Management of Public Health and Safety in Buildings, may be especially applicable to the design of health care facilities.

ASHRAE *Standard* 188-2015 requires designers to establish water management programs in health care buildings to control the 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 details 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.

The ASHRAE (2013) *HVAC Design Manual for Hospitals and Clinics* presents enhanced 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.

Advanced Energy Design Guides (ASHRAE 2009, 2012) for hospitals and ASHRAE *Standard* 189.3 provides guidance for design, construction, and operation of high-performance, green health care facilities.

American Society for Health Care 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.

State and local health agencies that may have standards and guidelines applicable to medical facilities, including 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 include the United States Pharmacopeia (USP), American Association of Operating Room Nurses (AAORN), and Association for the Advancement of Medical Instrumentation (AAMI).

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 *Health Care 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
- France's *Norme Francaise* NF SS 90-351
- Department of Health–Abu Dhabi's (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.ashraeasa.org/members.html for a list of associate organizations.

2. INDOOR ENVIRONMENTAL QUALITY

The level of indoor environmental quality is directly impacted by HVAC system performance. HVAC system design and operation requires careful consideration to provide the level of indoor air quality, thermal comfort, and acoustics to achieve the desired patient, resident, and staff experience and outcomes. In health care facilities, air conditioning can play a role beyond the promotion of comfort.

2.1 INFECTION, DISEASE, AND CONTAMINATION

In many cases, proper air conditioning is a consideration in patient therapy. Patients in well-controlled environments generally show more rapid physical improvement than those in poorly controlled environments. Examples include

- 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).
- Individuals undergoing 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 and Hugentobler (2016) found an increase in the number of health care associated infections in patients in medical-surgery and oncology wings when the

relative humidity dropped below 40% relative humidity.

- 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 benefit the 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°F32°C and relative humidity up to 95%.

Reducing **health care 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 et al. 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. However, ASHRAE research project RP-312 found that recirculation of most hospital air is appropriate (Chaddock 1983).

Many health care facilities contain large populations of immune-compromised or susceptible individuals, so lower thresholds of contaminants, particularly bioaerosols, may be helpful or necessary. However, the thresholds for bioaerosols are not well known, even for the general population. A detailed discussion of contaminant sources can be found in Chapter 10 of the 2021 *ASHRAE Handbook—Fundamentals*. Airborne contaminants include particles and gaseous contaminants. Bioaerosols, including fungal and bacterial pathogens, are a category of particles. Following are four categories of contaminants with examples of particles of concern.

Bacterial. *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 mm or less can remain airborne indefinitely.

Viral. Examples of airborne viruses are SARS-CoV-2, *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 patients with advanced leukemia, bone marrow conditions, organ transplant, and other immunocompromised conditions.

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

HVAC engineering controls, as discussed later in this chapter, will affect indoor environmental quality and impact the healing environment for the patient, contributing to shorter patient stays and a lower risk of HAIs. ASHE (2011) provides an engineering perspective with many additional references.

2.2 INDOOR AIR QUALITY

Indoor air quality is key to health care facility occupants' health and wellbeing. The quality of the air is affected by gases, particles, microbial contaminants, or any mass or energy stressor that can induce adverse health conditions. Examples of common gases include carbon monoxide, radon, and volatile organic compounds (VOCs).

Infectious Disease Transmission Modeling (Inhalation)

The relationship between ventilation control measures and infectious disease transmission can be modeled in several ways. A common mathematical model used in the engineering and scientific literature is the Wells-Riley model:

$$P = 1 - e^{(-Iqpt/Q)}$$

where

P = risk of infection for typical occupant, at standard exposure time, %

I = number of infectious aerosol sources (infected individuals) in space

q = quanta generation rate; standard rate of infectious aerosols generated by one infector, per hour or per minute

p = pulmonary ventilation rate of susceptible individuals, m^3/h, L/min, or cfm. Unless there is cause to deviate, use 0.36 m^3/h, 6 L/min, or 0.2 CFM, representing adults engaged in light activity

t = exposure time, h or min. (Note: units of time for t must match units of time in denominator or q, p, and Q.)

Q = effective space ventilation rate with uncontaminated air; the ventilation rate that effectively predicts control of contaminants in the space

Table 2 Airborne Infectious Agent Quanta Generation Rates per Hour

Infectious Agent	Mean Quanta Production Rate, quanta/h[a]	Quanta Production Rate, quanta/h[b]
Mycobacterium tuberculosis	12.7 ± 3	1 to 50, used 13
Influenza virus	100 ± 25	15 to 500, used 100
Measles virus	570 ± 143	570 to 5600
Rhinovirus	—	1 to 10, used 5
SARS-CoV	—	10 to 300

[a] Beggs et al. 2010.

[b] Stevens 2012.

Though the Wells-Riley model is commonly use, other models include susceptible-infected-recovered, mass action, and the Gammaitoni and Nucci epidemiological model. Memarzadeh (2013) compared various models. The Wells-Riley model can also be detailed by adding considerations of stochastic and proximity effects (Noakes and Sleigh 2008) to apply to the risk of airborne infection in hospital environments.

When using the Wells-Riley equation, the rate of infectious aerosol generation is in quanta per unit time. Table 2 summarizes sources of quanta generation rates from the literature.

Air Contamination Control Measures

Designers and operators need to consider the quality of the ventilation air and its impact on the health and well-being of the occupants. Control measures need to address levels of infectious particles, dust, dirt, odor, and chemical and radioactive pollutants. Air contamination control measures can be categorized into four areas: (1) capture, (2) dilution, (3) air cleaning, and (4) containment.

Capture. Local source capture is the most effective. Exhausted enclosures (e.g., biological safety cabinets, chemical fume hoods, benchtop enclosures) and localized collection methods (e.g., snorkels, direct equipment connections) are typical capture control measures. As an outcome of the COVID-19 pandemic, ventilated headboards and dental aerosol-generating capture arrangements are being developed.

Ventilated headboards can help isolate patients while protecting health care personnel from airborne infectious diseases (CDC/NIOSH 2008). Ventilated headboards deployed in combination with HEPA fan/filter units can provide surge isolation capacity in a variety of environments. See the section on HVAC Design Considerations for Specific Areas for more application details.

Dilution. Clean ventilation air can dilute the contaminates generated by the occupants or processes within those areas. Increasing the supply air flow rate, whether achieved by introducing clean outdoor air or clean recirculated air, can reduce particulates, odor, and the airborne burden of microorganisms, thus reducing opportunities for airborne exposures. Table 3 notes the theoretical time to remove particles from a room being flushed with clean air, assuming perfect mixing and ventilation. in the space and is derived from the following dilution equation:

$$t_2 - t_1 = -[\ln(C_2/C_1)/(Q/V)]60$$

where

t_1 = initial timepoint in minutes, = 0

t_2 = final timepoint in minutes

C_1 = initial concentration of contaminant

C_2 = final concentration of contaminant

C_2/C_1 = 1 – (removal efficiency/100)

Q = airflow rate, m^3/h

V = room volume, m^3

Q/V = air changes per hour

Table 3 Theoretical Effect of Air Change Rates on Particle Removal

Air Changes per Hour	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).

Using some fraction of outdoor air for diluting indoor contaminates is a common air quality control measure. Outdoor air quality should be evaluated to determine whether and what untreated outdoor air, if any, is hazardous to patients suffering from cardiopulmonary, respiratory, or pulmonary conditions. If necessary, treatment of outdoor air is discussed in ASHRAE *Standard* 62.1.

Locate outdoor air intakes as far as is practical and on different exposures, but not less than 7.6 m, from combustion stacks, exhaust outlets, exhaust outlets, medical/surgical vacuum systems, cooling towers, plumbing vent stacks, heliports, and areas that may collect vehicular exhaust and other noxious fumes. Air intakes should be located at least 9 m 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 3.7 m recommended) but not less than 1.8 m above ground level or, if installed above the roof, 1 m above the roof level.

Exhaust air outlets should be located a minimum of 3 m above ground level and away from doors, occupied areas, and operable windows. Preferably, exhaust outlets should be at roof level projecting upward or horizontally away from outdoor air intakes. Care must be taken in locating contaminated exhausts (e.g., from engines, fume hoods, biological safety cabinets, kitchen hoods, paint booths). Prevailing winds, adjacent buildings, and discharge velocities should be considered (see Chapter 24 of the 2021 *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 Cleaning. Air filters are the most common control measure for air cleaning. Compared to many other buildings, health care facilities need higher levels of filtration due to the higher potential for air contaminants, and some areas (e.g., operating rooms) require a high level of air cleanliness. Filter specifications typically reference the performance classification from ASHRAE *Standard* 52.2. This standard establishes the minimum efficiency reporting value (MERV) for air filters. Filters are classified from MERV 1 to 16. Tests are based on removal efficiency as a percent 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. Although there is no generally accepted ratio of organic to inorganic particles, it is generally accepted that the presence of more airborne particles correlates to a greater number of airborne microorganisms (Birgand et al. 2015).

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.

In some situations, filters are specified using the high-efficiency particulate air (HEPA) rating system. A common designation seen in health care is 99.97% HEPA rated filters. The percentage refers to the removal efficiency of 0.3 µm size particles. Their use might be a code minimum requirement, an operator preference, or design best-practice choice. Although there is no known method to effectively eliminate 100% of viable particles, HEPA and/or ultra-low-particulate air penetration (ULPA) filters provide the greatest air-cleaning efficiency currently available. Note that these efficiencies apply to the fraction of contamination that passes through the filter media. Indoor-generated contaminants present in health care facilities do not necessarily transport back to the filter media.

HEPA filters are required by ASHRAE *Standard* 170-2021 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 are also common for supply air in operating rooms with longer-duration surgeries involving extensive or deep wounds. HEPA filters have been used for discharge air from fume hoods or biological safety cabinets in which infectious, highly toxic, or radioactive materials are processed. 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. Racks need to be designed to withstand high lateral pressures. 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.

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 2020 *ASHRAE Handbook—HVAC Systems and Equipment* for additional discussion. Take appropriate precautions to prevent wetting the filter media by uncontrolled condensation or free moisture from humidifiers.

Air-handling systems should be designed and equipped to allow safe removal, disposal, and replacement of contaminated filters. HVAC ventilation systems may include prefilters, second-stage filters, and final-stage filters. Designers and operators need to understand the code (minimum) filtration requirements, then determine whether additional filtration is needed to meet the health care institution's standard of care. High-efficiency filters are expensive and cause fan systems to use more energy than less efficient filters. Once the level of air filtration is known, the next step is determining the filter type after understanding the facility operator's economic priorities between filter life, first cost, energy cost, and maintenance (installation, removal, and disposal). 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 extends the life of the high-efficiency final filter. As with most HVAC design considerations, a collaborative effort between the engineer and the facility stakeholders is suggested to make the best choice.

Consider providing a local manometer to measure pressure drop across each filter bank. Be sure the gauge range is appropriate (usually 0 to 500 Pa). Mark the gage with the manufacturer's recommended initial and final pressure drops. In addition, where practical, consider using the HVAC automated control system to monitor and alarm. Consider the ability to normalize or benchmark pressure drops and associated airflows and indicate when replacement is necessary, even when air handlers operate at less than full flow. Ensure that in-situ performance testing is done without introducing contamination into the delivery system or the area served.

During construction, openings in ductwork and diffusers should be protected in accordance with the appropriate SMACNA (2007) duct cleanliness level based on the type of facility and the medical services. For most health applications, the highest level of protection (Level C) is commonly specified. It is also a requirement of ASHRAE *Standard* 170, which aims 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.

Air temperature and humidity 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. 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. However, this is at odds with some recent findings that higher levels of humidity might reduce the transmission of infection.

Other types of air cleaning technologies include ultraviolet (UV) light, ionization, and chemicals. Guidance on using germicidal ultraviolet (GUV) energy as an adjunct infection control measure may be found in Chapter 62 of this volume and Chapter 17 of the 2020 *ASHRAE Handbook—HVAC Systems and Equipment*. These references provide information for using GUV for applications on both air and surface disinfection.

The range of ultraviolet (UV) radiation is typically divided further into UV-A (wavelength between 400 and 315 nm), UV-B (wavelength between 315 and 280 nm), and UV-C or germicidal UV (wavelength between 280 and 200 nm). Only UV-C provides the strongest disinfection radiation that inactivates bacteria, viruses, and fungi. In general, using GUV out of the sight of the occupant is suggested, because WHO and CDC deem UV-A, UV-B, and UV-C as carcinogenic to humans (American Cancer Society 2019).

ASHRAE's Epidemic Task Force web site (www.ashrae.org/covid19) provides guidance on new applications and emerging technologies, along with cautions and concerns. The U.S. Centers for Disease Control and Prevention and NIOSH are also recommended organizations for guidance and resources.

Some 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. Although ozone has disinfecting properties and reduces viruses, bacteria, and fungi, exposure to ozone creates risk for symptoms and diseases to the respiratory system. Therefore, it should only be used in unoccupied spaces and any air-cleaning devices that produce ozone and are not in compliance with UL *Standard* 2998 certification. This does not necessarily imply the technologies do not work as advertised. However, in the absence of an established body of peer-reviewed evidence showing proven efficacy and safety under as-used conditions, the technologies are still considered by many to be "emerging."

Containment. Directional airflow created by air velocity or air differential pressures is a control measure used to help prevent migration of contaminants. This can be applied in health care facilities to aid in limiting potentially infectious or contaminated particles transferring from one area to another. Figure 1 illustrates the concept of 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. If the level of cleanliness is critical, anterooms are a proven, effective measure to help provide additional protection or containment.

Air pressure differential will cause air to flow in or out of a room through various leakage areas (e.g., perimeter of doors and windows, utility/fixture penetrations, cracks). In some cases, the differential level only needs to be enough so that a visual conformation of the airflow direction can be made when the doors are closed. Smoke sticks or "ball-in-tube" devices are two methods used for these situations. In more critical applications, a minimum differential pressure level is required. ASHRAE *Standard* 170 requires some areas to maintain a minimum of 2.5 Pa. To effectively maintain this level of differential, a tightly air sealed room is key, both above and below the ceiling. Use tight-fitting doors with small undercuts, and seal all joints and penetrations of the walls, floors, and ceiling. It is critical to consider all

penetrations and air gaps, including those caused by the medical equipment and their subsystems (e.g., disinfection washers) and all their piping penetrations (including ones above the ceiling).

Opening a door between two areas immediately reduces the differential air pressure between them. 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.

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 dilution and control of air that passes from one space to another every time a door is opened and closed.

Table 4 Health Care Occupants and Thermal Comfort Factors[a]

Thermal Comfort Factors	Medical and Support Staff	Patients	Visitors/Caregivers
Environmental Air temperature, radiant temperature, air speed, humidity	Medical/support service specific varied control of the thermal environment: multi-occupant to individual, high air speeds in some medical procedures	Medical service specific Some control of the thermal environment by staff and caregivers	Common seasonal thermal adaptation
Personal Metabolic rate, clothing insulation	Medical/support service specific Limited personal thermal adaptation Required clothing/uniform Activity: steady – transient	Medical service specific Gowning / bedding Personal thermal adaptation Standing, sitting, lying, sleeping, immobilized	Common seasonal thermal adaptation
Other Psychological, work-related, health-condition-related	Mental stress, fatigue, workload, performance, arousal, health condition, well-being	Anxiety, length of stay, health/wellness condition, age, medication impact, healing, overall comfort	Anxiety, short stay, support

Source: Mora and Meteyer (2018).

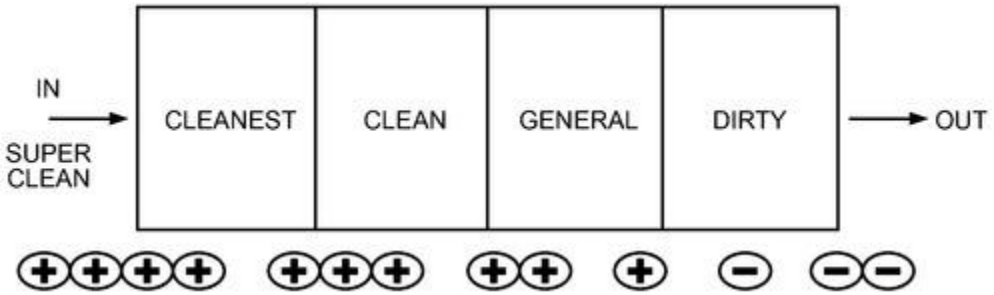

Figure 1. Controlling Air Movement through Pressurization

Another practice for sensitive ultraclean areas is placing laminar flow supply air outlets at the ceiling, and several perimeter exhaust outlets near the floor. This arrangement provides downward movement of clean air through the breathing and working zones towards the floor for exhaust.

2.3 THERMAL COMFORT IN HEALTH CARE

Patient and staff thermal comfort is a key design consideration for HVAC systems. HVAC designers should collaborate with the facility planners and operators on the temperature and humidity requirements for thermal comfort and for any clinical or medical needs.

Thermal comfort is critical: it has a role in supporting patient recovery (Van den Berg 2005) and impacts performance of medical staff (ASHRAE 2013). Challenges in designing for thermal comfort in health care facility applications include the diverse environments and occupants, and the transient nature of the occupants (Mora and Meteyer 2018).

Thermal comfort modeling research dates back to Fanger in the 1970s and is ongoing. ASHRAE *Standard* 55 provides methods to support thermal comfort analysis and design for buildings intended for human occupancy. These methods are based on well-established principles, models, and comfort metrics. See Chapter 9 of the 2021 *ASHRAE Handbook—Fundamentals* for a more comprehensive and detailed discussion of thermal comfort. The research suggests that there are four environmental (ambient air temperature, radiant air temperature, relative humidity, and air speed) and two personal factors (metabolic rate and clothing insulation) that, once known, can predict a level of satisfaction for a high

percentage of occupants. However, applying *Standard* 55 thermal comfort models to occupants in health care facilities involves special consideration. Such models identify a representative occupant for different activity and clothing levels. Table 4 outlines considerations related to the thermal comfort factors for three common groups of heath care facility occupants.

Figure 2 illustrates the effect of conditions on patients' ability to sense and regulate thermal comfort, ranging from healthy to unhealthy. Applying thermal comfort models such as those in *Standard* 55 requires judgment regarding the range of patient conditions.

Unlike many other types of building occupants, occupants in health care facilities are often transient, both patients and staff.Some patients may spend hours or days in a room, but many patients and medical staffs' daily activities are often transient, with constantly varying activity levels, moving between rooms and wards with different environmental conditions. The effects of transient conditions on thermal comfort are important because the body takes time to adapt to new conditions (Loomans et al. 2018).

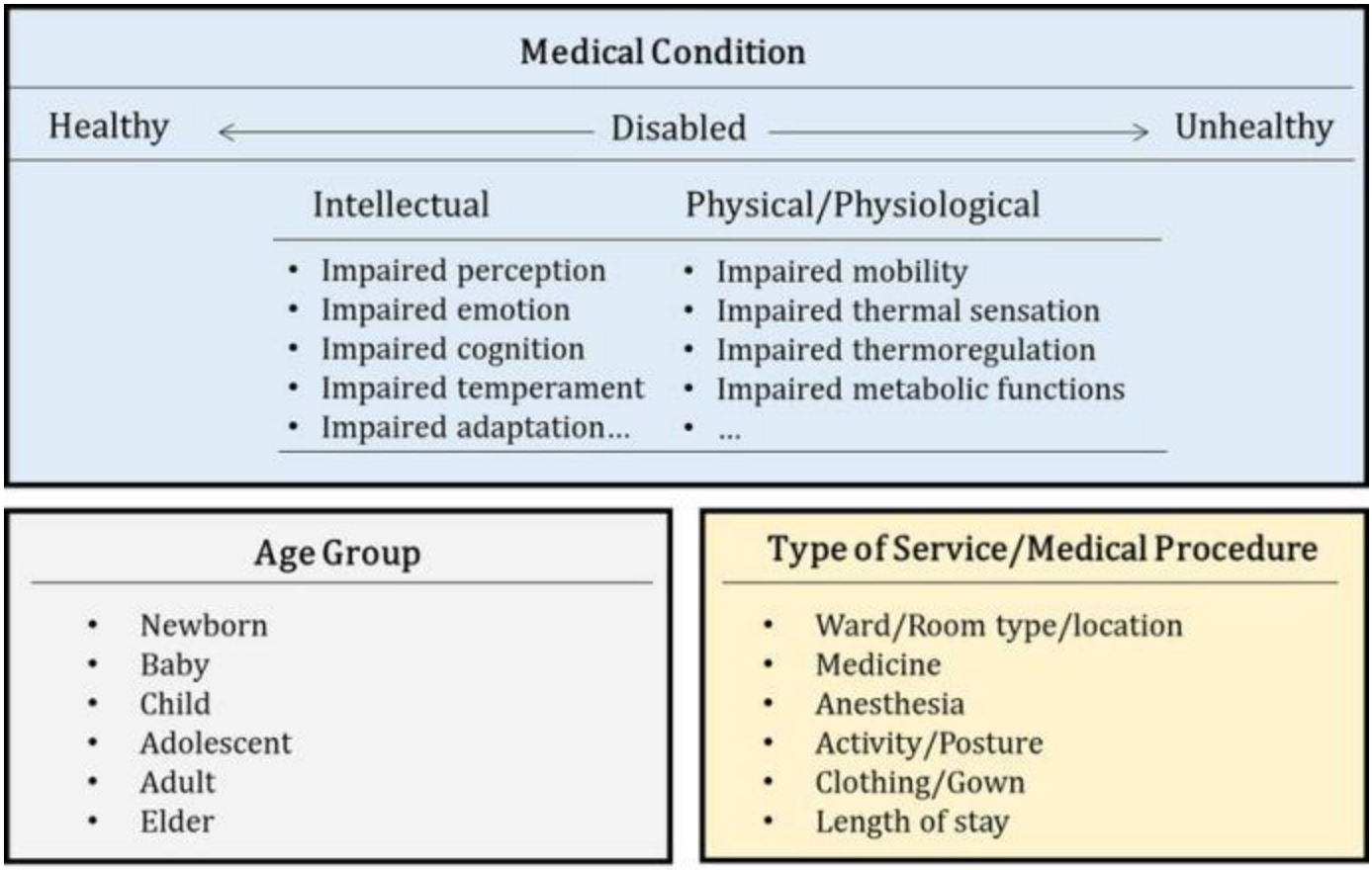

Figure 2. Thermal Comfort Factors for Patients (Mora and Meteyer 2018)

Medical-staff clothing and activity levels needed in thermal comfort models are wide ranging and data is limited. ASHRAE Research Project RP-1760 is under way to update the clothing database for Western clothing ensembles, including effects of posture, body and air movement; it includes a section for medical staff and patient clothing. Medical care staff typically wear task-specific uniforms for sanitary or protective reasons. For example, surgical and decontamination staff wear highly protective clothing, often with limited permeability, including gowns, hats, shoe coverings, and double gloves. Currently there is a lack of data on health care activity metabolic rates. There are some activities (e.g., performing surgery) where the stress and activity level are hard to characterize. Care and caution are advised when the estimated or expected metabolic rates are beyond the limits of the thermal comfort modeling.

HVAC designers should consider how thermal comfort can be achieved where the patient, medical staff, and/or guest are concurrently occupying spaces. One approach might be to apply *Standard* 55 for the medical staff to determine the range of acceptable thermal factors. Typically, staff activity and clothing levels are higher than the patients. In these situations, the staff would prefer lower air temperatures. According to Wyon et al. (1968), a way to reconcile the differences in thermal needs between patients and medical staff is through clothing adjustments. However, clothing adjustments are often not feasible when medical procedures require specialized protective clothing.

Room thermal environmental technologies and personalized comfort systems (PCS) have been proposed as a promising example to settle individual thermal comfort differences, to enable less uniform indoor temperatures and less strict space temperature control (Zhang et al. 2015). Warmed blankets have been proven effective in reducing cold discomfort in elder patients (Robinson and Benton 2002). Research in PCS in health care has mainly focused on specialized applications; for example, comparing the effects of warm forced-air, localized radiant heat, and conductive bedding approaches to prevent patient hypothermia during and right after surgery Giuffre et al. 1994; Wong et al. 2004).

2.4 ACOUSTICS

Acoustics in health care is another important environmental condition that HVAC designers need to understand and consider. The Hospital Consumer Assessment of Healthcare Providers & Systems (HCAHPS; www.hcahpsonline.org/) is a survey consisting of 29 questions to measure the patients' perceptions. A patient's level of satisfaction related to sound and noise is one of the 29 questions. Additionally, the Health Insurance Portability and Accountability Act (HIPAA), specifically the Privacy Rule, is intended to put reasonable provisions in place to safeguard individuals' personal health information (PHI).

Other resources that may offer guidance for the acoustical design or testing of spaces include

- FGI *Guidelines for Design and Construction of Hospitals*
- FGI *Guidelines for Design and Construction of Outpatient Facilities*
- FGI *Guidelines for Design and Construction of Residential Health, Care, and Support Facilities*
- *Health Technical Memorandum* 08-01: Acoustics, by the UK Department of Health

Acoustics and the Occupant. There is no single answer as to what constitutes good acoustics. However, the studies and surveys have affirmed that speech privacy, or more generally a notion of **acoustical privacy**, is the strongest indicator of acoustic satisfaction for a space (or the reverse: a lack of speech privacy is the most common and significant complaint). Other fundamental and common objectives to achieving acoustical satisfaction include intelligibility of sound (considers the application, e.g., speech or music) and the concept of **acoustical comfort**. Although there is no standardized methodology for assessing acoustical privacy, speech privacy metrics are defined and measurable. The Speech Privacy Class (SPC) was developed by the National Research Council of Canada in the early 2000s to obtain an indication of greater degrees of speech privacy (i.e., speech security; the degree to which speech is inaudible) than possible with the AI. The methodology of the SPC is covered in ASTM *Standard* E2638.

Acoustical Fundamentals. Table 1 of Chapter 49 is one source that lists acceptable sound level ranges. Although the specification of background noise limits target maximum allowable levels for noise, each table offers its own reservations (or assumptions) to address the different characteristics of sound:

- **Temporal:** Sound emitted from noise sources is expected to vary with time. Some schemes incorporate provisions for intermittent events exceeding maximum overall sound level limits (i.e., averaged measurements).
- **Spectral:** Sounds emitted from noise sources are assumed to be spectrally neutral or absent of tonal characteristics.
- **Spatial:** Measurements are to be conducted at highest-risk locations expecting highest levels of noise. Although such an effort is an effective precautionary strategy to ensure noise in a space does not exceed maximum allowances, it does not always provide for acoustic consistency in that environment.

Single-value acoustic or sound metrics are convenient yet imperfect solutions to reducing large amounts of acoustic data. There are two types of single-value metrics: (1) a measurement-based value that averages and sums, and (2) averages and curve fits.

Type 1: sound pressure is measured with a microphone and reported in units of decibels (dB). Many parameters can be used to characterize acoustic conditions in a space, so the application must be considered. Some examples include

- Slow- or fast-weighting
- Unweighted, A-weighting, C-weighting scales
- Range (minimum, maximum, overall, *n*-percent exceedance (i.e., a sound pressure level that is exceeded *n* percent of the time)

Type 2: this includes noise rating systems such as the noise criterion (NC) and noise rating (NR). NC uses measurement-based data to which a reference contour is applied. The room criteria (RC) method differs slightly.

Laboratory-Based Metrics. Products tested and measured under controlled settings following standardized testing procedures provide repeatable and reproducible results. This allows a designer to compare equipment options and determine the relative difference in sound production.

Field (In-situ)-Based Metrics. Unlike performance measurement of acoustical products in a controlled environment, in-situ acoustical standards and associated acoustic metrics have been developed to account for parameters that may contribute to uncertainty.

Speech Privacy. A brief review of speech privacy theory provides insight into understanding how to address acoustics in the built environment. Speech privacy metrics are often referred to as **signal-to-noise ratio** calculations because their formulation consists of three parts:

1. A sound source (e.g., speech of normal vocal effort)
2. The path of sound transmission (e.g., transmission of speech between rooms or between two positions in an open-plan area)
3. The receiver (e.g., normal or hearing-impaired listener, background sound level at the listener)

The physics explaining the degree to which speech (or any sound) is intelligible is referred to as the **masking effect**. The degree to which the received level of sound is intelligible or audible depends on the background sound level at that receiver position.

3. OPERATIONS AND RELIABILITY

With the varied types of facilities and corresponding occupants, HVAC design needs to consider reliability, including, in some situations, redundancy, standby, or other means to avoid the loss of the HVAC systems due to planned and unplanned equipment failures. Factors that impact the level of reliability include whether equipment and components are made for the application, quality of materials, quality of installation, whether systems operate within the equipment's tolerances, and proper and timely maintenance. The HVAC systems should have the appropriate level of reliability and maintenance features that align with the capacity and resources of the facility operators. Work with the operators to determine the appropriate level of resiliency and redundancy and agree on how the HVAC system design will meet their expectations. Include items like the expected downtime, ease of acquiring replacement parts, and level and location of specialty service technicians.

3.1 OPERATIONS

Benchmarking

The American Society for Health Care Engineering (ASHE) is a professional association that provides references, education, regulatory guidance, and professional development for those who design, build, maintain, and operate hospitals and other health care facilities. ASHE 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.

Planning and Design

Planning and design for the HVAC system must incorporate equipment and features, level of equipment quality, spare capacity, redundancy or standby, service access, level of automation, and alarms and notifications that support the facility operations during all the expected modes of operation. ASHRAE *Standard* 170 includes operational facility planning requirements. Characteristics mentioned include age, capacity, and reliability of HVAC equipment; its importance to the facility mission; and skill and number of personnel resources to operate and maintain it. Operational planning should address loss of normal power scenarios, planned maintenance and unexpected failures, back-up fuel sources, redundancy strategies, temporary measures, and other possible abnormal events.

Loss of normal power can occur without warning and last for extended periods. Depending on the nature of the facility, the planning and design to accommodate events will be different. In some cases, there are minimum code requirements for what HVAC systems must operate on emergency power and for how long. The code requirements are minimums and do not necessarily represent what the facility operators need or expect. Clarification with the operators and AHJs early in the design process will avoid costly alterations later.

ASHRAE *Standard* 170 is often referenced for the operational limits for space temperature, humidity, and airflow parameters even though the standard is intended only as a minimum design standard. This creates potential operational conflicts with various functions in the facility. One of the most frequently cited examples is operating room conditions. There are often clinical, staff, or patient needs for space temperature and humidity that might be outside the *Standard* 170 listed temperature and humidity range. It is important for HVAC designers to understand the medical and facility operator's requirements for the space temperature and humidity. Select the equipment and components to not only meet the code but also the operator's requirements. Do not make the mistake of sizing and selecting equipment to meet a code (minimum), standard, or guideline unless that is the direction given by the medical and facility staff.

Construction

During construction, remodel, and maintenance activities in and around a facility, special considerations apply. Construction and maintenance activities can have adverse impacts on IEQ within facilities. Risk assessments such as an **infection control risk assessment (ICRA)** and interim measures must be evaluated, documented, and implemented to protect the IEQ of the operating facility. FGI *Guidelines*, NFPA *Standard* 99, and ASHRAE *Standard* 170 outline requirements related to these assessments and the evaluation of risk.

Operations

Certifying agencies require facilities to create operational plans that outline normal operating parameters for the systems and set limits on monitored parameters to determine when systems are operating outside of normal conditions. These are created based on industry standards published by varying organizations such as ASHE, Association for the Advancement of Medical Instrumentation (AAMI), Association of periOperative Registered Nurses (AORN), and ASHRAE.

ASHRAE TC 9.6 published a white paper dealing with humidity control within perioperative care areas (tinyurl.com/TC96periop Humidity). It provides a framework for developing a set of actions for when humidity falls outside requirements. A cross-functional team of medical and facility representatives should develop the action plans, taking into account how critical humidity control is for the room, and the length of time and amount the humidity is outside the requirement. The white paper contains an example from an actual facility that has implemented it. ASHRAE *Standard* 170 also provides recommended operations and maintenance procedures for certain health-care-specific rooms in its Informative Appendix A; also see Chapter 40 of this volume.

Maintenance

Without routine inspection and maintenance of HVAC system components, systems might operate outside of their optimum performance parameters. Often, manufacturers' maintenance information applies only to their components, not the entire system. ASHRAE *Standard* 180 establishes minimum HVAC inspection and maintenance requirements to preserve a system's ability to achieve acceptable thermal comfort, energy efficiency, and indoor air quality.

Designers and operators of health care facilities need to consider preventative maintenance and unpredictable failures in the same manner as the level of reliability at the beginning of this section. The cost/benefit in minimizing downtime and disruptions depends on the health care services provided, patient and resident conditions, and health care organizations' priorities.

In facilities with centralized HVAC systems, automated control systems can be set up to alarm or alert when certain parameters are outside the expected operating range. Over time, automated control systems are often overridden or altered to address an immediate issue and would benefit from periodic tune-ups to avoid unplanned downtime or unexplained operational issues that commonly arise after these overrides and alterations. Often, sensors are out of calibration, resulting in parameters out of intended limits. Training and consistent commissioning are necessary to keep the systems operating correctly.

3.2 LIFE SAFETY

HVAC designers must know where within a facility and to what degree the patient population is incapable of "taking action for self-preservation" (NFPA *Code* 101) during an emergency. Some patients are dependent on life-support equipment. It is key to understand the building systems that have life safety features and systems providing early warning, suppression, and containment of fire and smoke.

Life safety as it applies to health care facilities is covered in detail in ASHRAE's (2013) *HVAC Design Manual for Hospitals and Clinics*. Before beginning design, be sure to check for new reference editions and code versions.

The designer must understand what is required to support a "defend-in-place" fire response as it relates to the interaction between the smoke compartments, HVAC air system zoning, automated controls, and the fire alarm system. During a fire or smoke event, facilities have emergency plans for how the medical staff will aid moving patients to adjacent smoke compartments and then to another floor, with building evacuation as a last resort. Even practicing these plans is a logistical challenge.

Awareness of the various codes and standards with requirements to support life safety in these facilities is critical. The engineer and code authority should carefully plan system operation and configuration to define smoke compartment and air system sequences that occur once smoke is detected or when a fire alarm is activated. Refer to Chapter 53 and NFPA *Standards* 70, 72, 90A, 92A, 99, 101 and 110 as enforced by the AHJ.

Elevator Hoistway Opening Protection

When the building is considered a high-rise or I-2/I-3 occupancy and connects more than three stories, hoistway opening protection is required. The *International Building Code* allows several ways to protect the openings, such as using an enclosed and rated elevator lobby at each floor, fire/smoke curtains at each opening with smoke and draft control, or an elevator hoistway pressurization system. Recent code changes to the pressurization method makes the last method difficult and costly. Caution and expertise are required if considering the pressurization method. There have

been multiple examples reported that fan systems had to be increased three to five times over the original airflow (e.g., DeVore 2021).

3.3 EMERGENCY OPERATIONS

Resiliency planning is quite different between inpatient, outpatient, and residential facilities. Many outpatient facilities can develop resiliency plans based on the cost/benefit of preventing or limiting interruption of services compared to the potential life safety impact in hospitals and some health care residential facilities.

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.

Seismic Considerations

Recent changes in U.S. building codes have increased the number of locations where new hospital construction requires seismic certifications for most of the HVAC equipment, along with independent, qualified special inspectors, and specification and installation of equipment and component seismic restraints. Refer to ASHRAE (2013) for more information.

Many health care facilities have on-site diesel-engine-generated electric power, which can necessitate EPA fuel storage permitting, security requirements, and air permitting issues. Again, see ASHRAE (2013) and the Emergency Operations section for more guidance.

In response to the recent weather disasters and the recent global pandemic, the FGI has developed a set of guidelines specific to health care facilities. The Facility Guidelines Institute (FGI) Emergency Conditions Committee has developed *Guidance for Designing Health and Residential Care Facilities that Respond and Adapt to Emergency Conditions* (FGI 2022). This resource provides guidance on performing risk assessments, recommendations for resiliency, and methods to address surge capacity. Some of the most significant recommendations are summarized in the following sections: Risk Assessment, Resiliency and Surge Capacity Considerations. Designers are also encouraged to evaluate local, state, and federal emergency guidelines from FEMA and CMS.

Risk Assessment for Facility Adaption to Emergency Conditions

It is recommended that a risk assessment process be used to identify potential hazards, analyze what could happen if a hazard occurs, and determine the capability and the plan to respond. If performed during the design phase, features and components can be specified appropriately. The FGI "Emergency Conditions Guidance" document identifies these risks by recommending a **disaster, emergency, and vulnerability assessment (DEVA)**. The three steps of this assessment are as follows:

1. **Identification:** To identify hazards specific to a health care facility, the facility's location, how it operates, and its points of failures must be known. Consider the following questions: What is the acuity level of the occupants? What are the expectations for remaining operational; does the facility need to be considered a shelter-in-place? Is the area prone to flooding, snowstorms, earthquakes, hurricanes, or power outages? It is important to understand how these hazards could interrupt operations at the facility. Consider reliability, maintenance, and redundancy of HVAC systems in this phase.
2. **Evaluation:** Identify the potential risk and severity of impact of possible hazards on the facility. Identify infrastructure and resources required to be operational during an emergency or disaster. Consider the following questions: How would a utility failure effect the operation of the facility? How much fuel does the facility have in reserve to operate a generator or any other fuel-based equipment for an anticipated outage? Is 100% of the cooling capacity backed up by emergency power? Consider other resources, such as domestic water for continuity of service of HVAC systems and sterilization of instruments. This will help to build a prioritization matrix/triage plan that focuses on addressing the most critical issues first.
3. **Solutions:** The last phase of the risk assessment is generating and recording solutions to potential hazards to the facility. Disruption to existing facility operations, cost implications and safety should be considered when developing solutions.

Resiliency

The design team and facility operation team need to have a common understanding of the need to remain operational and to what degree during various adverse events. The design should provide the features and flexibility to adapt to meet those expectations. Regardless of the event, adapting in place means having the ability to reasonably

address the event while still fulfilling the basic needs of the facility. The following system considerations start to provide the framework for determining the adaptability features for a facility.

Heating and Cooling Systems. Include equipment and distribution redundancies, spare or standby capacity and control, provisions for connecting to portable equipment, spare part availability, and local service expertise and response. Provide a plan for system load shifting or shedding capability. Anticipate failures and have the features or components for the adaption plan (e.g., isolation valves for piping failure).

Common mitigation approaches include on-site fuel storage; dual-fuel equipment; on-site water storage (and treatment); multiple incoming utility sources for power, fuel and water systems; looped utilities where remote plants are used; and emergency connections for portable equipment to replace or supplement critical infrastructure when added capacity is needed.

Ventilation Systems. Include temporary means such as air filtration units, portable negative air machines, manual operation of control systems, and adjusting airflows in areas of the facility in addition to the equipment and distribution redundancies that are common among all systems. Consider whether any non-patient care areas need to be adaptable to function as an impromptu patient area. What provisions are needed to address filtration/cleaning of air when outside air quality is less than adequate?

Common mitigation approaches include the use of redundant fans or fan array systems that allow for partial or full redundancy of equipment, maintenance of a set number of negative air and HEPA filter machines that can be deployed to areas to increase local ventilation or create pressurized areas, inclusion of space for additional filtration in air handling systems to allow for upgrading filtration efficiency or type and configuring equipment to allow for 100% outdoor air operation.

Water Supply. For most buildings, the water service is a single source and thus a single point of failure. For health care facilities, some jurisdictions (IAPMO 2021) require a minimum of two potable water service sources to ensure continuity in the event of normal water main interruptions. This is good practice, even if not required. However, even with multiple incoming municipal water entrances, the public water supplies should not be completely relied upon in all scenarios, because natural disasters may render the public water system unusable or contaminated. Additional provisions should be made for potable water needs as part of a facility's operations plan, which may include one or more of the following: secondary connections to utilities, a private well, on-site storage, site water retention, and/or emergency connection for trucked in potable water (CDC/AWWA 2019; FGI 2022). Water treatment and delivery must be considered with each of these as each option may need various additional components for proper operation. Any equipment related to these measures should be powered by the building's essential electrical system.

To support the continued use of the building systems, facility operators and administration should develop a plan to ensure that all necessary water demands are addressed during the planning phase. Nonessential uses should be identified in the plan, along with ways for minimizing usage during emergencies to allow for proper sizing of any redundant supplies. The CDC and American Water Works Association developed a guide (CDC/AWWA 2019) to help facilities and designers with this process.

Water can be critical for HVAC systems. Water is needed to replenish evaporated water from cooling towers or other evaporative cooling systems and water-cooled air-conditioning systems serving critical functions like food refrigeration and imaging equipment. It is also needed in steam systems for blowdown and end-use consumption for heating, humidification, and sterilization. These needs are in addition to the water necessary for human consumption and disposal of human waste; without water for these systems the building will become nonfunctional relatively quickly.

Surge Capacity Considerations

Occasionally the health care facility may need to adapt to a temporary increase in medical provisions in a specific area that exceeds the planned, intended capacity of a particular health care building, facility, or system. This surge capacity may require the emergency department to expand to increase ICU bed capacity or the capacity of general inpatient populations, or create a temporary morgue.

Interior. The architectural and HVAC system surge plans need to align. During design, planning for flexibility is key. Plan for the highest patient acuity level that is practical. Anticipate requirements needed for a quick conversion of the space. Where possible, providing **universal care rooms** or **surge capacity rooms** allows facilities to quickly convert a private patient room to a semiprivate room, ICU space, or negative pressure room. What is the plan for adapting or supplementing the HVAC systems for the increase occupancy? Include increased cooling and ventilation needs and the ability to adjust supply and return/exhaust offset points on the air terminal units. Consider portable air filtration systems or negative pressure machines to increase air change rates, facilitate protective directional airflows, and control pressurization.

Exterior. Where expansion potential is limited within the existing hospital interior, there may be a need for an on-site exterior treatment area (also referred to as **alternate care site**), such as a triage station. Depending on the nature of the triage, HVAC may be necessary to provide containment for infectious patients. Climate control may also be necessary to provide proper care to the patients and protect the staff. This surge strategy should be carefully considered, especially when extreme weather events (heat, cold, wind, precipitation) are possibilities during the occupancy of the space. The facility workflow for care of the occupants should be closely reviewed to determine the HVAC requirements and limitations for such an installation.

4. ENERGY USE AND PERFORMANCE

Health care facilities, especially hospitals, are energy intensive. Hospitals operate 24 h a day, year-round, and require large quantities of highly filtered ventilated air to meet code requirements that are intended to assist in improving the air quality. Energy is also used to power diagnostic, therapeutic, and monitoring equipment, and to support services such as food storage, preparation, and service and laundry facilities.

4.1 BENCHMARKING

Figure 3 shows hospital energy consumption by country, hospitals in North America use the most energy. Those in Germany use the least, with hospitals of United Kingdom and Scandinavia in between.

The data in Figure 3 was compiled from several sources, including CADDET (1997), CBECS (2012), Department of Health (2015), Gonzalez et al. (2018), and Integrated Design Lab (2012).

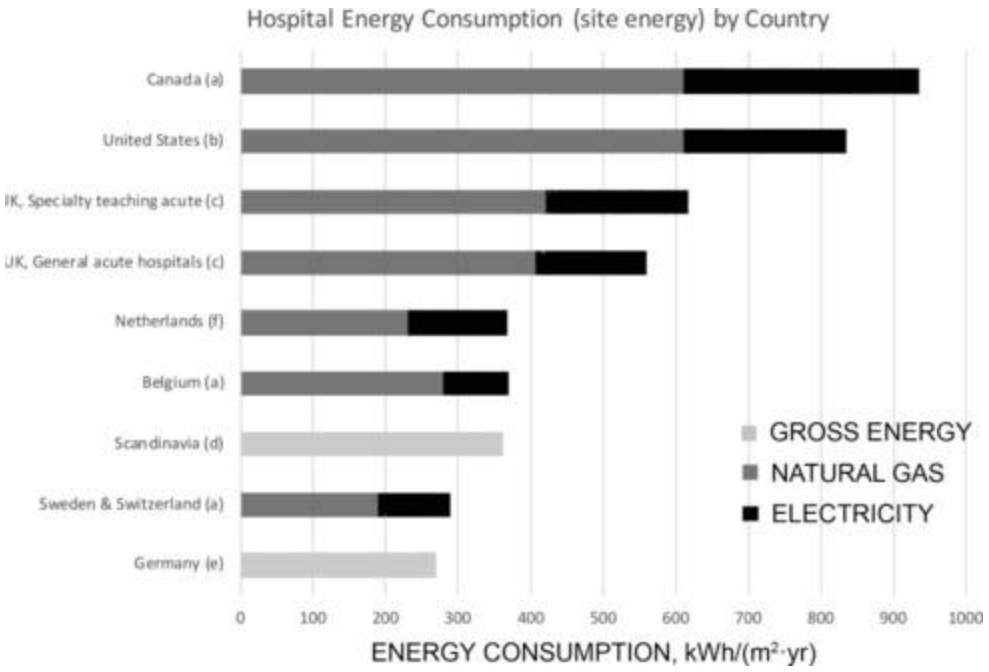

Figure 3. Benchmarking of International Hospital Energy Use

U.S. hospital energy use contrasts with the remainder of the U.S. commercial building portfolio, as Figure 4 shows. Hospitals have the second highest energy intensity of any building type. The U.S. Health Sector generates nearly 8% of US carbon emissions (Health Care Climate Council 2017), at a cost of more than $9 billion in annual energy costs. U.S. hospitals consume more than 2.5 times the average primary energy of office buildings: 231 kBtu/ft^2·yr728 kWh/(m^2·.yr) compared to 88 kBtu/ft^2·yr277 kWh/(m^2.·yr) (CBECS 2003).

Energy end-use studies, where available, show that ventilation and thermal energy consume more of a hospital's energy than any other element (CBECS 2003, 2012; Hatten et al. 2011). Therefore, HVAC systems are an obvious area to seek reductions. Figure 5 illustrates measured energy by end-use in a U.S. hospital, showing the total electricity and natural gas serving the hospital and the proportion of energy attributed to each function of the hospital (Hatten et al. 2011). This is one of the few studies that has actual measured data for each of the categories shown compared to estimates from energy use modeling.

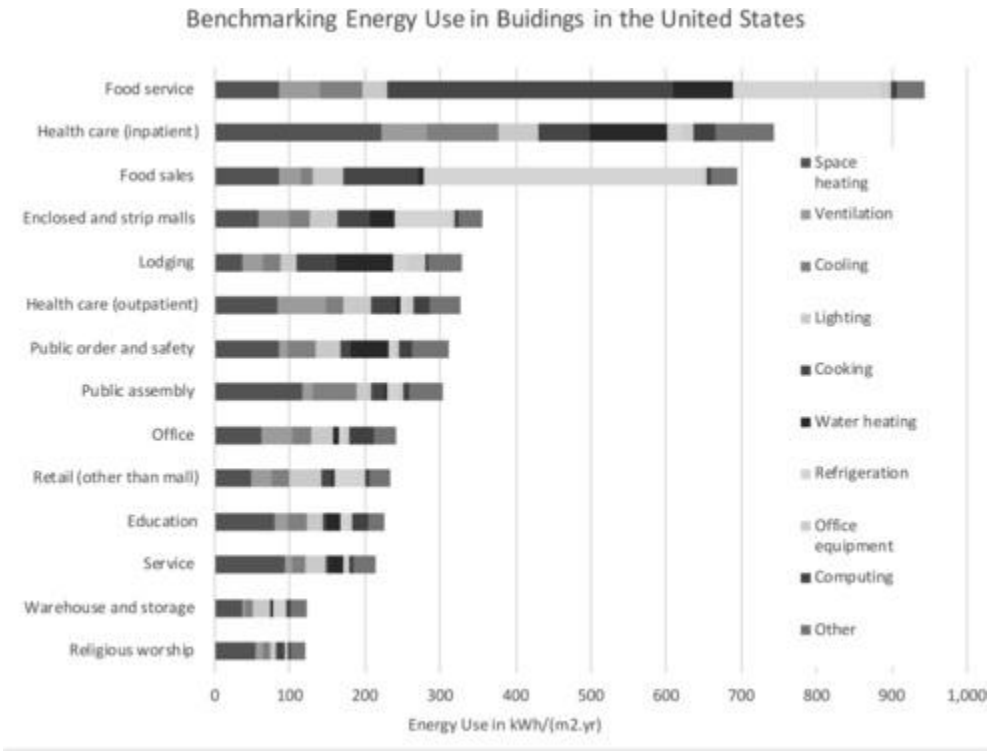

Figure 4. U.S. Building Type Energy Use Benchmarking Benchmarking from CBECS (2003, 2012) comparing different building typologies in the United States with energy end-uses indicated.

4.2 PERFORMANCE

Hospitals can conserve energy in various ways, including 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) provides substantial savings (Setty 1976).

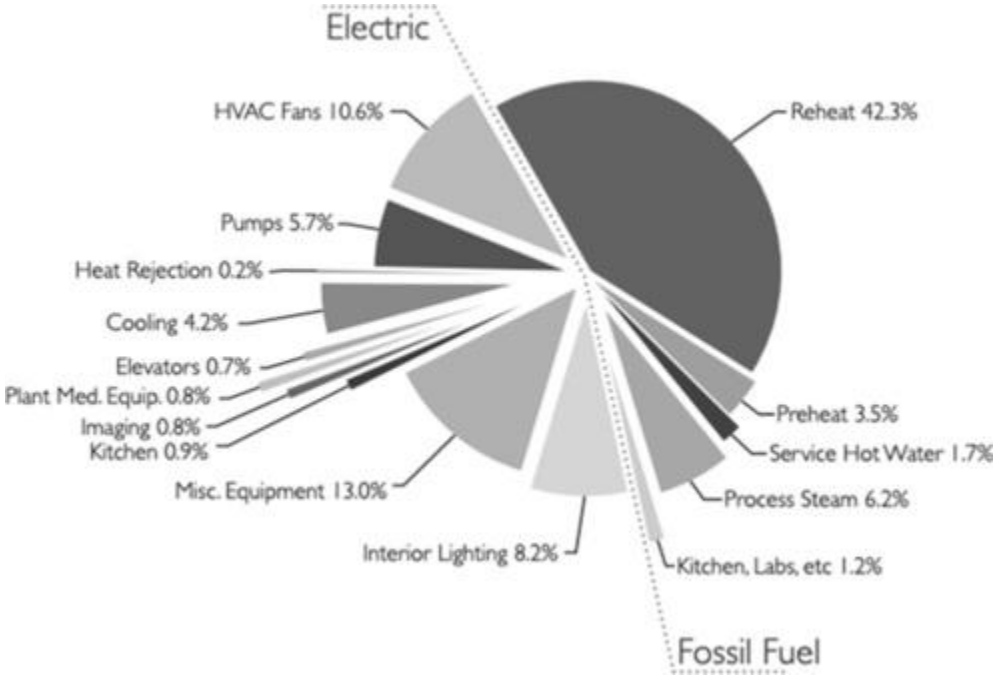

Figure 5. Energy by End Use in U.S. Hospital (Hatten et al. 2011)

Figure 5 shows that over 40% of U.S. hospital energy is for reheat. That level of reheat is consistent in most U.S. hospitals. The cause and the challenge are the result of the ventilation air change rates required by code exceeding the amount needed to cool the room. The air changes per hour cause more supply air than needed to meet the cooling load coupled with the low supply air temperature needed for dehumidification. To prevent cooling the room to unacceptable temperatures, the air is reheated at a terminal unit. This occurs almost 24/7, year round, and is not significantly influenced by climate because hospitals have relatively small amounts of envelope or exterior skin compared to interior areas and are heavily cooling dominant. This level of energy use is important to those interested in reducing the carbon or energy footprint of hospitals.

Resources to help reduce energy consumption in hospital facilities include ASHRAE *Standard* 90.1, the *Advanced Energy Design Guides* on hospitals (ASHRAE 2009, 2012), and ASHRAE *Standard* 189.3. Control strategies such as supply air temperature reset on variable-air-volume systems and hydronic reheat supply water temperature reset on variable pumping systems may be applied with good results but should be applied with care: undesired impacts on temperature and (especially) humidity can result. In general, alternative design options should not only include comparing the energy savings and first-cost difference, but also should consider the impact on the systems reliability and maintenance. The facility operator needs to be staffed and be able to operate the systems to realize the energy saving benefits. An example of a common energy saving strategy and how it often falls short of delivering the savings in hospital applications is presented by Koenigshofer and Roberts (2018).

Gvozdenovic et al. (2014) presented a five-step method, illustrated in Figure 6, that can help develop strategies and options to achieve target energy performance in hospitals. The steps are

1. **User demand and behavior.** Provide the optimal amount of services based on user demand and behavior. Eliminate or minimize over-running of energy-using systems (e.g., do not run HVAC systems overnight in administrative or day-clinic areas).
2. **Reduce energy use.** Apply conventional measures to reduce energy use. Consider better insulation, less infiltration, and higher-efficiency mechanical and electrical equipment and systems. Also consider medical and office equipment, elevators, kitchen systems, laundry systems, and any equipment that requires energy.
3. **Apply sustainable energy sources.** Wherever possible, substitute energy from sustainable energy sources. Investigate use of sustainable and renewable energy sources, either on-site (e.g., aquifer thermal energy storage [ATES], photovoltaic [PV], geothermal, biomass, wind energy) or off-site (e.g., wind energy, solar PV or thermal, biofuel).
4. **Energy exchange and storage systems.** On- and off-site energy sources vary in availability. Optimize energy exchange for the site and its surroundings (e.g., using surplus heat in offices for homes) and store energy from available hours (e.g., short-term heat and cold storage, and long-term energy storage in the soil).
5. **Use renewable energy when possible, and use fossil fuel efficiently.** The remaining amount of energy needed should be purchased, as much as possible, in the form of renewable energy.

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.

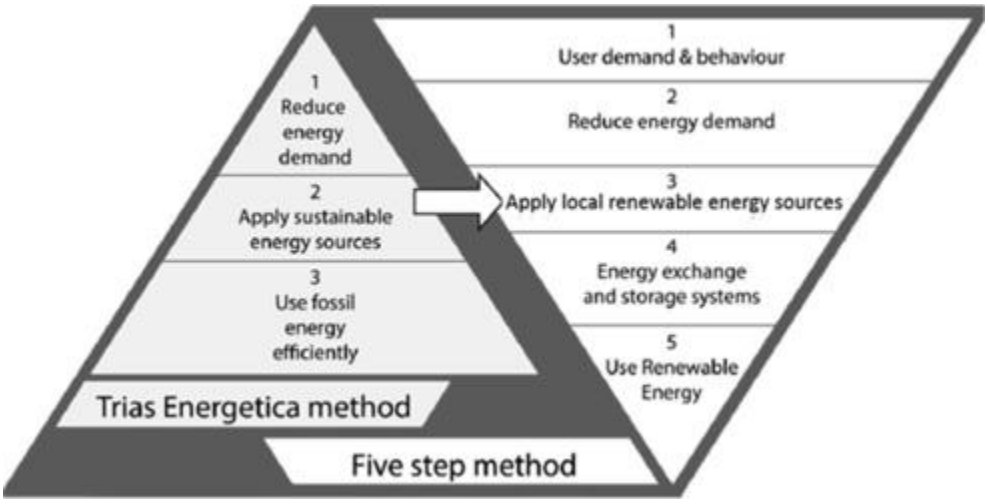

Figure 6. Five-Step Method to Systematically Achieve Energy Performance (Gvozdenovic et al. 2014)

Natural Ventilation

In the right climate, location, and application, natural ventilation can enhance the healing environment. Natural ventilation has been successfully implemented in health care facilities throughout the world. A 2017 ASHRAE task group report (Ninomura et al. 2017) suggested natural ventilation for most health care spaces, except for operating rooms, procedure suites, sterile core areas, interventional radiology, cardiology spaces, compounding pharmacies, airborne infection isolation areas, and protective environments, and any critical care areas or patient care spaces that require pressurizations. Natural or mixed-mode ventilation designs may offer some benefits.

The most likely benefits of natural ventilation are energy reduction and enhanced occupant satisfaction. Perhaps less likely benefits may include enhanced indoor air quality and a better microbiome. Patient perception of fresh air may be another measure of enhanced occupant satisfaction (Ninomura et al. 2017). Some U.S. designers or owners may be averse to natural ventilation due to its newness, possible added costs, or perceived impacts on clinical outcomes. When considering natural ventilation in health care, designers must fully address the fundamental challenges of space appropriateness, climate appropriateness, acoustics, security/safety, and outdoor air quality. Projects implementing natural ventilation should anticipate commissioning challenges; many commissioning and air balance providers in the United States are not experienced with natural ventilation systems.

5. HVAC SYSTEM DESIGN CONSIDERATIONS

Designing HVAC systems for health care facilities presents unique challenges. The type of medical services provided, length of stay, and patient or resident physical capabilities determines many of the codes that apply to the building including the HVAC systems. The codes are typically focused on human safety considerations and represent the minimum standard. The design and operation teams should understand and agree if and to what degree the design is going beyond the code requirements. Additional information can be found in the ASHRAE (2013) *Design Manual*.

5.1 COMMISSIONING AND TESTING, ADJUSTING, AND BALANCING

Commissioning is an established and common practice in the building industry. However, there remains a wide range of understanding in the construction industry around its scope and responsibilities. Its application to heath care facilities follows the same process as other building types, but there may be more systems included in the scope. Specifying and performing **testing, adjusting, and balancing (TAB)** in some health care facilities requires changes compared to many other commercial buildings.

Commissioning

Regulations and Requirements. For any facility following the FGI *Guidelines*, commissioning is and has been a requirement since the 2010 edition. Some U.S. states require some level of commissioning as part of their energy code. Besides ASHRAE, there are a few other commissioning organizations, such as the Building Commissioning Association (BCA). ASHE (2013) addresses the specific needs of commissioning health care facilities.

Planning and Design. Designers and operators should review commissioning code requirements to determine any additional commissioning requirements for health care buildings, and determine how and when the commissioning agent is going to be engaged. Common deliverables during the design phase include the owner project requirements (OPR), basis of design (BOD), a commissioning plan, and design reviews. The commissioning plan should clearly outline the scope of which systems are being commissioned and the division of responsibilities during each phase. Be sure the specifications are clear on the scope for the general contractor and all the specialty subcontractors, including meeting requirements, installation verification, and acceptance (functional performance) testing.

Construction. Most of the commissioning scope occurs in the construction phase as the commissioning plan and specifications are executed. Software platforms can significantly reduce the time required and improve documentation of key steps, including installation verification, performance acceptance testing, and issue identification and resolution steps. This information can be useful to facility operators. In some cases, the platform can transfer data into facility management software. Consider requiring trend data from the automated control systems as part of the acceptance requirements.

Testing, Adjusting, and Balancing (TAB)

When the design for the HVAC system includes meeting the code minimum air exchange rates or air pressurization requirements, the approach to the TAB tolerance needs to make sure the minimums are achieved. The common TAB practice of ±10% tolerance needs to be considered to meet the minimum air flow. Consider overdesigning the rooms by 10% or altering the TAB tolerance to 0 to 10%.

TAB contractors also need to understand the relative air pressurization requirements and which system (supply, return, or exhaust) must meet the air change minimum requirements. For example, if the room is required to be a negative pressure, the exhaust airflow must meet the air exchange requirement and the supply needs to be adjusted until the air pressure requirement is reached, even if it goes outside the tolerance.

It is good practice to retest existing systems prior to any remodeling that may impact the system. 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.

Table 5 Summary of Heat Gain to Air from Imaging Systems

System	Maximum 60 min Time-Weighted Average, kW	Calculated Idle, kW	Manufacturer's Design Information, kW
MRI #1	24.42	22.23	—
MRI #2	23.58	19.14	—
X-ray	1.25	1.08	1.35
Fluoroscopy #1	12.13	9.18	7.31
Fluoroscopy #2	5.01	4.43	5.90
CT–64 slice	7.06	6.57	19.18
PET/CT	12.60	9.80	—
Nuclear camera	1.11	1.06	—
Linear accelerator	32.59	19.87	9.16
Ultrasound (portable)	0.86	0.50	—
Cyberknife	13.40	10.38	—

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.

5.2 MEDICAL EQUIPMENT

The medical equipment field is rapidly evolving and changing. Large medical diagnostic systems have a significant impact on the architecture as well as the mechanical and electrical systems. The impact varies depending on the medical equipment manufacturer. Final selection and procurement of the medical equipment typically occurs late in the design stage or even after construction begins, which poses a challenge for the design team. To overcome this challenge, it is important early in the design process to base the design and functional program on specific manufacturers and models for the large complex diagnostic systems. Once the final site-specific medical equipment manufacturer information becomes available, the design team can accurately define the differences between the early and final design, including the architectural and engineering designs and the associated costs.

Table 6 Summary of Heat Gain to Air

Equipment	Calculated Idle, kW	High, kW
Dialysis machine	0.40	0.69
Film processor	0.40	0.42
Pharmacy freezer	0.73	0.82
Pharmacy refrigerator	0.48	0.59

Chapter 18 of the 2021 *ASHRAE Handbook—Fundamentals* tabulates some heat gain information for 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 5 and 6 include data for equipment tested in ASHRAE research project RP-1343. Medical equipment heat outputs can vary widely among different manufacturers, even for equipment that performs a similar function.

5.3 HEATING SYSTEMS

Space Heating

Depending on the operator preference, size, type of facility, and whether it's part of a campus will influence the choice of centralizing or decentralizing space heating systems. The heating fuel source is typically a fossil fuel that is combusted to generate hot water or steam. Hospitals and ambulatory surgery facilities nearly always have hydronic hot-water reheat systems. The economics are typically more favorable for hot water compared to electric reheat in facilities required to provide air exchange rates. With the recent focus on decarbonization, there is a need to develop other non-

fossil-fuel systems and new products and designs. Refer to the energy section of this chapter for more discussion on that topic.

In small outpatient facilities, the heating system is often decentralized in packaged rooftop units with possible electric reheat coils at the terminal level. The geographic location (heating degree days) and local utility costs are key elements in determining the best economic option. Heat pumps are energy efficient and offer a lower carbon alternative and with recent technical advancements are expanding their applications.

Redundancy, stand-by, or a spare (N + 1) boiler should be considered with input from the operators. The N + 1 arrangement allows for adequate capacity whenever one boiler or heating device breaks down or is temporarily taken out of service for routine maintenance. The boilers, heat exchangers, coils, and main piping should have isolation valves so that the entire system does not have to be taken out of service to make a repair.

Additional information and guidance can be found in ASHRAE (2013).

5.4 COOLING SYSTEMS

In hospitals, chilled-water systems combined with large, centralized air-handling systems typically provide most of the space cooling. Typically, there are a few dedicated cooling units for rooms such as IT equipment rooms. When using larger-capacity chillers located indoors, understand when and how to apply the requirements of ASHRAE *Standard* 15. During cost/benefit analysis, consider that water-cooled chillers are more efficient than air-cooled but require significantly more space and maintenance resources.

The necessary chilled-water supply temperature depends on the temperature and humidity levels required in the coldest rooms. Operators need to understand under what conditions the system is not capable of maintaining the desired conditions. For example, to meet common operating room temperature and humidity levels, the chilled-water temperature needs to be near 8.3 °C. Most other spaces do not need supply air temperature this low. It may be justified to have a dedicated chilled-water system for areas needing these colder temperatures. Additional information and guidance can be found in ASHRAE (2013).

Heat recovery chillers have become a common energy saving system used in hospitals. They generate hot water as a byproduct of the chiller water cooling process. This hot water can then supplement the space heating hot water system. Often, they are sized to cover the cooling season hot-water reheat load, making the boilers unnecessary during summer. Refer to the energy section for more references on this application.

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 the desired temperature and humidity in spaces. DX systems are a lower-first-cost option compared to chilled-water systems. Communicate the limitations to facility operators when considering using DX systems, especially when they are more familiar with chilled-water systems.

5.5 AIR HANDLING AND DISTRIBUTION SYSTEMS

Air Handlers

The air distribution system design will vary depending on facility type and medical services provided. It is often desirable to minimize the airflow between critical care or specialty departments (e.g., surgical, obstetrical, pathological, laboratory areas). Separating the air systems and automatic closing doors are common options.

If the facility has a defend-in-place fire emergency response, it will be divided into smoke compartments. Designers should review with the operator and AHJs which smoke compartments each air-handling system will serve and what the smoke control sequence is. See the Life Safety section for more guidance.

Exhaust Systems

Fan systems serving hazardous chemicals or bioaerosols (e.g., exhaust systems connected to chemical fume hoods) should use high-velocity, high-stack exhaust equipment made for that application.

Duct Systems

In some health care facility applications, oversizing ducts can improve the energy performance and provide future adaptability and flexibility. 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. Whether this or another means, some form of standby protection is essential if the air supply is not to be interrupted by routine maintenance or component failure.

As mentioned previously, air quality is a key design consideration. It is commonly considered good design practice to avoid using duct lining in health care facilities. ASHRAE *Standard* 170 does not allow duct lining to be used downstream of the second filter bank (final filter). However, 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. Using 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.

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.

5.6 HUMIDIFICATION SYSTEMS

As mentioned in the section on Indoor Environmental Quality, recent studies report a relationship between the lower limit of humidity and infection transmission. Some studies recommend minimum levels of 40% or higher. However, currently ASHRAE *Standard* 170's required minimum is at 20 or 30% RH, depending on the room type. For a given project, designers and operators need to collaborate to determine the design humidity requirements and acceptable variance range.

Generally, humidification will be required anytime the outside air dew point is below approximately 1°C. Hospitals most often use direct steam from a centralized steam boiler system. ASHRAE *Standard* 170 states that "chemical additives used in the steam systems that serve humidifiers shall comply with FDA requirements." Thus, steam-to-steam humidifiers are not required if the facility uses FDA-approved chemicals in its central steam system. A central air system-wide approach to humidity control is simpler and much more reliable than individual zone control. Consider using a similar approach to redundancy as described in the Space Heating section.

Previously, the most common method of controlling humidifiers has been based on return air relative humidity. This is typically about 60% at 9°C. Most relative humidity sensors are not very accurate and measuring in the return air creates a slow control response that results in wide swings in humidity levels.

Recently, an alternative method of measuring humidity has shown success. The humidity is controlled by maintaining a supply air dew point. It simplifies the controls sequence making it easier to understand and maintain. Figure 7 shows the arrangement.

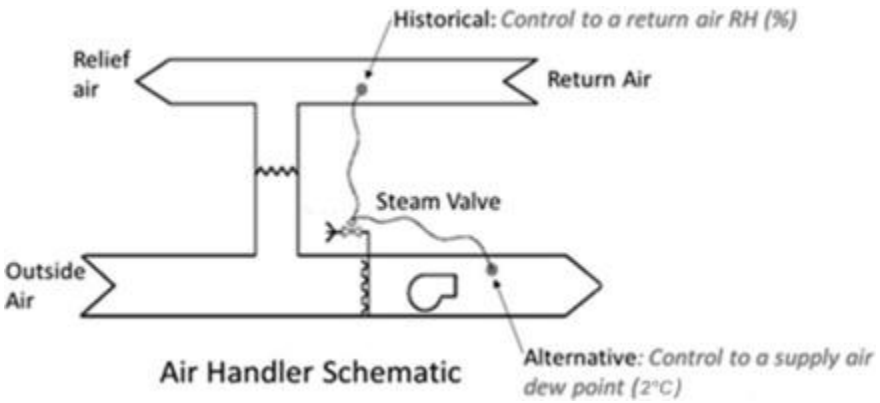

Figure 7. Humidity Control at Air Handler (Koenishofer 2018)

Humidity systems require frequent service and maintenance. Designers should provide easy access and ample space to service them. Operators need to understand the control limitations and capabilities of the humidification systems. This is especially critical for rooms that require minimum humidity levels and monitoring. Facility operators should consider developing a response plan addressing when and what level of action is required when the humidity level is outside the required range (a humidity control event). Examples and ideas on this topic can be found in the ASHRAE white paper titled Humidity Control Events in Perioperative Care Areas (2019).

6. HVAC DESIGN CONSIDERATIONS FOR SPECIFIC AREAS

This section provides HVAC design guidance for specific departments or rooms to address their unique indoor environmental requirements. Additional information can be found in ASHRAE (2013). ASHRAE *Standard* 170 also provides HVAC design requirements for spaces in health care facilities that directly affect patient care. Those requirements are not repeated here.

6.1 SURGERY AND CRITICAL CARE

Surgical suites require a high level of engineering controls to help minimize concentrations of airborne organisms at the surgical site. The greatest number of bacteria found in the operating room comes from the surgical team and is a result of their activities during surgery. During an operation, members of the surgical team are near the operating table, creating the undesirable situation of concentrating contamination in this sensitive area.

Operating Rooms

ASHRAE *Standard* 170 requires a unidirectional diffuser array in the ceiling, covering the sterile field area, with a downward air flow at an average velocity of 0.13 to 1.8 m/s. The unidirectional diffuser, combined with exhaust or return grilles located low on opposite walls, will help create an airflow pattern that minimizes contamination of the surgical field. This requirement is based on Memarzadeh and Manning (2002). Completely perforated ceilings, partially perforated ceilings, and ceiling-mounted diffusers have also been applied successfully (Pfost 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. Figure 8 is a schematic representation of a common operating room layout with design criteria, components, and features.

Room humidity and temperature indicators should be located for easy observation by the surgical staff. Systems should be designed to maintain the space temperature and temperature rates of change for the expected procedures to occur in these rooms.

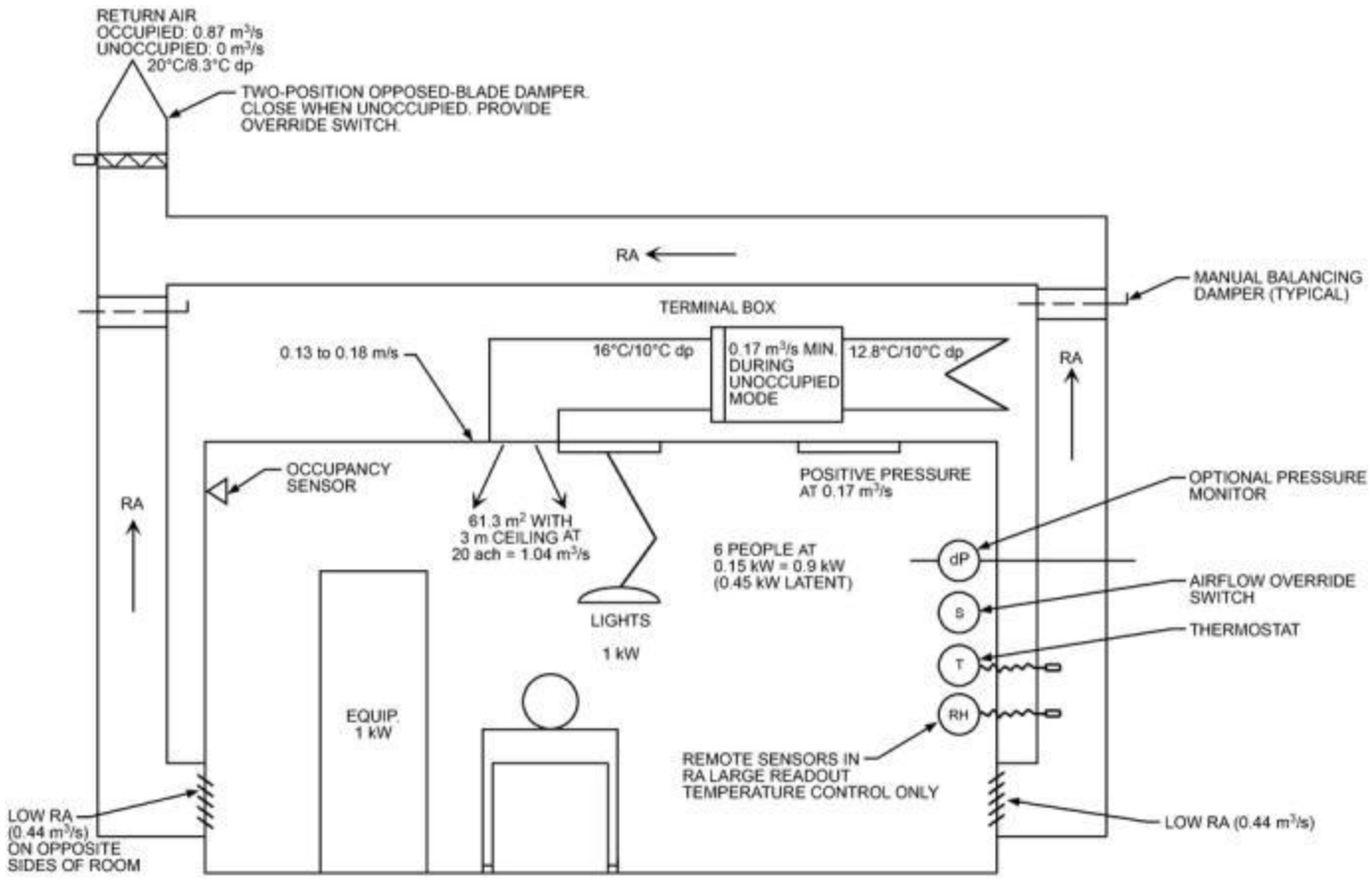

Figure 8. Operating Room Layout (ASHRAE 2013)

Dedicated cooling equipment for the operating suite may be a cost-effective alternative used to satisfy the lower temperature needs compared to combining the surgery suite with other 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 the wall, ceiling, and floor penetrations are essential to maintaining pressure differential.

Filter efficiencies should be in accordance with ASHRAE *Standard* 170 and the user's requirements. Supply air HEPA filtration has been used in 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.

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.

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.

Reducing airflow in operating rooms is an energy saving strategy; Love (2011) presents the concepts in detail. Depending on facility type, operating room suites may only be used 8 to 12 h per day and not necessarily every day. During unoccupied times, airflow is reduced and the air temperature can increase to reduce the amount of reheat energy. The airflow setback must be sufficient to maintain the room's positive air pressure. Design of the airflow setback control sequence should balance the level of control, complexity, and cost. Be sure to thoroughly test the transitions between the normal and the setback modes. Anticipate and test a variety of situations, including when the cleaning staff prop open the door. There is not consensus that this energy saving strategy is worth the complexity of controls and the risk of issues it may present.

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

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

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 systems are like those used in general inpatient rooms unless used for wound (burn) intensive care.

Burn Units. Thermal injury disrupts the skin's ability to control the surface temperature and to function as a barrier to evaporation. This results in an increase in metabolic rate when the space temperature is below thermoneutrality. Heat loss increases in proportion to the burn size when the ambient temperature is below thermoneutrality. Studies suggest that reducing this hypermetabolic state will decrease the extent of the burn (e.g., Zhou et al. 1998). Burn patients prefer an increase in ambient temperatures compared to non-burn patients. Consider designing the HVAC range to allow clinicians to increase the air temperature up to 32 °C. Carefully consider that higher room temperatures will impact the relative humidity. Burn units are commonly designed as positive air pressure environments with HEPA 99.97% filtered supply air.

Emergency Departments. Emergency departments are typically the most highly contaminated areas in the hospital. Waiting rooms and triage areas require special consideration due to the potential for patients with undiagnosed conditions and communicable airborne infectious diseases. Clean-to-dirty directional airflow and air pressurization techniques should be considered to reduce the potential of airborne exposure.

Trauma Rooms. Trauma rooms located in 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 for the storage of compressed gases.

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 75 mm above the floor. Some experts question this exhaust arrangement, 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 workspace 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. These same conditions should be maintained 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 like 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.

6.2 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. This requirement appears to be based on odor control, though research has documented that toilets may generate droplets and aerosols (Johnson et al. 2013). Where recirculating room unit systems are used in 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 toilet rooms, bedpan closets, bathrooms, and all interior rooms should conform to applicable codes.

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.

Behavioral Health Areas. Confirm with the design and operator team where anti-ligature HVAC components will be required such as in secure holding rooms or other areas. The Joint Commission defines **ligature-resistant** as without points where a cord rope, bedsheet or other fabric/material can be looped or tied to create a sustainable point of attachment that may result in self-harm or loss of life. In those areas, air terminal devices should be in the ceiling and made for anti-ligature applications with small perforations behind the louvers, so they are not used as an anchor point. There may also be a need for additional sound management in areas that might impact the HVAC design and components.

Protective Environment (PE) Isolation. Immunosuppressed patients (including bone marrow or organ transplant, leukemia, burn, and AIDS patients) are highly susceptible to diseases. In cases where immunosuppressed patients are treated in a PE room, the room 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. An air distribution of 12 ACH supplied through a non-aspirating diffuser is often used. In some cases, the supply air is HEPA filtered with return air removed at or near the door to the room. Where airflows are relatively low compared to room leakage, return is reduced or removed to achieve desired pressurization. Figure 9 shows a 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.

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 can be 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. Pressure controls in the adjacent area must maintain the correct pressure relationship relative to the other adjacent areas. A separate, dedicated air-handling system to serve the protective isolation unit simplifies pressure control and air quality (Murray et al. 1988).

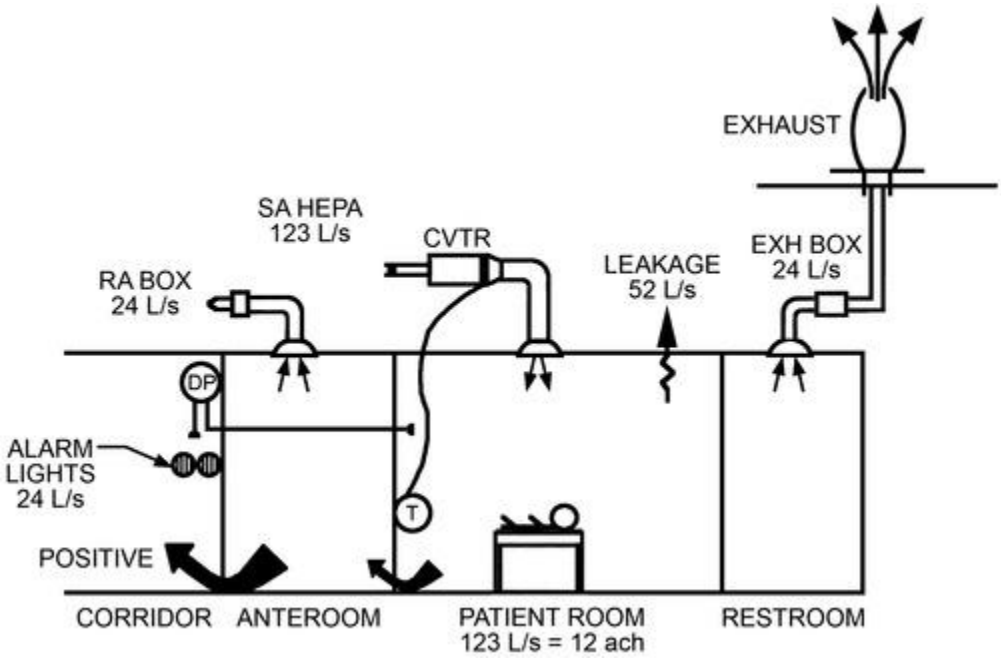

Figure 9. Protective Environment Room Arrangement (ASHRAE 2013)

Some facilities have switchable isolation rooms, which can be set to function with either positive or negative pressure. The CDC (2005) and FGI (2018a) 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.

Airborne Infection Isolation (AII) Unit. The airborne infection isolation (AII) room protects the rest of the facility from patients' airborne infectious diseases. Multidrug-resistant strains of TB have increased the importance of pressurization, air change rates, filtration, and air distribution design in these rooms (Rousseau and Rhodes 1993). Temperature and humidity 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 a separate anteroom used as an air lock to minimize potential cross contamination. Design approaches can be found in CDC (2005). AII room exhaust may include HEPA filtration where there is a concern about exhaust air discharge, such as where maintenance staff may be working. Figure 10 shows a AII room arrangement with an anteroom. The 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.

In AII rooms, the exhaust outlets should be placed 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 staff or visitors are likely, then across the infected patient, and then to the exhaust. Because of the relatively low air exchange rates and minimal influence of the exhaust outlet, 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 exit the room or to disturb the function of the exhaust to remove contaminants (Memarzadeh and Xu 2012).

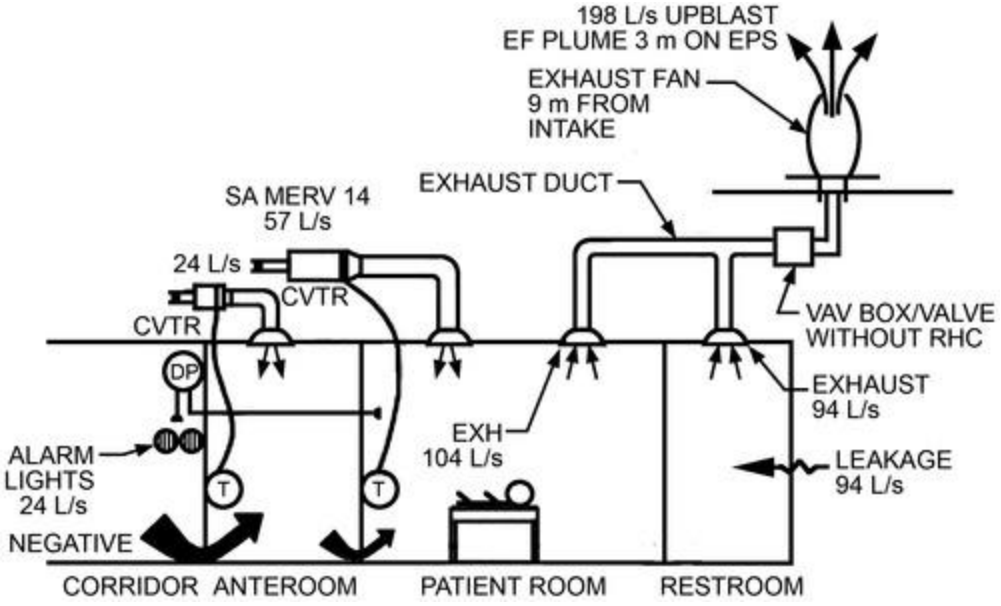

Figure 10. Airborne Infection Isolation Room (ASHRAE 2013)

As discussed in the section on Indoor Environmental Quality, ventilated headboards are an effective, proven source-capture strategy. When deployed in combination with HEPA fan/filter units, they can provide surge isolation capacity in a variety of environments. They are a cost-effective alternative to building modifications and can be rapidly deployed. CDC (2020) discusses how they work, various ways to apply them, and do-it-yourself instructions to make them. Ventilated headboards may be factory built, built from kits, or field constructed by hospital facility staff. Consider a validation test for each representative model. Currently, there is no standardized method of test but there are examples that were used in the COVID-19 pandemic.

If the headboard exhaust is ducted out of a room in a way that was not anticipated by the design, it can create positive or negative pressure in other rooms and may require that the associated system be rebalanced. Headboard exhaust which is passed through a HEPA filter is typically considered 99.97% decontaminated and can be directly discharged into the room or any other occupied space.

Biocontainment Treatment Areas (BTAs). These patient treatment areas (also called **biocontainment patient care units**) are of increasing interest. Consider using a clean-to-dirty airflow paradigm. BTAs are specifically designed to minimize nosocomial transmission during treatment of patients with potentially highly contagious and hazardous illnesses. The focus of design for these areas should protect both the facility and attending health care workers, while providing an environment conducive to patient treatment and recovery. This is partially achieved by following protective engineering and design principles such as those used in biosafety level 3 and 4 laboratory facilities (Smith et al. 2006). Exact design features for BTAs vary depending on illness, modes of disease transmission, and available resources. BTAs may be designed to address 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 a 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) and for clean observation areas for use by unexposed observers. Patient rooms in 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 air-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 air pressure, enhanced exhaust airflow volumes, and strategic exhaust louver placement to facilitate capture and removal of toilet plume aerosols are appropriate considerations. Exit points and pathways from the patient room should account for 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 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 the wall of a clean observation area) that allow for safe familial interaction with pediatric patients. Figure 11 shows a sample layout of a biocontainment unit.

6.3 DIAGNOSTIC AND TREATMENT

Medical diagnostic technology, systems, and equipment is continuously advancing. These systems can have multiple rooms with equipment, all with unique HVAC requirements based on the diagnostic system manufacturer. It is key to develop a strategy with the entire project team at the conceptual phase on how to manage the design requirements, recognizing that final site-specific manufacturer requirements are often not known until the project is in construction. MRI, CT, or linear accelerator manufacturers will typically not provide site-specific requirements until the equipment is purchased. Heat gains from equipment can be significant and vary by manufacturer. Caution is advised when trying to use a worst-case scenario strategy: variations can be significant and vary across the architectural and engineering disciplines. Consider selecting a specific manufacture and model and follow the manufacturer's requirements for the initial design. When the design team receives the site-specific manufacturer requirements, the changes can be reconciled with the initial design requirements and associated costs.

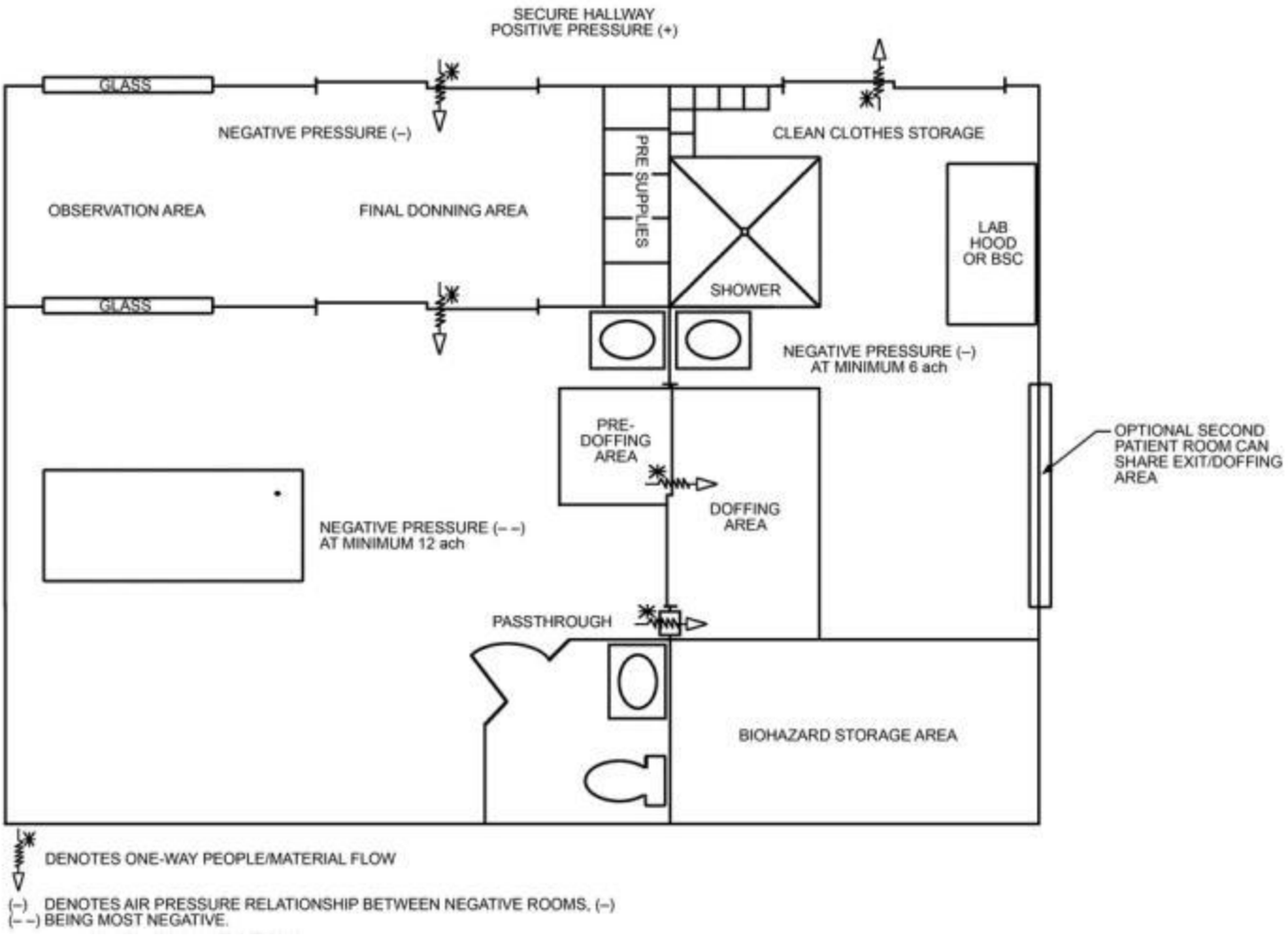

Figure 11. Biocontainment Treatment Areas (Meade et al. 2019)

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. Temperature and humidity should correspond to those specified for patients' rooms.

Bronchoscopy, Sputum Collection, and Pentamidine Administration Procedures. These procedures have a high potential for discharges of possibly infectious droplet nuclei into the air via coughing. Bronchoscopy procedures can release airborne aerosols 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.

Imaging. 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 25.5 to 26.7°C 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.

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 from computer equipment, and in the exam room because of the cryogens used to cool the magnet. Nonferrous material requirements and shielding penetrations should be used in accordance with the specific manufacturer's requirements.

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 26.5°C. The potential latent heat load in this area should not be overlooked. The exercise section requires no special treatment; temperature and humidity should address the thermal comfort needs. 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 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. Room temperature and humidity should be maintained within thermal 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 have an airborne infection 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.

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. Air temperature and humidity should be in the comfort range and account for protective clothing requirements required for the room occupants.

6.4 PHARMACY

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 necessary PECs. See Chapters 17 and 19 for more information. Before designing a pharmacy, select the appropriate USP compounding chapter(s) that apply to the type of compounding and associated risk. It should be noted that USP compounding chapters are actively under review and update. The following discussion is believed to be accurate at the time of this chapter's writing, but designers should refer to the most recent versions of the applicable USP chapter and latest requirements enforced by the local State Board of Pharmacy to identify their current design requirements (particularly for Hazardous Drugs).

The physical design features separating the buffer area from the ante area are based on the pharmacy's Compounded Sterile Preparations (CSP) risk level (low, medium, or high) for microbial, chemical, and physical contamination. USP Chapter 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 by the health care organization before designing the pharmacy layout.

Non-Sterile Compounding. Non-sterile pharmaceutical compounding requirements are prescribed by USP Chapter 795 and cover compounding practices for the preparation of nonsterile compounded formulations for dispensing and/or administration.

HVAC systems shall be controlled to avoid decomposition and contamination of chemicals and the manufacturers' labeled storage conditions. Appropriate temperature and humidity monitoring should be maintained as required for certain components and compounded dosage forms. All components, equipment, and containers shall be stored off the floor and, in a manner, to prevent contamination and permit inspection and cleaning of the compounding and storage area.

Sterile Compounding. Sterile pharmaceutical compounding requirements are prescribed by USP Chapter 797 and is enforceable under the U.S. Food and Drug Administration. These requirements are 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 Chapter 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 Chapter 797, which is under continuous maintenance, as well as applicable sterile compounding design guidance adopted by their state boards of pharmacy.

USP Chapter 797 prescribes that all CSP sterile pharmaceutical preparations to be administered must be compounded entirely within a critical work zone protected by a unidirectional HEPA-filtered airflow of ISO class 5 (per ISO *Standard* 14644-1; see Chapter 19 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. When compounding low risk CSPs, a PEC may be located within an unclassified area without an ante-room or buffer room. If medium or high risk CSPs will be compounded, USP Chapter 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, and donning and doffing of protective overgarments. The air cleanliness in the ante area must be a minimum of ISO class 8 (exception: see the section on Hazardous Drug Compounding). The ante area and buffer area constitute secondary engineering controls. Although ASHRAE *Standard* 170 does not prescribe a design temperature for health care pharmacies, USP

Chapter 797 recommends a maximum temperature of 20°C 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.

Selecting pharmacy PECs can be a complicated 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 Chapter 797 addresses this shortcoming by referencing isolator testing and performance guidelines developed by the Controlled Environment Testing Association (CETA 2006).

Hazardous Drug Compounding. Compounding hazardous drugs is another pharmaceutical operation that requires special design considerations that are found in USP General Chapter <800>: Hazardous Drugs—Handling in Healthcare Settings. As of current writing (April 2022) USP Chapter 800 is still informational and is not yet legally enforceable. The new chapter applies to all hazardous drug compounding, whereas the published hazardous drug guidance in USP Chapter 797 is only applicable to sterile compounding. As a USP chapter numbered less than 1000, it will be federally enforceable once it is fully adopted by USP, as well as adoptable (in whole or in part) by individual state boards of pharmacy. The USP Chapter 800 chapter will apply to all health care facilities (including veterinary facilities) where hazardous drugs are handled, manipulated, stored, or distributed. Most of the USP Chapter 800 guidance for hazardous drug sterile compounding carries over from USP Chapter 797, but there are two major changes: (1) the low-volume exemption mentioned in USP Chapter 797 no longer applies, and (2) USP Chapter 800 allows low risk CSP sterile compounding to occur in an ISO 5 PEC placed in a non-classified area (segregated compounding area) in accordance with USP Chapter 797 use limitations. Environmental controls for CSP scenarios are summarized in Table 7. The USP Chapter 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.

Table 7 Minimum Environmental Control Guidance for Pharmacies

Compounding Scenario	Nonhazardous Drug	Hazardous Drug (HD) (Requires Separate Area)	Radiopharmaceuticals
Nonsterile compounding	No sterility or occupational exposure controls required (USP Chapter 795)	Needs compounding containment isolator or BSC (See immediate use scenario)	Needs compounding containment isolator or BSC (See immediate use scenario)
Immediate-use sterile compounding: Administered within 4 h	If immediate use and low risk: ISO 5 PEC within segregated compounding area (USP Chapter 797)	If immediate use and low risk: ISO 5 PEC within segregated compounding area (per USP Chapter 800)	If immediate use and low risk: ISO 5 PEC within segregated radiopharmaceutical processing area (SRPA). (USP Chapter 825)*
Sterile compounding to be administered within 12 h	ISO 5 PEC in unclassified segregated compounding area (SCA) or ISO 5 PEC + ISO 7 buffer + ISO 8 ante areas (USP Chapter 797) If buffer/ante area option is used, compounding may use physical barrier with min. positive pressure (2.5 Pa) in buffer room relative to anteroom or clearly identified line of demarcation between buffer and ante areas	ISO 5 PEC + ISO 7 buffer + ISO 7 ante areas Compounding may use physical barrier with min. positive pressure (2.5 Pa) in buffer room relative to anteroom or clearly identified line of demarcation between buffer and ante areas	ISO 5 PEC + ISO 7 buffer + ISO 8 ante areas (USP Chapter 825) Compounding may use physical barrier with min. positive pressure (25 Pa) in buffer room relative to anteroom or clearly identified line of demarcation between buffer and ante areas
Sterile compounding to be administered after 12 h	ISO 5 PEC + ISO 7 buffer + ISO 8 ante areas (USP Chapter 797) Compounding may use physical barrier with min. positive pressure (2.5 Pa) in buffer room relative to anteroom or clearly identified line of demarcation between buffer and ante areas	ISO 5 CACI or BSC within negative-pressure ISO 7 buffer + ISO 7 ante areas Compounding may use physical barrier with min. positive pressure (2.5 Pa) in buffer room relative to anteroom or clearly identified line of demarcation between buffer and ante areas	ISO 5 PEC + ISO 7 buffer + ISO 8 ante areas (USP Chapter 825) Compounding may use physical barrier with min. positive pressure (25 Pa) in buffer room relative to anteroom or clearly identified line of demarcation between buffer and ante areas

Other recommendations for hazardous drug compounding may be found from National Institute of Occupational Safety and Health (NIOSH 2004). NIOSH 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. Check with the state boards of pharmacy on the specific requirements for compounding sterile hazardous drugs.

Radiopharmaceutical Compounding. The preparation, compounding, dispensing, and repackaging of sterile and nonsterile radiopharmaceutical processing activities, including those with radionuclides that emit a single photon, a positron, or therapeutic particles for the practice of pharmacy and medicine is addressed in USP Chapter 825.

The classified areas and SRPA must be continuously maintained at a temperature of 25° C or cooler and should be continuously maintained at a relative humidity below 60% to minimize the risk for microbial proliferation and provide comfortable conditions for personnel attired in the required garb.

Table 8 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, (2.5 Pa) 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, (2.5 Pa) 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, (2.5 Pa) negative pressure, 30 ACH plus ISO 7 anteroom, (2.5 Pa) positive pressure relative to all adjacent unclassified areas, 30 ACH
Segregated compounding area configuration (for immediate use only; see USP<797> for compounding risk determinations)	C-PEC: ISO 5 direct compounding area, externally vented [e.g. Class II (Types A2, B1 or B2), Class III BSC or CACI]
	Non-classified air cleanliness, 12 ach, 2.5 Pa negative pressure
Radiopharmaceuticals	
Buffer room configuration	C-PEC: ISO 5 direct compounding area, externally vented [e.g. Class II BSC or LAFW]
	C-SEC: externally vented, ISO 7 buffer area, (25 Pa) negative pressure, 30 ACH plus ISO 8 anteroom, (25 Pa) positive pressure relative to all adjacent unclassified areas, 30 ACH

Segregated compounding area configuration (for immediate use only; see USP Chapter 797 for compounding risk determinations)	C-PEC: ISO 5 direct compounding area, externally vented [e.g. Class II BSC or LAFW] Non-classified air cleanliness, 12 ACH, 2.5 Pa 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.

There may be both positive and negative air pressure within the facility; positive pressure to minimize the potential of microbial contamination in sterile drug preparation areas, and negative pressure to minimize potential radioactive contamination from volatile or airborne radiopharmaceuticals. For preparation of sterile radiopharmaceuticals, consideration of both concerns could be addressed as follows:

Table 8 provides a matrix of design and equipment decision logic based on USP Chapter 797 and NIOSH (2004).

6.5 ANCILLARY

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 2021 *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 re-entrained 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 3 m above the roof at velocities up to 20 m/s. The entire laboratory area should be under slight negative pressure to reduce the spread of odors or contamination to other hospital areas. Temperature and humidity 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, 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 315°C. HEPA filters are a more common and less expensive method of sterilizing the exhaust.

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 0.5 m/s 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). 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 17 has further information on animal room air conditioning.

6.6 STERILIZATION AND SUPPLY

Decontamination and Sterile 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. The decontamination area must be physically separated from the sterile prep and sterilization areas. Endoscopy suites commonly have endoscope reprocessing areas. Although AAMI allows for decontamination and high-level disinfection to be 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. The design team is recommended to collaborate with the washer/disinfection equipment provider to address the equipment and piping penetrations that can be above the equipment and out of view. Consider having medical equipment providers include the manufacturer's optional accessories that seal or limit air gaps. All air gaps around penetrations into adjacent rooms or areas to be addressed to achieve the required pressurizations.

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 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%.
- Ensure tight construction is used, walls are extended up to deck and sealed to maintain pressure relationships between the decontamination and sterile areas. Gypsum ceilings are recommended. If gasketed grid ceilings are

desired, ensure a quality system is used to provide a tight seal between the room and the plenum.

6.7 SERVICE AND SUPPORT AREAS

Service areas include dietary, housekeeping, biohazardous waste storage, and mechanical/electrical rooms. Provide ventilation and exhaust to create environments conducive to support the services and the need for air contamination and odor control. Ventilation of these areas needs to provide conditioning for the occupants working in these areas as well as the needed make-up air for the exhaust systems. Air-to-air heat exchangers offer possibilities for energy savings.

Dietary. These areas can include a kitchen, bakery, dietitian's office, dishwashing room, and dining space. Because of the various conditions encountered with high heat, moisture production, and cooking odors 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 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 needs to conform to local codes. Consider using the ventilation air serving dining space as ventilation and make-up air for the food preparation and cooking exhaust hood. Where cafeteria service is provided, serving areas and steam tables are usually hooded. Ventilation systems for food preparation and adjacent areas should include an interface with hood exhaust controls to assist in maintaining pressure relationships.

Kitchen Refrigerator/Freezer. Ventilation of these spaces should conform to all codes, with the following additional considerations: (1) 165 L/s of ventilating air per compressor kilowatt should be used for units located in the kitchen; (2) condensing units should operate optimally at 32°C 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. In this area, 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, like 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 / Electrical Rooms. There are many different types of mechanical/electrical rooms with wide varying requirements for ventilation, room temperature, and potentially humidity requirements. Work with the facility stakeholders early in the design process to review the rooms and their expected environmental conditions. Identify and address not only the typical design day conditions but the expected extremes and what level and duration and tolerances should be incorporated into the design. Determine if and what level of redundancy or stand-by is required. Samples of the equipment that found in these rooms are

- Data center/IT servers
- Electrical transfer switches
- Fire alarm and fire protection equipment
- Electrical panels, and transformers
- Chiller/refrigerant machine rooms
- Fuel combustion boilers (steam or hot water)
- Fuel combustion or electric sterilizing equipment
- Domestic water heating and treatment equipment

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.

The amount of refrigerant in the cooling equipment determines w *Standard* 15 requirements need to be implemented.

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 hazards and should conform to all applicable codes. Maintenance shops where welding occurs should have exhaust ventilation.

6.8 DENTAL

Dental facilities include reception and waiting areas, treatment rooms (called **operatories**), and workrooms where supplies and instruments are cleaned, sterilized, and stored. There may also be laboratories where dental appliances such as partial dentures, orthodontic retainers, and night guards 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). There is limited information and research available on the level, nature, or persistence of bioaerosol and particulate contamination in dental facilities. Consider using high ventilation rates to dilute and control these bioaerosol generated by dental procedures and that escape the high-volume evacuators.

To manage aerosol risk, source control is the most beneficial strategy for all parties. Source control measures reduce risk for workers in a room with the source and having removed aerosols, reduce risk for occupants outside the room. Air treatment very near the source, with a local HEPA filter device, can also effectively reduce risk locally and outside the room. Closed doors are quite effective in containing aerosols. If patients can be seen in private rooms with normally closed doors, risk for occupants in other areas can be significantly reduced.

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.

Dental lab procedures have been shown to generate dusts and aerosols containing metals. Provide local exhaust to capture the dusts and fumes generated by dental lab processes (Ninomura and Byrns 1998).

STANDARDS

AENOR/UNE	
Standard 100713:2005	Air Conditioning in Hospitals
ANSI/AAMI	
Standard 58:2013	Chemical Sterilization and High-level Disinfection in Healthcare Facilities
ANSI/AIHA	
Standard Z9.5-2012	Laboratory Ventilation
ANSI/ASHRAE	
Standard 15-2013	Safety Code for Mechanical Refrigeration
52.2-2012	Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size
55-2017	Thermal environmental conditions for human occupancy
62.1-2013	Ventilation for Acceptable Indoor Air Quality
ANSI/ASHRAE/IES	
Standard 90.1-2013	Energy Standard for Buildings Except Low-Rise Residential Buildings
ANSI/ASHRAE/ASHE	
Standard 170-2017	Ventilation of Healthcare Facilities
ANSI/ASHRAE/ACCA	
Standard 180-2012	Standard Practice for Inspection and Maintenance of Commercial Building HVAC Systems
ASHRAE	
Standard 145.2-2016	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 Healthcare Facilities

Guideline 10-2011	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
29-2009	Guideline for the Risk Management of Public Health and Safety in Buildings
ANSI/ASTM	
Standard E84-2014	Standard Test Method for Surface Burning Characteristics of Building Materials
ANSI/NFPA	
Standard 45-2011	Standard on Fire Protection for Laboratories Using Chemicals
90A-2015	Standard for the Installation of Air Conditioning and Ventilation Systems
92A-2009	Recommended Practice for Smoke-Control Systems
99-2012	Healthcare Facilities Code
255-2006	Standard Method of Test of Surface Burning Characteristics of Building Material
Code 101-2012	Life Safety Code®
ANSI/NSF	
Standard 49-2012	Biosafety Cabinetry: Design, Construction, Performance, and Field Certification
ANSI/UL	
Standard 181-2013	Factory-Made Air Ducts and Air Connectors, 10th ed.
CAN/CSA	
Standard Z317.2-15	Special Requirements for Heating, Ventilation, and Air-Conditioning (HVAC) Systems in Healthcare Facilities
FGI 2022	
Guidance for Designing Health and Residential Care Facilities that Respond and Adapt to Emergency Conditions	
UK Department of Health and Social Care	
Health Technical Memoranda (HTM) 03-01	Specialized Ventilation for Healthcare Premises

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