HVAC Design Manual for **Hospitals and Clinics**

Second Edition

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Second Edition

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FOREWORD

This second edition of *HVAC Design Manual for Hospitals and Clinics* adds updated information, provides in-depth design recommendations based on best practices, and presents proven, cost-effective, and reliable solutions that result in low maintenance cost and high reliability. Our intent is that this edition of the manual focuses specifically on heating, ventilating, and air-conditioning (HVAC) system design for health care facilities, omitting general system descriptions that are readily available in other ASHRAE publications. Instead, our focus has been to present "what's different" about health care HVAC.

Although not a consensus document, this manual draws heavily on ANSI/ASHRAE/ASHE Standard 170-2008, *Ventilation of Health Care Facilities,* which is. Citations of the standard throughout this book should be understood to include its Addenda a to t and v.

This edition is the result of a concerted effort by a fine group of volunteers whose job was made immensely easier by having the first edition to build upon. By intent, the authoring committee was composed primarily of consulting engineers with long experience in the design and construction of health care facilities. Jeff Hardin and John Kramer worked hard on both editions. Hospital engineers John Kramer, Heather Platt, and Ron Westbrook also wrote chapters and provided invaluable input to the entire book. Engineering editorial assistance was provided by John Murphy, and Walter Grondzik was technical editor. Kelly Short and Kelsey Grondzik assisted with tables and illustrations.

The intended audience for this manual includes

- consulting engineers;
- experienced hospital designers who will use it as a reference;
- mechanical engineers who wish to become familiar with health care design;
- young engineers who seek a career specializing in health care HVAC design;
- facility managers;
- infection control personnel;
- managers of planning and design;
- maintenance staff;
- contractors;
- developers; and
- code, accreditation, and licensure officials.

Finally, I want to thank Layle Thomas for her fantastic organizational and editorial expertise, which was invaluable in coordinating the efforts of over 32 volunteers.

It has been my honor to chair this committee.

Dan Koenigshofer, PE, M Public Health, HFDP, SASHE
Dewberry Engineers
January 2013

CHAPTER 1

OVERVIEW OF HEALTH CARE HVAC SYSTEMS

1.1 INTRODUCTION

HVAC systems in health care facilities provide a broad range of services in support of populations who are uniquely vulnerable to an elevated risk of health, fire, and safety hazard. These heavily regulated, high-stakes facilities undergo continuous maintenance, verification, inspection, and recertification; typically operate 24 hours/day, 7 days/week; and are owner-occupied for long life cycles. Health care HVAC systems must be installed, operated, and maintained in spatial and functional conjunction with a host of other essential building services, including emergency and normal power, plumbing and medical-gas systems, automatic transport, fire protection, and myriad IT systems, all within a constrained building envelope. Health care facilities and services are characterized by high rates of modification because of the continuously evolving science and economics of health care, and consume large quantities of energy and potable water. The often unique environmental conditions associated with these facilities, and the critical performance, reliability, and maintainability of the HVAC systems necessary to their success, demand a specialized set of engineering practices and design criteria established by model codes and standards and enforced by authorities having jurisdiction.

1.2 BASIC CLASSIFICATION OF HEALTH CARE FACILITIES

Health care facilities vary widely in the nature and complexity of services they provide and the relative degree of illness or injury of the patients treated—from a neighborhood general practitioner's office to large regional or university medical centers and specialty hospitals. Facilities in the health care category can include, in addition to the practitioner's office, neighborhood clinics, mental wellness centers, birthing centers, imaging facilities, hospice care, and long-term nursing care, among others. As a rule, environmental control requirements and

the role of the HVAC system in life safety and infection control become more important with increasing complexity of the medical services provided and the acuity of illness of the patient population. This manual is primarily intended to address HVAC systems for inpatient hospitals, except where otherwise indicated.

1.3 HEALTH CARE HVAC SYSTEM FUNCTIONS

In support of the health care process, HVAC systems are called upon to perform several vital functions that affect environmental conditions, infection and hazard control, and building life safety. Staff and patient comfort, and the provision of therapeutic space conditions, facilitate optimum patient treatment outcomes. Environmental conditioning for electronic data storage, supporting IT systems, and special imaging and other medical equipment is critical to the operation of these essential services. Through containment, dilution, and removal of pathogens and toxins, the HVAC system is a key component of facility safety and infection control. In inpatient and many ambulatory treatment facilities, the inability (or reduced ability) of patients to respond properly to fire emergencies requires the HVAC system to support vital smoke exhaust and building compartmentation features of the life safety system. Finally, the HVAC system should interact with the architectural building envelope to control the entry of unconditioned air, together with outdoor contaminants and moisture.

1.3.1 Comfort Conditioning

Across the range of health care facilities, health care practices often expose patients and staff to conditions that dictate unique environmental requirements. As in any facility, the comfort of building occupants is fundamental to overall well-being and productivity. In the health care facility, a comfortable environment has a significant role in facilitating healing and recovery. A sick or injured patient in an uncomfortable environment is subject to thermal stress that may hinder the body's ability to properly regulate body heat, interfere with rest, and be psychologically harmful. At the same time, a health care provider stressed by an uncomfortable environment may not function at peak performance levels. Patients clothed in a simple gown in an examination room, for example, or orthopedic surgical staff heavily garbed in scrub suits during an hours-long, complex, and stressful procedure, require special room temperature and humidity levels and controls. Similarly, room airflow patterns and air change rates influence thermal comfort. For these reasons, health care codes and criteria establish specific requirements for space temperature, relative humidity, and total air change rates.

1.3.2 Therapeutic Conditioning

Certain medical functions, treatments, or healing processes demand controlled environmental temperature and/or relative humidity conditions that deviate from the requirements for personal comfort. Operating rooms and nursery units, for example, often require a range of room temperatures spanning several degrees, regardless of the season, to best facilitate a given procedure or patient condition. Burn-patient treatment rooms and bedrooms may require elevated temperature and relative humidity (RH) conditions (up to 100°F

[37.7°C] and 35% to 40% rh, according to DOD [2011]). Some clinicians desire the ability to reset emergency department room temperatures to as high as 90°F [32.2°C] for treatment of hypothermia cases. Criteria call for long-term in-patient spaces to be humidified to minimum levels to avoid the dry skin and mucous membranes associated with very low RH levels that add to discomfort and possibly impede respiratory immune function. As of the date of this publication, however, there is no scientific evidence to firmly establish that extended exposure to very low humidity contributes to poorer patient outcomes.

1.3.3 Infection Control

With few exceptions (such as free-standing behavioral health, sports medicine, or maternity care centers), medical facilities are places where relatively high levels of pathogenic (disease-causing) microorganisms are generated and concentrated by an infected patient population or by procedures that handle or manipulate infected human tissues and bodily fluids. These pathogens are spread by a number of contact and, to a lesser extent, noncontact (airborne) causes, which are dealt with in detail in Chapter 2. To some degree, the entire building population is at elevated risk of exposure to these pathogens. Sick and injured patients, having suppressed or compromised immune function, are highly susceptible to new infections. Visitors often accompany sick or injured friends or loved ones to high-exposure areas such as clinical waiting rooms and emergency departments. By the nature of their profession, health care staff work in proximity to infectious agents on a daily basis. Health care facilities therefore require stringent operational practices and engineering controls to safeguard the building population. The HVAC system is one of several tools and processes used in the control of infection.

1.3.4 Ventilation and Environmental Control for Special Functions

Many medical facilities include functions or processes in which chemical fumes, aerosols, or harmful gases are stored and generated, posing health or safety hazards. Examples include laboratories where aerosolizing chemicals are used to fix slide specimens, preserve tissues, or perform other processes; orthopedic appliance and artificial limb shops involving adhesives and other aerosolizing agents; and anesthetizing locations, in which long-term exposure to even trace concentrations of anesthetizing gases can have harmful consequences. In such applications, HVAC equipment operates in conjunction with primary containment equipment, such as fume hoods, radioisotope hoods, laminar flow benches, and waste anesthesia evacuation systems, to contain and exhaust these contaminants or dilute them to safe levels.

In other health care applications, the HVAC system is called upon to assist in the maintenance of a sterile environment for products or procedures that must be protected from environmental contamination. Laboratory culturing procedures, and certain pharmaceutical handling and compounding procedures, are examples where the HVAC system functions in conjunction with containment equipment to protect the product.

1.3.5 Life Safety

In facilities classified as Health Care or Ambulatory Health Care by *NFPA 101: Life Safety Code*® (NFPA 2012) from the National Fire Protection Association or Type I-2 by the *International Building Code*® *(IBC®)* (ICC 2012), HVAC systems are required to support special building compartmentation, opening protection, smoke control, and detection systems providing for the "defend in place" concept of life safety. Containment is facilitated by the application of smoke and fire dampers and, in some cases, by restricting HVAC system cross-over between smoke zones. HVAC systems contribute to the detection and containment of fire and smoke and may be called upon to evacuate or exclude smoke from atria or exit enclosures. Engineered smoke control systems may be required to provide complex zoned pressurization control. More detailed information on HVAC applications and building life safety is provided in Chapter 5.

1.3.6 Role of the Building Envelope

The integrity of the building envelope is essential to minimize the introduction of unconditioned, unfiltered air into a building, as well as to effectively exclude moisture. Condensation of humid outdoor air within building envelope assemblies is conducive to mold colonization, which, in addition to causing expensive material damage, poses a risk of deadly infection from *Aspergillus* and other so-called opportunistic mold genera. No envelope is perfect, and abundant evidence shows that even well-designed and constructed envelopes allow some degree of infiltration from building pressurization differentials caused by wind, stack effect, and operation of the HVAC system. Generally, with the exception of very cold climates where neutral pressurization may be called for, it is desirable to positively pressurize the building interior to minimize infiltration. Some HVAC designs approach controlled, continuous, positive pressurization by maintaining a controlled offset between outdoor ventilation air and exhaust. These systems are simple and reliable. More complex pressure-control approaches are now being suggested by some design engineers. HVAC designers should be aware, and make the building architect aware, that the deliberate depressurization of spaces on the building perimeter, including disease isolation rooms and patient toilets, and the depressurization of plenums and exterior wall cavities by plenum return systems, poorly balanced ducted return systems, and central exhaust systems can exacerbate the passage of moisture and unconditioned, unfiltered air across the building envelope in those locations.

1.3.7 Patient Privacy

The need to prevent room-to-room transmission of private patient conversations is addressed by codes and standards and by the Health Care Information Portability and Accountability Act (HIPAA). Codes and standards provide minimum sound transmission class (STC), or other acoustical performance criteria, for the architectural enclosure elements of critical spaces such as provider office and exam rooms, and may address recommendations for background noise, and for minimizing sound transmission through connecting ductwork. Transfer air ductwork and common plenum returns for such spaces require special consideration and treatment, such as built-in attenuating

features, to minimize "crosstalk." Even with fully ducted returns, consideration must be given to the attenuating qualities (chiefly the extent and configuration of layout and fittings) of interconnecting ductwork. Although a great deal of attention is normally focused on minimizing HVAC background noise, some degree of "white noise" from HVAC systems helps to minimize conversation intelligibility.

1.4 CRITERIA AND ACCREDITATION

1.4.1 Design Criteria

One of the HVAC designer's first tasks is to establish the project design criteria. Most state and federal government agencies, and many local governments, establish criteria for the design of health care facilities within their jurisdictions. A jurisdiction may utilize its own criteria and codes or cite model, national, or international building codes or design standards. Some private health care institutions and corporations also establish their own design criteria that go beyond jurisdictional requirements. Frequently adopted or cited codes, standards, and design guidelines relating to health care facility HVAC systems include the following:

- *Guidelines for Design and Construction of Hospital and Health Care Facilities* (known as the "FGI Guidelines"), 2010, The Facility Guidelines Institute (FGI)
- ANSI/ASHRAE/ASHE Standard 170-2008, *Ventilation of Health Care Facilities*
- ANSI/ASHRAE/IES Standard 90.1-2010, *Energy Standard for Buildings Except Low-Rise Residential Buildings*
- (Proposed) ASHRAE Standard 189.3P, *Design, Construction and Operation of Sustainable High Performance Health Care Facilities* (under development as of date of this publication)
- *HVAC Design Manual for New, Replacement, Addition, and Renovation of Existing VA Facilities,* 2011, U.S. Department of Veteran Affairs
- The Joint Commission, Environment of Care standards
- National Fire Protection Association (NFPA) standards
- *Industrial Ventilation,* 2004, American Conference of Governmental Industrial Hygienists (ACGIH)
- Centers for Disease Control and Prevention (CDC) guidelines and recommended practices
- Model building and mechanical codes, including the *International Building Code (IBC)*, *International Energy Code,* and *International Mechanical Code*
- Leadership in Energy and Environmental Design (LEED®) for Healthcare™
- Unified Facilities Criteria (UFC) Manual 4-510-01, U.S. Department of Defense
- CAN/CSA Z317.2-10, *Special Requirements for Heating, Ventilation, and Air Conditioning (HVAC) Systems in Health Care Facilities*
- United States Pharmacopoeia Chapter 797

Typical criteria for HVAC design include indoor and outdoor environmental design conditions; outdoor air and total air change requirements; economic considerations for equipment selection; requirements for redundancy or backup equipment capacity, room pressure relationships, required filtration, and other benchmarks for systems and equipment selection and sizing. Other criteria that influence the HVAC design may involve envelope configuration and thermal performance, environmental requirements for special equipment and processes, operation and maintenance considerations, and clearance and conditioning requirements for electrical and electronic equipment.

Every jurisdiction can be expected to have its own design criteria, more or less supplemented by that of the building owner, which must be understood by the designer at project initiation. These criteria normally include much of the information in the previously listed sources, but may include only certain elements of these documents, or involve modifications of the published requirements. With rare exceptions, a designer can never safely assume appropriate criteria. Authorities having jurisdiction and building owners must be consulted. Authorities and owners should also be consulted as to design preferences, which often dictate specific system and equipment types, configurations, redundancies, and operating and maintenance considerations; such project-specific preferences may also involve building and space design conditions that deviate from standard criteria.

In addition to fundamental design criteria, the designer is responsible for becoming acquainted with applicable government environmental regulations and should establish in the project's scope of work who has responsibility for permits required by the jurisdiction.

1.4.2 Role of Accrediting Organizations

For a health care organization to participate in and receive payment from the U.S. Medicare or Medicaid programs, it must meet conditions and standards established under federal regulations by the Centers for Medicare & Medicaid Services (CMS). Eligibility requires a certification of compliance with the CMS conditions of participation, which is typically provided by a national accrediting organization providing and enforcing standards recognized by CMS as meeting or exceeding its own. Such organizations are considered by CMS to have "deeming authority," and the primary such deeming authority for health care facilities in the United States is The Joint Commission, formerly known as The Joint Commission for the Accreditation of Healthcare Organizations. The CMS conducts random validation surveys of health care facilities certified by deeming authorities.

The Joint Commission in an independent, not-for-profit organization governed by a board of commissioners that includes clinicians, facility administrators, health plan leaders, educators, and a variety of other professionals experienced in health care practice, administration, and public policy. The Joint Commission publishes a variety of educational materials and standards including its Environment of Care (EOC)

standards, which establish both administrative and physical requirements for creating and maintaining an optimally safe and healing health care environment.

The Environment of Care standards extend to the facility's physical plant. Of greatest interest to the HVAC engineer, the EOC standards require compliance with the FGI Guidelines and ANSI/ASHRAE/ASHE Standard 170, or with equivalent state or federal agency codes establishing design criteria for health care facilities. EOC standards (utility section) also establish facility administrative, documentation, and operational requirements relating to HVAC systems and the built environment, some of which include

- documentation of the intervals for inspecting, testing, and maintaining "all operating components of the utility system;"
- a process to minimize *Legionella* colonization of cooling towers and heating water systems;
- maintenance of drawings of utility distribution systems;
- proper ventilation systems to maintain required airflow rates, pressurization, and filtration levels for spaces or areas with airborne contaminant control requirements;
- control of noise levels and maintenance of speech privacy; and
- maintenance of building documentation, including distribution plans for building mechanical, electrical, and plumbing (MEP) services, utility system maintenance records, and building life safety plan.

The Joint Commission has a survey staff of approximately 1000 inspectors who conduct the random facility surveys required for a facility to maintain its accreditation status.

1.5 SUSTAINABLE DESIGN

Sustainable design embraces the conservation of energy, water, and other natural resources to minimize a building's impact on the earth's environment, while promoting evidence-based design elements that enhance the health, comfort, and efficiency of the building occupants. Considering that health care facilities in general are serious energy and water consumers, and their user populations are physiologically and psychologically sensitive, sustainable design approaches can uniquely impact the efficiency and effectiveness of health care delivery. Environmental design guidelines published by the U. S. Green Building Council (USGBC) and ASHRAE establish target design outcomes that encourage building owners and designers to minimize utility costs, improve building flexibility and maintainability, and maximize the application of building features that improve the comfort and sense of well being of the building occupants.

USGBC has published several rating systems with potential application to health care, including LEED for New Construction and Major Renovations™, LEED for Commercial Interiors™, and LEED

1.5.1 Sustainable Sites

for Healthcare™, the latter being developed specifically for inpatient and outpatient medical treatment facilities. Each rating system establishes minimum rating point values necessary to achieve a range of certification levels. In addition to providing a green rating tool, the LEED certifications and publications provide valuable insight into the advantages of green/sustainable design features and encourage a project team to exceed code-minimum requirements. Some owners may not choose to pursue LEED or other certifications; when pursued, however, the HVAC designer should consider payback, performance, and reliability in determining which features and strategies to implement. Three important categories of design considerations addressed in LEED are discussed in the following sections.

The main thrust of this category is to encourage selection of a building site that will have minimal impact on the natural environment. Two credits within this category (in LEED for Healthcare), however, directly affect the well being of patients, staff, and visitors: connection to the natural world via places of respite, and/or direct exterior access for patients. These credits address the advantages of human contact with nature in reducing stress and depression, through the provision of interior places of respite, healing gardens, exposure to daylight, views to the outdoors, ready accessibility to the outdoors, and walking paths, among other approaches.

1.5.2 Water Conservation

Hospitals are among the largest consumers of domestic water among all building types because of a variety of requirements that may include HVAC systems (chiefly via makeup for cooling tower and steam generation systems), sanitation, sterilization, humidification, food preparation, laundry, dialysis and other water treatment systems, and equipment cooling for vacuum and other process equipment. Sustainable design guidelines are a valuable tool for education and encouragement regarding water conservation practices that can substantially reduce water consumption and the considerable costs associated with metered water and sewage utilities.

1.5.3 Energy and Atmosphere

The objective of this category is a reduction in energy use and associated pollution. The U.S. Department of Energy (DOE) reports that hospitals have more than 2.5 times the energy intensity of commercial office buildings, with these energy costs representing 1% to 3% of a typical hospital's budget or an estimated 15% of profits (DOE 2009). The average energy use index (EUI) for hospitals in the northwestern United States is 270 kBtu/ft^2·yr [851 kWh/m^2·yr] (BetterBricks 2010). To qualify for the U.S. Environmental Protection Agency's (EPA) ENERGY STAR® certification, hospitals must meet EUI criteria that are based on size and location. For example, a 500-bed hospital in central North Carolina would require an EUI of 170 kBtu/ft^2·yr [536 kWh/m^2·yr] to qualify for ENERGY STAR. At that EUI, the hospital is in the top 25% of similar hospitals in the country. For more information, refer to the ENERGY STAR website.

Baseline energy modeling data from *Advanced Energy Design Guide for Large Hospitals* (ASHRAE 2012) suggest that, on average across the continental United States, HVAC energy consumption in conventional large hospitals (i.e., those not utilizing the best currently available approaches) amounts to more than 80% of these facilities' total energy consumption. Given these statistics, the cost savings potential in HVAC energy and the corresponding environmental benefits of reducing the carbon footprint of a facility give building owners a powerful incentive to pursue energy-conserving features and equipment.

1.6 EQUIPMENT SIZING FOR HEATING AND COOLING LOADS

Design criteria for health care facilities that affect equipment capacity and cooling/heating loads include temperature, relative humidity, and ventilation requirements. In some cases, it may be necessary to establish and maintain a range of room conditions, with different setpoints for summer or winter operation or for differing patient requirements. The HVAC design must provide for the required room conditions under the most stringent operational or weather conditions defined by applicable design criteria.

1.6.1 Design Capacity

1.6.2 Exterior Design Conditions

ASHRAE has several design weather publications and products to aid the designer, including the *Weather Data Viewer* CD, WYEC2 data, and ASHRAE *Extremes* (see www.ashrae.org for further information). Many design criteria call for use of the ASHRAE 0.4% dry-bulb (DB) and mean coincident wet-bulb (MWB) temperatures for cooling applications and the 99.6% dry-bulb temperature for heating—typically for inpatient and some outpatient (normally surgical) facilities where environmental conditions are relatively critical to patient well-being. Typical criteria for outpatient clinics call for using the ASHRAE 1% and 99% design temperatures for cooling and heating loads, respectively. Maximum cooling load can occur at peak WB conditions when outdoor air demands are high; for this reason, and for sizing evaporative and dehumidification equipment, designers should consider peak total load (latent plus sensible) climatic conditions for each project. The designer should also consider that many parts of the world are experiencing temperatures higher than the 0.4% design conditions. If the HVAC system is designed so that it cannot accommodate more extreme design conditions (when outdoor conditions exceed the 0.4% or 99.6% values) interior design requirements may not be met. Most hospital owners would deem this situation unacceptable.

1.6.3 Equipment Redundancy and Service Continuity

The fundamental importance of maintaining reasonable interior conditions in critical patient applications often dictates that some degree of backup heating capacity and, in many cases, cooling and/or ventilation capability, be available in the event of major HVAC equipment failure. Additionally, health care facilities are typically the go-to place in the case of natural or human-caused disasters, and may represent the single source of critical utility service availability (e.g., water, electricity, sanitary, shelter, etc.) within a stricken region.

Applicable codes or criteria may require inpatient facilities (and many outpatient surgical facilities) to have up to 100% backup capability for equipment essential to system operation. Even in cases when loss of a major HVAC service does not jeopardize life or health, it may lead to inability to continue medical functions and unacceptable economic impact to the building owner. Designers should also recognize that routine maintenance requirements will, at least on an annual or seasonal basis, require major plant equipment to be taken off-line for extended periods. Even where 100% redundancy is not required, it is often prudent to size and configure plant equipment for "off season" operation to enable extended maintenance of individual units.

Emergency power systems (EPS) are mandated by several codes and standards for HVAC equipment considered essential for safety and health. Facility heating, particularly for critical and patient room spaces, must normally be connected to the EPS, as is the cooling system, in some jurisdictions. Federal government regulations and/or guidelines require that ventilation equipment serving disease isolation and protective isolation rooms be connected to the EPS. The AHJ and/or owner may require that cooling sources, pumps, air-handling units, and other equipment necessary to provide cooling for critical inpatient or sensitive equipment areas be supplied by an EPS.

1.7 VENTILATION AND OUTDOOR AIR QUALITY

Ventilation rates for typical health care spaces are addressed by ANSI/ASHRAE/ASHE Standard 170, *Ventilation of Health Care Facilities*. Such facilities require large amounts of fresh, clean, outdoor air for occupants and for control of contaminants and odors through dilution ventilation and exhaust makeup. In addition to outdoor air change rates, minimum total air change rates are provided in order to supplement ventilation "air cleaning," or to establish adequate distribution and circulation of air within a space. Filters with a minimum efficiency reporting value (MERV) 14 or higher (MERVs established by procedures specified in ANSI/ASHRAE Standard 52.2-2007) are very effective at removing microorganisms and similarly sized particulates. In certain locations, the quality of outdoor air may be compromised by combustion exhaust fumes or other objectionable or harmful odors or gases, such as ozone, which require the provision of activated carbon or other adsorption filtration of outdoor air.

1.7.1 Location of Outdoor Air Intakes

Outdoor air intakes must be located an adequate distance away from potential contamination sources to avoid intake of contaminants. Typical minimum separation requirements are 25 ft [7.6 m], established by the FGI Guidelines, and 30 ft [9.1 m], according to the *ASHRAE Handbook—HVAC Applications*. These distances should be considered only as preliminary guides: greater separation may be required, depending upon the nature of the contaminant, direction of prevailing winds, and relative locations of the intake and contaminant sources. The *ASHRAE Handbook—Fundamentals* provides further design guidance and calculation methods to help predict airflow

characteristics around buildings, stack/exhaust outlet performance, and suitable locations for intakes. See Chapter 3 of this manual for more details.

1.7.2 Air-Mixing and Ventilation Effectiveness

In most health care applications, it is desirable to introduce supply air into a space in such a manner as to maximize distribution throughout the space and minimize stratification. Doing so maximizes the effectiveness of ventilation and contributes to overall comfort. Good air mixing is enhanced by meeting minimum total air change requirements and by careful selection of diffuser location and performance, with proper attention to room construction features that can affect distribution. Air-mixing effectiveness is also influenced by perimeter envelope exposure and the temperature difference between supply and room air. Additional information is available in Chapters 3 and 8.

1.7.3 Exhaust of Contaminants and Odors

Exhaust systems provide for removal of contaminants and odors from a facility, preferably as close to the source of generation as possible. In addition, exhaust systems are used to remove moisture, heat, and flammable particles or aerosols. Examples of source exhaust in health care applications include the following:

- Chemical fume hoods and certain biological safety cabinets used in laboratories and similar applications where health care workers must handle highly volatile or easily aerosolized materials
- Special exhaust connections or trunk ducts used in surgical applications to remove waste anesthesia gases or the aerosolized particles in laser plumes
- "Wet" X-ray film development machines (now being rapidly replaced with digital equipment), which are normally provided with exhaust duct connections for removal of development chemical fumes
- Cough-inducement booths or hoods used particularly in the therapy for contagious respiratory disease
- Kitchen and sterilizing equipment that produce moisture and heat

When contaminants or odors cannot practically be captured at the source, the space in which the contaminant is generated should be exhausted. Rooms typically exhausted include laboratories, soiled linen rooms, waste storage rooms, central sterile decontamination (dirty processing), anesthesia storage rooms, PET scan, hot laboratories (for work with radioactive materials), airborne infection isolation (AII), and bronchoscopy. For potentially very-hazardous exhausts, such as from radioisotope chemical fume hoods or disease isolation spaces, codes or regulations may require HEPA filtration of the exhaust discharge, particularly if the discharge is located too close to a pedestrian area or outdoor air intake.

1.8 ENVIRONMENTAL CONTROL

1.8.1 The Role of Temperature and Relative Humidity

As discussed in section 1.3, temperature, and in some instances relative humidity, can be important in establishing therapeutic conditions for patient treatment, and in maintaining a comfortable environment for all of the building's occupants.

Conditions of temperature and relative humidity that would be considered comfortable for healthy individuals dressed in normal clothing may be very uncomfortable for both patients and health care workers, for a variety of reasons, including the following:

- Patients in both clinical and inpatient facilities may be very scantily clad or, in some instances, unclothed—and have little or no control over their clothing.
- In hospital settings, patients are often exposed to a specific environment on a continuous basis, not merely for short periods of time.
- In a variety of cases of disease or injury, patient metabolism, fever, or other conditions can interfere with the body's ability to regulate heat.
- Health care workers often must wear heavy protective coverings, as in surgery and the emergency department, and engage in strenuous, stressful activities near heat-generating lights and equipment.

1.8.2 Noise Control

Noise control is of high importance in the health care environment because of the negative impact of high noise levels on patients and staff and the need to safeguard patient privacy. The typical health care facility is already full of loud noises from a variety of communications equipment, alarms, noisy operating hardware, and other causes without the noise contribution from poorly designed or installed HVAC equipment. High noise levels hinder patient healing largely through interference with rest and sleep. In addition, loud noises degrade the health care provider's working environment, increase stress, and can cause dangerous irritation and distraction during the performance of critical activities. Sources of excessive HVAC noise include

- direct transmission of mechanical and/or medical equipment room noise to adjacent spaces;
- ductborne noise generated by fans and/or high air velocities in ducts, fittings, terminal equipment, or diffusers and transmitted through ductwork to adjoining occupied spaces;
- duct breakout noise, where noise in ductwork penetrates the walls of the duct and enters occupied spaces;
- duct rumble, a form of low-frequency breakout noise caused by the acoustical response of ductwork to fan noise—particularly high-aspect-ratio, poorly braced rectangular ductwork; and
- vibrations from fans, dampers, ductwork, etc.

Patient privacy can be compromised when private conversations are intelligibly transmitted to adjoining spaces. Frequent causes of this problem are inadequate acoustical isolation properties of the construction elements separating rooms, inadequate sound-dampening provisions in ductwork, and/or inadequate background room sound pressure level. HVAC ductwork design and diffuser/register selection can greatly mitigate the latter two concerns, by providing a minimum level of background sound contribution from the air distribution system and by providing effective attenuation in ductwork. Chapter 3 provides more detailed information on the causes of, and solutions to, HVAC noise.

1.9 HVAC SYSTEM HYGIENE

In addition to the general topic of infection cause and control discussed previously, the designer must be aware of the potential for infection risks that can arise through poor design or maintenance of HVAC equipment. As explained in greater detail in Chapter 2, infections acquired within the health care facility are referred to as nosocomial infections, or health-care-acquired infections (HAI). Any location where moisture and nutrient matter come together can become a reservoir for growth of harmful microorganisms. Generally, hard surfaces (such as sheet metal) require the presence of liquid water to support microbe growth, whereas growth in porous materials may require only high relative humidity. Nutrient materials are readily available from sources such as soil, environmental dust, insects, animal dander and droppings, and other organic and inorganic matter. The task of the HVAC designer is to minimize the opportunity for moisture and nutrients to collect in the system, through proper design of equipment, including adequate provisions for inspection and maintenance. Potential high-risk conditions in an HVAC system include the following:

- Outdoor air intakes located too close to collected organic debris, such as wet leaves, animal nests, trash, wet soil, grass clippings, or low areas where dust and moisture collect; this is a particular concern with low-level intakes and a primary reason for code-mandated separation requirements between intake and ground, or intake and roof
- Outdoor air intakes not properly designed to exclude precipitation; examples are intakes without intake louvers (or with improperly designed louvers) and intakes located where snow can form drifts or splashing rain can enter
- Improperly designed or installed outdoor air intake opening ledges where the collected droppings of roosting birds carry or support the growth of microorganisms
- Improperly designed or installed cooling-coil drain pans or drainage traps that prevent adequate condensate drainage
- Air-handling unit or duct-mounted humidifiers not properly designed or installed to provide complete evaporation before impingement on downstream equipment or fittings

- Filters and permeable linings, which collect dust, located too close to a moisture source, such as a cooling coil or humidifier
- Improper attention to maintenance during design, resulting in air-handling components that cannot be adequately accessed for inspection or cleaning

Designers must always bear in mind that even properly designed equipment must be maintainable if it is to remain in clean, operating condition. Chapter 3 provides additional information regarding the proper design of HVAC system components to minimize the potential for microbe growth.

1.10 FLEXIBILITY FOR FUTURE CHANGES

Changes in space use are common in health care facilities, and periods of less than ten years between complete remodelings are commonplace. The trend is normally toward more medical equipment and increasing internal cooling loads. The initial design should consider likely future changes, and the design team and owner should consider a rational balance between providing for future contingencies and initial investment costs. Future contingencies may be addressed by features such as

- oversizing of ductwork and piping;
- provision of spare equipment capacity (oversizing) for major plant, air-moving, or pumping equipment or provision of plant/floor space for future equipment installation; and
- provision of interstitial utility floors where maintenance and equipment modification or replacement can occur with minimal impact on facility operation.

1.11 INTEGRATED DESIGN

1.11.1 General

To succeed, the HVAC design process must be thoroughly coordinated with the other design disciplines. The HVAC engineer's involvement should begin no later than preconcept design and continue until design completion. This chapter has addressed some of the design features essential to good air quality, hygienic design, and comfort conditioning; obtaining these features requires the HVAC designer's early influence on building arrangement and floor plan features that affect equipment location and space availability. Early involvement and design coordination are essential to ensure that

- outdoor air intakes and building exhausts are optimally located to avoid contamination of the building air supply;
- plant and equipment rooms are well located in relation to the areas they serve, to enable economic sizing of distribution equipment and air and water velocities well within noise limitation guidelines;
- plant and equipment rooms are located so that equipment noise will not disrupt adjacent occupied spaces;

- HVAC equipment room locations are coordinated with electrical, communications, and plumbing equipment rooms to minimize distribution equipment (ductwork, piping, cable trays, and conduit) congestion and crossover, while providing adequate space for installation and maintenance of these services;
- sufficient vertical building space is provided for the installation and maintenance of distribution equipment of all trades; and
- sufficient space is provided for plant and equipment rooms and vertical utility chases, to enable proper installation, operation, and maintenance of equipment, including provisions for eventual equipment replacement.

1.11.2 Equipment Interface: "Make it Fit"

Because of the many engineering systems that provide services in health care facilities, the need to provide adequate access for future maintenance, and because criteria may restrict where distribution equipment can be installed, the HVAC designer must carefully coordinate the physical space requirements for equipment. Health care facilities are served by a wide variety of fire protection, electrical power, plumbing, medical gas, and telephone, data, nurse call, and other electronic communication and monitoring systems. All of these must physically fit within allowable distribution spaces along with HVAC ductwork and piping. Often, codes or criteria restrict main utility distribution to circulation spaces to minimize the need for maintenance personnel to enter occupied spaces and/or to control noise. Codes also restrict certain utilities from passage over electrical and communications spaces, exit enclosures, and certain critical health care spaces, such as operating rooms.

It is the responsibility of design engineers to verify that the equipment depicted in design drawings can be installed in the spaces indicated, with sufficient space for maintenance access, by a prudent contractor using standard construction practices and reasonable judgment, according to the provisions of the construction contract. When the designer knows that space is so limited as to require special construction measures and/or limited or proprietary equipment selections, it is wise to make this information known in the design documents. A prudent designer depicts and dimensions the equipment on design drawings (including ductwork and piping, and all major fittings and offsets required for coordination, balancing, and operation) such that it could reasonably be installed as depicted. These design responsibilities do not detract from the construction contractor's responsibility to properly coordinate the installation work between trades and do not supplant his/her responsibility to execute detailed, coordinated construction shop (installation) drawings.

Building information modeling (BIM) collision-avoidance tools are increasingly being used to assist in the spatial coordination of distribution equipment with architectural and structural elements. Designers should be aware of their BIM software's capabilities and

limitations in depicting maintenance clearances, as these must typically be manually defined and input. Similar attention must be paid to the correct modeling of gravity drainage, steam, and other sloped piping systems. Many designers still accomplish systems coordination the "old fashioned way" by a variety of methods that may include multidimensional overlays and representative sectional views or sketches. Such sectional views should be provided from at least two perspectives in each congested plant and equipment room and at representative "crowded" locations in distribution areas throughout the facility. Some building owners require submission of such "proof-of-concept" documents to demonstrate satisfactory interdisciplinary coordination.

1.11.3 Special Considerations for Retrofit/Renovation

Designs for retrofit or renovation of existing health care facilities, particularly when health care functions in areas surrounding or adjacent to project work must continue during construction, require special attention to factors that can affect patient health and safety. Designs must include provisions to minimize the migration of construction dust and debris into patient areas or the possibility of unplanned interruptions of critical engineering services.

Construction work almost invariably involves introduction or generation of substantial airborne dust or debris, which, without appropriate barrier controls, may convey microbial and other contaminants into patient care areas. Demolition activities, the transport of debris and personnel traffic in and out of a facility can directly introduce contaminants—as can disruption of existing HVAC equipment, removal of barrier walls or partitions, and disturbance of building elements and equipment within occupied areas. Project architects and engineers must work closely with the owner's infection control representative to help assess the potential risks to the patient population during construction activities, and jointly identify appropriate barrier controls and techniques. Typical barrier approaches can include separation of construction areas by dust-tight temporary partitions, exclusion of construction traffic from occupied areas, and isolation of duct systems connecting construction with occupied spaces. In addition, negative relative pressurization and exhaust of construction areas are usually required. In cases of severe patient vulnerability, the use of supplemental HEPA filtration units in patient rooms or other critical spaces may be considered.

Of equal concern, designers must seek to minimize the possibility of unplanned service interruptions during the construction project. Designers should become well acquainted with the existing engineering systems and building conditions to be able to evaluate the impact of new construction. Site investigations should always include inspection of existing equipment plants, rooms, and other equipment and building areas with reasonably available access. Maintenance personnel can often provide information on concealed as-built conditions, and as-built drawings are often available; in many cases, however, the

latter are inaccurate or not up to date. Predesign testing, adjusting, and balancing (TAB) of existing conditions is advisable; otherwise, new design work will often be held responsible for deficiencies in original equipment or system performance.

When as-built information is lacking or suspect, designers should attempt to identify existing services that are installed in, or are likely to be affected by, project work, to the extent feasible under the scope of the design contract and the physical or operational limitations of building access. Building owners should recognize the value of accurate as-built information and, when not available from in-house sources, contractually provide for more thorough investigations by the design team. It is the designer's responsibility to identify the nature of alterations of, or extensions to, existing services and equipment, including temporary features, and any required interim or final rebalancing, commissioning, or certification services necessary to accommodate new building services while minimizing impact to ongoing functions. This will often require the development of a detailed phasing plan, developed in close coordination with the building owner. The goal should be "no surprises"—no interruptions or diminishment of critical services to occupied areas that are not planned and made known to the building owner during the design process. Chapter 7 provides more information on this topic.

1.12 COMMISSIONING

Health care HVAC systems provide critical functions that justify a comprehensive commissioning process that goes beyond the level of quality oversight/control, static testing, and TAB typically practiced on commercial facilities. Commissioning should begin with concept design and continue through the project, with the active participation of qualified commissioning professionals in development and review of commissioning documents that define the responsibilities of all parties involved, and clearly convey the scope and rigor of the commissioning process and the owner's project requirements (OPR). Among other features, proper commissioning involves expert oversight of equipment and system startup, prefunctional performance checks, functional performance testing, owner training, and other activities overseen by a qualified representative of the building owner, based on comprehensive specifications developed during the design phase. A rigorous commissioning process will demonstrate that the as-built HVAC system operates according to the owner's requirements and the designer's intentions, by achieving the following objectives:

- Providing assurance that equipment and systems are properly installed and received adequate operational checkout by the installation contractors
- Verifying and documenting the proper operation and performance of equipment and systems, to include operation in part-load and failure modes
- Establishing that performance setpoints are achieved and optimized

- Providing thorough documentation of the commissioning process and results
- Providing assurance that the facility operating staff is adequately trained

Depending upon the size, complexity, and budget for the project, the tasks involved in commissioning can vary widely. Consequently, the commissioning process should be customized for each project. It is worth repeating that the required scope and rigor of the commissioning process must be clearly defined before award of the construction contract, so that the necessary qualifications, responsibilities, and scope of effort for all parties involved in construction phase commissioning are clearly understood.

1.13 CONCLUSIONS

The design of HVAC systems for health care facilities is a unique and challenging art and science—demanding specialized experience and knowledge of the character of these high-stakes facilities, the sensitivity and vulnerability of their populations, and the complex interactions of the HVAC system with the other architectural and engineering elements that make up the building. The design process requires familiarity with a specialized and diverse set of criteria, regulations, codes, and design standards, and the ability to weigh their application in the face of an owner's economic limitations associated with the business of health care (addressed in detail in Chapter 9). This manual describes best practices for the design of HVAC systems for health care facilities. It is not intended as a code document, and readers should consider that even best practices, unless codified, may be rejected by the building owner.

REFERENCES

ASHRAE. 2012. *Advanced energy design guide for large hospitals.* Atlanta: ASHRAE.

BetterBricks. 2010. Energy in healthcare fact sheet, May 2010. Portland, OR: Northwest Energy Efficiency Alliance. Available at http://www.betterbricks.com/.

DOD. 2011. *Unified facilities criteria (UFC) design: Medical military facilities* (UFC 4-510-01), Change 4, August 2011. Washington, DC: U.S. Department of Defense.

DOE. 2009. Department of Energy announces the launch of the Hospital Energy Alliance to increase energy efficiency in the healthcare sector, April 2009. Washington, DC: U.S. Department of Energy. Available at http://energy.gov/articles/department-energy-announces-launch-hospital-energy-alliance-increase-energy-efficiency.

EPA. ENERGY STAR® Program. Washington, DC: U.S. Environmental Protection Agency. Available at http://www.energystar.gov/.

ICC. 2012. *International building code® (IBC®)*. Washington, DC: International Code Council.

NFPA. 2012. *NFPA 101: Life safety code®*. Quincy, MA: National Fire Protection Association.

CHAPTER 2

INFECTION CONTROL

2.1 INTRODUCTION

As noted in Chapter 1, a unique aspect of hospital HVAC systems is their role in mitigating the spread of airborne contaminants that could cause infections. Hospital-acquired infections (HAIs, also referred to as nosocomial infections) have a significant impact on patient care. Mortality rates from HAIs are significant and affect the overall cost of health care delivery. In the United States, HAIs occur in an estimated 4% to 5% of admitted patients; at an estimated annual cost approaching $7 billion. It is generally agreed that 80 to 90% of HAIs are transmitted by direct contact, with 10% to 20% resulting from airborne transmission (representing 0.4% to 1% of admitted patients) (Memarzadeh 2011a).

Transmission of airborne hazards is influenced by factors beyond the control of the engineer that include movement of patients, undiagnosed patients, visitors, concentration of patients, and patient susceptibility. The nature of infectious pathogens, the modes of transmission, the causation of infections, and the relationships to HVAC system design are complicated and not fully understood. HVAC systems can affect the distribution patterns of airborne particles by diluting or concentrating them, moving them into or out of the breathing zones of susceptible persons, or by accelerating or decelerating the rate of growth of airborne microbes. Improperly operated and maintained HVAC systems can even become a reservoir for microorganisms.

Surgical site infections (SSIs) are caused by a variety of sources, including deposition of particles either directly on the patient or on the staff and equipment, which are then transferred to the surgical site.

This chapter is intended to give a brief overview of the ways HVAC systems can help mitigate airborne infections. A more thorough discussion of this subject can be found in *The Environment of Care and Health Care-Associated Infections: An Engineering Perspective* (Memarzadeh 2011a).

2.2 ROLE OF HVAC SYSTEMS IN INFECTION CONTROL

Although the majority of nosocomial infections are caused by factors such as poor hygiene practice, lack of hand cleaning, or surface-to-surface contamination, there is some risk of infection spread via HVAC systems; consequently, codes and guidelines covering design and operation of health care HVAC systems have been developed. Some of the ways that potentially infectious microorganisms can be spread in a health care environment include

- sneezes and coughs,
- inhalation,
- contact,
- deposition in surgical site or open wound,
- water mist, and
- insect bite.

HVAC systems can impact HAIs by affecting

- dilution (by ventilation),
- air quality (by filtration),
- exposure time (by air change and pressure differential),
- temperature,
- humidity,
- organism viability (by ultraviolet [UV] treatment), and
- airflow patterns.

The science of controlling infections caused by airborne microorganisms is a complex mixture of engineering, particle physics, microbiology, and medicine. The rates at which particles settle are a function of their size, shape, density, and of course, air movement. Turbulence within a room increases the residence time of larger particles in the air, hence the desire for laminar airflows in operating rooms. Particles or aerosols below about 1μm in size are virtually unaffected by gravity and stay in suspension because of Brownian motion. Aerosols generated by coughs and sneezes generally affect other persons only within 3 to 6 ft [0.9 to 1.8 m]. It is virtually impossible for HVAC systems to exert control at this close exposure; therefore, transfer must be controlled using personnel protection and/or isolation.

The viability of microorganisms embedded in water droplets (aerosols) is affected by temperature, humidity, and air velocity. Memarzadeh (2011a) summarizes and provides an extensive bibliography on this subject.

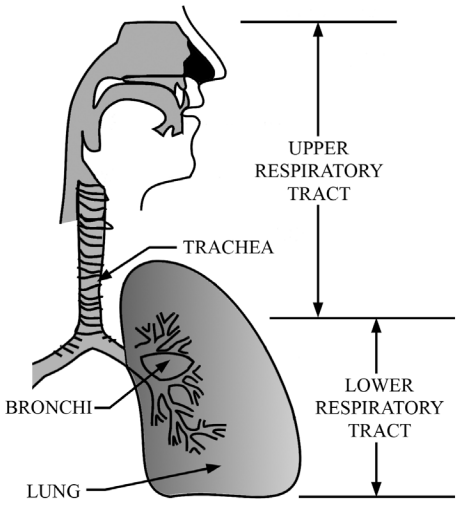


Figure 2-1 *The Respiratory Tract*

Although the number of airborne-spread infections is a small percentage of the total number of HAI infections, the number is significant enough to warrant care in the design of HVAC systems for health care facilities. Therefore, many aspects of current HVAC design codes and guidelines are motivated by a desire to reduce infections caused by inhalation and deposition.

2.3 HOW THE HUMAN BODY IS AFFECTED BY AIRBORNE CONTAMINANTS

The normal human body has excellent protection systems to prevent respiratory infections. There are several layers of ”filtration” starting with the mouth and windpipe (which have moist surfaces—a mucous layer—to attract and collect particles before they enter the trachea) and beyond that further collection within the bronchi (Figure 2-1). Infections such as pneumonia affect the lungs, where they can thrive and enter the bloodstream if they manage to penetrate the body’s defense systems. Pneumonia is a deep-seated infection once it reaches the lungs and presents a serious risk to anyone who encounters it, particularly patients who may be immune suppressed and less able to resist its presence.

Airborne particles can affect the human body and the health care environment in several ways. These particles can be toxic chemicals, allergens, or infectious agents. Airborne contaminants may enter a building from the outdoors or from processes that occur inside the building. Harmful substances from the outdoors may enter the space through openings in the building envelope or through outdoor air intakes. Outdoor air in an urban environment can contain fumes from motor vehicles or emissions from building-related equipment such as diesel generators. Facilities in rural areas may be near pesticides and agricultural dust. Equally hazardous are emissions from materials and processes inside a building. Exhalations of patients create yet more sources of potentially infectious agents.

The building itself may produce toxic or annoying fumes and allergens. Usually, contaminants from medical processes are carefully

contained in laboratories or specialized procedure or storage rooms, but it is important that the HVAC system maintain isolation of these substances from the building occupants. Other potential sources of air quality problems are off-gassing from materials inside the building and from activities such as cleaning. Sensitive, vulnerable patients (as well as visitors and staff) may suffer from exposure to such substances, and it is incumbent upon the HVAC system to minimize their transmission and delivery (although controlling them at the source is the preferable strategy, when feasible). People vary widely in their sensitivities to various allergens, and allergic reactions can exacerbate other medical conditions. Common airborne allergens include mold, fungal spores, and tree and grass pollen.

A virulent infection in a hospital setting will find the body an easier target than normal. People recovering from an operation are vulnerable, as their immune system is preoccupied with repairing the body after surgery. A hospital is also a place with more infectious agents than normal, because building occupants are likely to have a variety of illnesses, some of which relate to infectious diseases. These are a threat to all other patients, staff, and visitors.

Infectious diseases (also known as transmissible diseases or communicable diseases) comprise clinically evident illness resulting from the infection, presence, and growth of pathogenic biological agents in an individual host organism. Infectious pathogens include some viruses, bacteria, fungi, protozoa, multicellular parasites, and aberrant proteins known as prions.

The term infectivity describes the ability of an organism to enter, survive, and multiply in the host, while the infectiousness of a disease indicates the comparative ease with which the disease is transmitted to other hosts. Transmission can occur in various ways including physical contact, contaminated food, body fluids, objects, airborne inhalation, or through a vector organism.

Infection occurs when all of the following elements are present: an infectious agent, a source of the agent, a susceptible host to receive the agent, and most critically, a way for the agent to be transmitted from the source to the host. The interaction among these elements is known as the "chain of infection," or "disease transmission cycle," terminology that emphasizes the necessary linkages among all elements. Generally, the severity of the impact of exposure to microorganisms is described by the following relationship:

$$\text{Infection} = \frac{\text{Dose} \times \text{Site} \times \text{Virulence} \times \text{Time}}{\text{Level of Host Defense}}$$

Thus, the severity of the impact on persons exposed is determined by the length of the exposure, virulence of the microbes to which they are exposed, location of the exposure, and quantity of microorganisms;

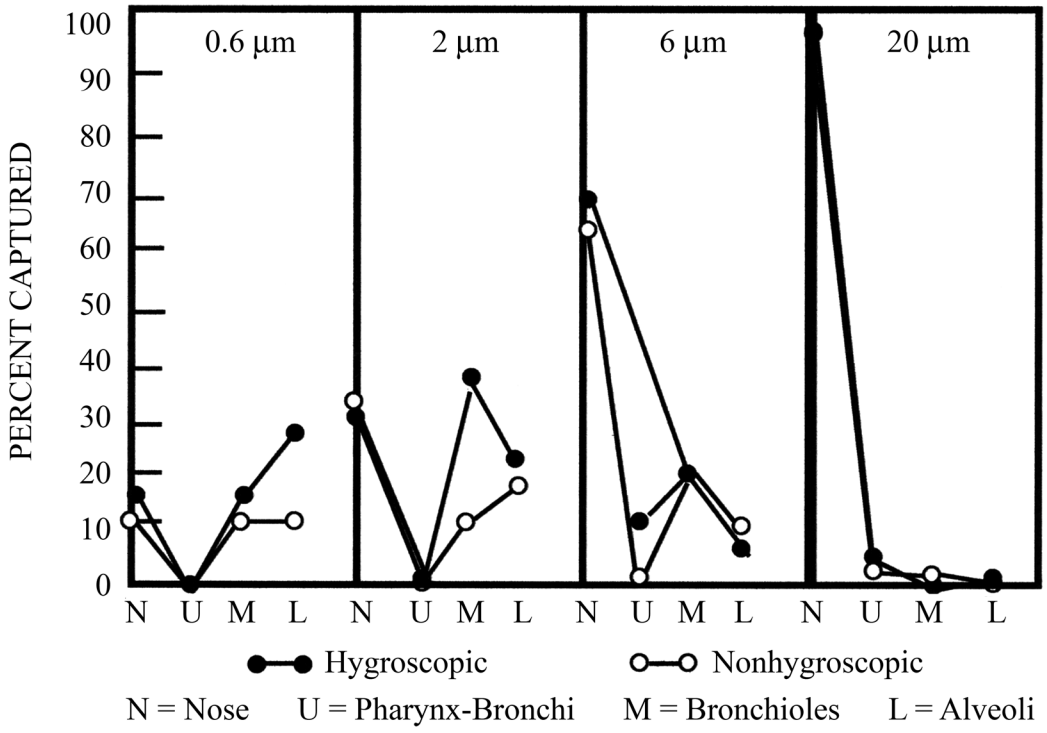


Figure 2-2 *Particle Arrestance by Size, Moisture Absorption Type, and Entry Portal*

whereas, the impact is mitigated or exacerbated depending upon the vitality of the exposed person. Generally, the methods by which HVAC systems are intended to reduce HAIs are all designed to address components of this simple equation.

The infectious agent is the microorganism that can cause infection or disease. The ability to penetrate the respiratory system relates to size of particle. Figure 2-2 indicates that, while particle sizes around 20 µm are generally stopped at the nose, those of 0.6 to 2 µm can reach the lower respiratory tract (alveoli).

A reservoir is the place where the agent survives, grows, and/or multiplies. People, animals, plants, soil, air, water and other solutions, instruments and items used in clinical procedures can serve as reservoirs for potentially infectious microorganisms. There are two sources of infectious agents in a hospital or health care setting:

- *Endogenous source:* the causative agent of the infection is present in the patient at the time of admission to the hospital but there are no signs of infection. The infection develops during the stay in the hospital as a result of the patient's altered resistance or through introduction of microbes into normally sterile areas, such as insertion of an intravenous catheter into a vein, or from a surgical procedure.

- *Exogenous source:* infection occurs from introduction of microbes into or on the patient from an outside source. For example, the patient may acquire infectious agents from the hands of staff or from contaminated equipment and subsequently develop an infection.

The infectious agent can be transmitted via tiny droplet nuclei (< 5 μm) containing microorganisms that remain suspended in the air and that can be carried by air currents greater distances than large droplets (e.g., measles, *M. tuberculosis*). The susceptible host then inhales these droplets. The droplet nuclei may remain suspended in the air for long periods of time.

The route by which the infectious agent leaves the reservoir is called the exit. An infectious agent can exit the reservoir through the mucous membranes (e.g., eyes, nose, and mouth), and the respiratory tract (e.g., lungs), or through droplets that come from these sites.

The place of entry is the route by which the infectious agent moves into the susceptible host. An airborne infectious agent can enter the susceptible host through mucous membranes (e.g., eyes, nose, mouth) or the respiratory tract (e.g., trachea, bronchi, lungs).

This is the route of many disease agents that cause respiratory illnesses, such as the common cold, influenza, tuberculosis, measles, mumps, rubella, pertussis, *Haemophilus influenzae* type b (Hib), and pneumococcal disease (pneumonia). The respiratory tract is the most important portal and the most difficult to control.

Airborne transmission via aerosols is important in some respiratory diseases. Aerosols are particularly dangerous because their size (1 to 5 μm) allows them to be drawn deep into the lungs and retained. Turbulent air may also spread large particles from contaminated soil or from objects such as clothing and floors.

In general, the following factors affect whether or not an infection occurs in a particular situation:

- Aerosol and droplet transmission dynamics
- Nature of dust levels
- Health and condition of individual's nasopharyngeal mucosal linings
- Population density
- Ventilation rate
- Air distribution pattern
- Humidity
- Temperature
- Susceptibility
- Length of exposure

- Number of infected people producing contaminated aerosols
- Infectious-particle settling rate
- Lipid or nonlipid viral envelope or microorganism cell wall
- Surrounding organic material
- UV radiation or antiviral chemical exposure
- Vitamin A and D levels
- Microorganism resistance to antibiotic or antiviral therapy
- Type and degree of invasive procedures
- Spatial considerations
- Contact with carrier
- Persistence of pathogens within hosts
- Immunoepidemiology
- Genetic factors

2.4 RISK MANAGEMENT APPROACH TO INFECTION CONTROL

Risk assessment and management provide a systematic approach to discovery and mitigation of risks facing an organization or facility. The goal is to help objectively state, document, and rank risks and prepare a management plan for implementation. Risk management techniques are used to identify appropriate countermeasures, options, or alternatives for a known or anticipated situation.

The general principles that should be considered for any risk assessment are

- identifying the risk,
- estimating the level of exposure,
- estimating the probability of risk occurrence,
- determining the value of the loss,
- ranking risks, and
- identifying vulnerabilities

The approach to infection control and environmental control outlined in FGI (2010) considers the susceptibility of patients versus the degree of environmental contamination. Such an infection control risk assessment (ICRA) requires communication between clinical and facility staff and includes both design and remediation issues to protect patients and staff. ICRA is described in more detail in Chapter 11. Risk assessment design strategies for infection prevention and control include consideration of the patient population served, range and complexity of services provided, and settings in which care is provided. Other variables include status (e.g., infectious, susceptible, or both); the area under consideration (e.g., isolation or protective); the type of filtration, ventilation, and pressurization; and the operations and maintenance procedures and management that are in place. Risk assessment design strategies for environmental controls include the use of positive pressure environments (PPEs) for the health care professional, the type of isolation necessary (e.g., protective or

contaminant), and the ventilation standards applicable to the type of facility being assessed (Kosar 2002).

2.5 SURGICAL SITE INFECTIONS

Surgical site infections (SSIs) are less prevalent than they used to be, as a result of the trend toward less invasive procedures. In complicated cardiac, vascular, orthopedic, and prosthetic and transplant surgeries requiring lengthy procedures, there is a higher risk of SSI. SSIs are classified as incisional or organ/space. Incisional infections are further divided into superficial (skin and subcutaneous tissue) and deep (deep soft tissue, bone, muscle, and fascia) (Horan et al. 1992; Edwards et al. 2008). Organ/space SSIs are associated with high morbidity and mortality.

The source of the SSI pathogen(s) is usually the patient's skin, mucous membranes, or bowel and rarely from another infected site in the body (endogenous sources). Organisms associated with SSIs vary with the type of procedure and the anatomic location of the operation. Exogenous sources of SSI pathogens may include members of the surgical team (e.g., hands, nose, or other body parts); contaminated surfaces in the operating room; the air; and contaminated instruments, surgical gloves, or other items used in the surgery as shown in Figure 2-3. Exogenous organisms are primarily aerobic *staphylococci* or *streptococci* species.

Operating rooms (ORs) are one of the most critical areas for infection control; this is where patients are opened to the surrounding environment while in an immune-suppressed condition. The patient is vulnerable to attack from any infectious agents that get into the room and to the surgical site. Although clean conditions can be created by

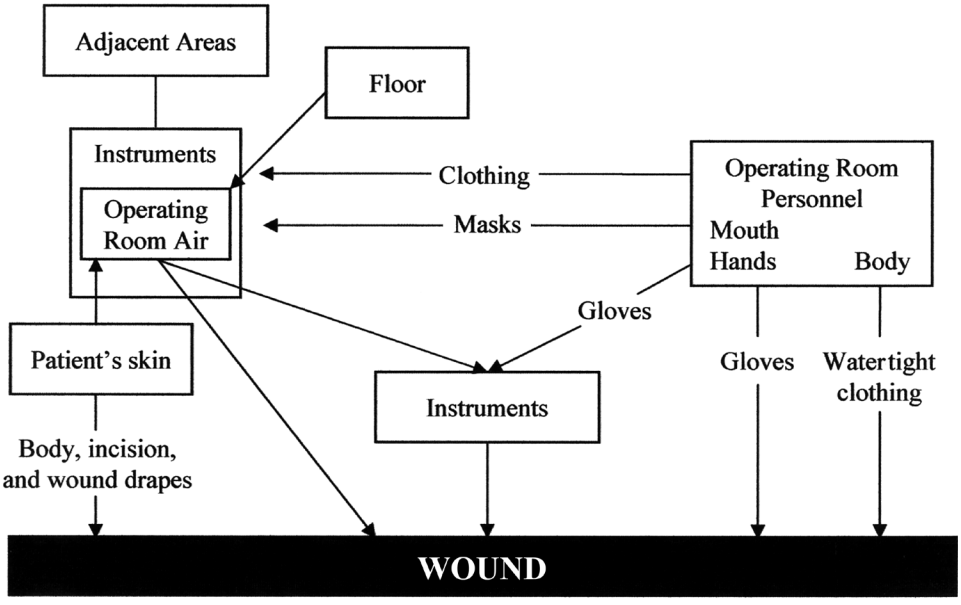


Figure 2-3 *Routes for Surgical Site Infections*

appropriate HVAC design (see Chapter 3), there is always a risk that the surgical team itself can bring infectious agents into the room. *Staphylococcus aureus* is commonly found on the skin of many people and there is risk from the skin squames shed by each person present during an operation. Between 1 million and 900 million squames are shed during surgery (Hambraeus 1988). As described later in this chapter and in Chapter 8, airflow patterns in ORs are dictated by the intent to reduce SSIs.

2.6 PROTECTING POPULATIONS

Positive pressure environment (PPE) rooms are designed for patients with severely compromised immune systems, such as bone marrow transplant and HIV patients. The HVAC systems for PPE rooms are designed to preclude airborne pathogens through the use of high-quality filtration, high air exchange rates, anterooms, and pressurization.

Airborne infection isolation (AII) rooms are designed for patients diagnosed as having communicable contagious diseases. These rooms are designed with anterooms, are under negative pressure, and have a dedicated direct exhaust system. Optionally, the exhausts from these rooms have HEPA filters to control the dispersion of airborne pathogens to the surrounding environment. The emergency waiting room is an area of particular risk because both immune-compromised and undiagnosed contagious patient populations often coexist there. This type of space has high air exchange rates and all air is exhausted directly outside. PPE, AII, and ED (emergency department) waiting rooms are discussed in Chapter 8.

Procedurally, staff and patients wear facemasks to mitigate potential airborne contamination—particularly short-range droplet transmission from sneezing, talking, coughing, or just breathing. Special procedures such as surgeries entail more sophisticated PPEs to protect both staff and patient, including fully-ventilated suits for procedures on high-risk contagious patients. The size of a particle affects its ability to penetrate the respiratory system.

2.7 AIR CHANGE RATE/ DILUTION

One method of reducing the time and/or number of microbes to which a person is exposed is by increasing the dilution rate of clean air into a space. This reduces the exposure time of microorganisms generated within the room by objects, staff, or the patient. Table 2-1 indicates the length of time it takes for a room to be flushed with filtered air, assuming perfect mixing.

As indicated, microbes can be expected to be resident in a room for 14 minutes at 20 ach (air changes per hour [ACH]) and 28 minutes at 10 ach. The general concept of dilution and replacement with clean air is a fundamental driver of the ACH rates provided in the ANSI/ ASHRAE/ASHE Standard 170 ventilation table; as shown in Table 2-2. The entire table is shown in Chapter 3 of this manual.

Table 2-1 *Effect of Air Change Rates on Particle Removal*

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

Source: CDC (2003). **Note:** assumes perfect mixing.

Table 2-2 *Excerpt from ANSI/ASHRAE/ASHE Standard 170-2008 Ventilation Table*

Space	T, °F	T, °C	RH, %	Pressure	OA	ACH
Class B and C operating room	68 to 75	20 to 24	30 to 60	Positive	4	20
Operating/surgical cystoscopic rooms	68 to 75	20 to 24	30 to 60	Positive	4	20
Delivery room (Caesarean)	68 to 75	20 to 24	30 to 60	Positive	4	20
Critical and intensive care	70 to 75	21 to 24	30 to 60	Positive	2	6
Wound intensive care (burn unit)	70 to 75	21 to 24	40 to 60	Positive	2	6
Radiology waiting room	70 to 75	21 to 24	Max 60	Negative	2	12
Class A operating/procedure room	70 to 75	21 to 24	20 to 60	Positive	3	15
X-ray (surgery/critical care and cath.)	70 to 75	21 to 24	Max 60	Positive	3	15
Sterilizer equipment room	—	—	—	Negative	—	10
Soiled and decontamination	72 to 78	22 to 26	—	Negative	2	6
Sterile storage	72 to 78	22 to 26	Max 60	Positive	2	4

Source: ASHRAE (2008). *T* = indoor design temperature range RH = relative humidity OA = outdoor air ACH

These air change rates are also a result of research on odor control and comfort (Klaus 2011). Studies in London in the early 1900s documented lung volume and calculated outdoor air ventilation rates to reduce odor. Other studies documented the volume and velocity of airflows from sneezes and coughs and concluded that about 35 cfm [16.5 L/s] per person of outdoor air was needed. However, Memarzadeh and Xu (2012) questions current ACH standards.

2.8 NATURAL VENTILATION

In the World Health Organization (WHO) interim guidelines (WHO 2007), natural ventilation is considered an effective environmental measure to reduce the risk of spread of infections in health care settings.

Recent research carried out in the UK (Short and Al-Maiyah 2009) showed that as much as 70% by area of a hospital can be successfully naturally ventilated, 40% using simple natural ventilation, and 30% using advanced natural ventilation (controlled via air shafts and ground

Table 2-3 *Minimum Efficiency Reporting Values (MERVs) and Filter Efficiencies by Particle Size*

MERV	0.3-1.0 µm	1.0-3.0 µm	3.0-10 µm
Category E-3			
6	—	—	35 to 50%
7	—	—	50 to 70%
8	—	—	70 to 85%
9	—	—	85% +
Category E-2			
10	—	60 to 65%	85% +
11	—	65 to 80%	85% +
12	—	80% +	85% +
Category E-1			
13	< 75%	90% +	99% +
14	75 to 85%	90% +	99% +
15	85 to 95%	90% +	99% +
17	99%	99%	99%

Source: Adapted from ANSI/ASHRAE Standard 52.2-2007 (ASHRAE 2007).

coupling), with as little as 7% of the hospital area needing minimum efficiency reporting value (MERV) 14 or better filtered air conditioning.

Where natural ventilation is to be used in health care applications, reference to WHO and other sources is recommended to ensure infection control is maintained. At this time, there are few hospitals in North America using natural ventilation.

2.9 FILTRATION

The efficacy of air filters is determined primarily by particle size, but can be affected by the relative electrical charges of particles and filters. Bacteria typically are quite small, requiring filters that remove particles below 1 µm in size. ANSI/ASHRAE Standard 52.2-2007 (ASHRAE 2007) specifies a test procedure for evaluating the performance of air-cleaning devices as a function of particle size, resulting in a minimum efficiency reporting value (MERV) for a given device. As shown in Table 2-3, for example, MERV 14 filters remove 75% to 85% of particles in the range of 0.3 to 1.0 µm. Table 2-4, from ANSI/ASHRAE/ASHE Standard 170-2008, gives requirements for prefiltration and final filtration in different areas.

As indicated in Table 2-4, true HEPA (MERV 17; 99.99%) filters are required only for protective environment (PE) rooms; such filters are also required for pharmacies per U.S. Pharmacopoeia General Chapter 797 (USP 2012). HEPA filters are often specified for bone marrow and organ transplant patient rooms and orthopedic surgery. The MERV rating system is described in detail in ASHRAE Standard 52.2-2007 (ASHRAE 2007). It is based on a test over a range of particle sizes. Standard designations of overall percent filter efficiency are no longer commonly used.

Table 2-4 *Minimum Filter Efficiencies*

Space Designation (According to Function)	Filter Bank #1, MERV[a]	Filter Bank #2, MERV[a]
Classes B and C surgery; inpatient and ambulatory diagnostic and therapeutic radiology; inpatient delivery and recovery spaces	7	14
Inpatient care, treatment and diagnosis, and those spaces providing direct service or clean supplies and clean processing (except as noted below); AII (rooms)	7	14
Protective environment rooms (PE)	7	17 (HEPA)[c]
Laboratories; Class A surgery and associated semirestricted spaces	13[b]	N/R[d]
Administrative; bulk storage, soiled holding spaces; food preparation spaces; and laundries	7	N/R
All other outpatient spaces	7	N/R
Skilled nurses facilities	7	N/R

Source: ANSI/ASHRAE/ASHE Standard 170-2008.
Notes:
a. Minimum efficiency reporting value (MERV) is based on method of testing described in ANSI/ASHRAE Standard 52.2-2007
b. Additional prefilters may be used to reduce maintenance for filters with efficiencies higher than MERV 7
c. Filter Bank #2 may be MERV 14 if MERV 17 tertiary terminal filter is provided for these spaces
d. N/R = not required.

2.10 HUMIDITY

Humidity affects the rate at which the body can release moisture into the air—either by evaporation from the skin (sweating) or through breathing, where it can reduce the antiseptic layer of mucous that lines the respiratory system. The key criterion is relative humidity (RH), rather than absolute humidity, because RH affects the rate of evaporation. Although the human body is generally tolerant to a wide variation in RH (typically between 35% and 75%) there can be serious concerns at the extremes of dryness (low RH) and dampness (high RH). Either of these can occur at high or low temperatures. See Chapter 3 for a discussion of psychrometrics and Chapter 12 regarding human comfort. Memarzadeh (2011b) states "there is no conclusive evidence that any single factor, whether it be a specific temperature, RH or geographic location can be universally applied to the wide variety of infectious viruses to reduce airborne or contact transmission, but there is pervasive evidence in the literature that the survival of viruses and other infectious agents depends partly on levels of RH."

Allergies and respiratory illnesses are associated with high humidity and mold growth, particularly for asthma and rhinitis. Asthma is a difficulty in breathing, often associated with coughing. Rhinitis is an inflammation of the nose which causes similar effects. Both asthma and rhinitis are now closely associated with an allergic response to dust mites and their waste products.

Dust mites prosper in warm, damp conditions where there is a supply of food in nutrients such as dead skin particles. The insulating properties of soft finishes (e.g., carpets) can create a temperature gradient with a corresponding increase in RH. Places where there are prolonged high air humidities are likely to experience problems such as airborne fungi and house dust mites, particularly if room relative humidity exceeds 70% for long periods. Fungi generally grow on damp organic material but they do not necessarily require either high air humidity or high air temperature for growth if the substrate conditions are suitable. The growth rate is dependent upon the nutrient, temperature, and humidity. Each mold has its special growth characteristics. Once mold has started to grow, it is difficult to stop by lowering the humidity, because one of the metabolic products of growth is water, which then enables the mold to continue to grow in drier conditions.

For the purposes of air-conditioning system design, a maximum room RH of 60% generally provides acceptable comfort conditions for human occupancy and minimizes the risk of mold growth and dust mites. Condensation should be avoided on surfaces within buildings that could support microbial growth or be stained or otherwise damaged by moisture. This may be achieved by ensuring that all surfaces are above the dew-point temperature of the adjacent air; or that the dew point is above the surface temperatures.

There is some evidence of a correlation between low room humidity and symptoms associated with dryness and irritation of the mucosa. It has been suggested that low room moisture content increases evaporation from the mucosa and can produce microfissures in the upper respiratory tract that may act as sites for infection. The reduction in mucous flow inhibits the dilution and rejection of dust, microorganisms, and irritant chemicals. This is a particular problem for wearers of contact lenses.

2.11 ULTRAVIOLET RADIATION

Ultraviolet (UV) radiation can be effective in reducing the virulence of microorganisms and, therefore, in attempting to reduce infection rates. The efficacy of ultraviolet systems is determined by the following equation, which is a variant of the previous equation dealing with the effect of microorganisms on a person. The effectiveness of the radiation is determined by the UV resistance of the microorganism, the UV radiation's intensity (dose), and the length of time the microorganism is exposed to it.

$$\text{Microorganism Kill Effectiveness} = \frac{\text{UV Dose} \times \text{Time}}{\text{Virulence}}$$

Although UV devices have been used effectively in static situations, such as where irradiating coils, filters, and pans, their efficacy is still in question when applied to ductwork. In a fast-moving airstream, the length of exposure time is very short; therefore, the intensity must be very high to kill a significant number of microorganisms. The more

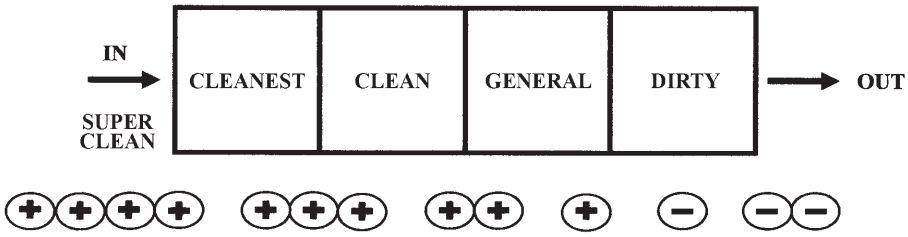


Figure 2-4 *Controlling Air Movement via Pressure Relationships*

UV-resistant the microorganism, the longer and/or stronger the irradiation must be.

More information on UV air and surface treatment is available in Chapter 60 of the 2011 *ASHRAE Handbook—HVAC Applications* and Chapter 17 of the 2012 *ASHRAE Handbook—HVAC Systems and Equipment.*

2.12 AIR MOVEMENT AND PRESSURIZATION

Another common method of mitigating the spread of infections is through pressure relationships. As noted in Table 2-2, many rooms require positive or negative pressure relative to adjacent spaces. As shown in Figure 2-4, the intent of pressurization is to move potentially infectious particles from the cleanest areas to less clean areas. A clear understanding of these areas is essential. A hospital is not totally clean throughout, but has various areas—from sterile-clean to semiclean to dirty.

Therefore, for example, operating rooms must be at a positive pressure relative to adjacent corridors to prevent potentially harmful microorganisms from entering the operating room. In contrast, airborne infection isolation (AII) rooms must be maintained negative because patients in these rooms may be highly infectious with diseases such as tuberculosis or SARS. Design considerations for specialty rooms are covered in more detail in Chapter 8.

Many operations are carried out by surgeons wearing simple masks across their lower face. In fact, it is important that surgeons are comfortable during operations to ensure their concentration during long or complex procedures. Clean supply air from overhead helps to achieve this although it also tends to induce air from surfaces of anyone close to the table and could deposit squames on or in the patient. Memarzadeh and Manning (2003) modeled airflow in operating rooms using computational fluid dynamics (CFD). They postulated that there is a thermal plume at the patient's wound site that can have the beneficial effect of deflecting the deposition of particles away from the wound. Using the CFD model, Memarzadeh concluded that the face velocity of the diffuser above the operating table should not exceed 30 fpm [0.15 m/s] to avoid disrupting the patient's thermal plume. As described in Chapter 8, limiting diffuser face velocity is one of the basic means of designing operating room air distribution to reduce

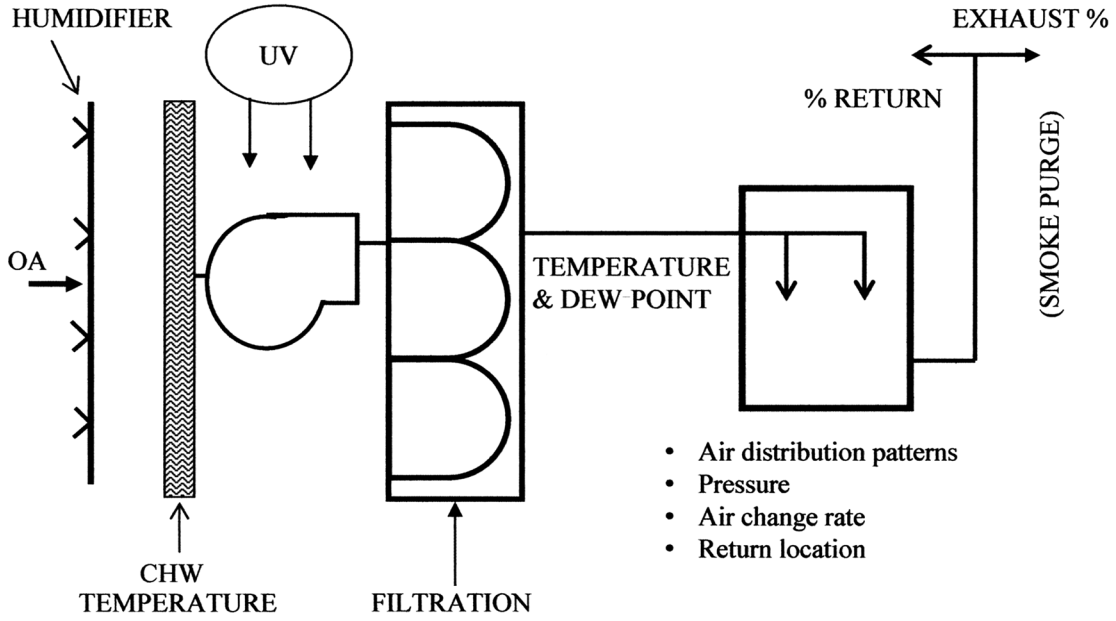


Figure 2-5 *HVAC Design Parameters Affected by Infection Control*

deposition. However, field research on this theory is limited. Kurz et al. (1996) provided indirect evidence of the existence of a plume. It is also noted that work within the surgical site with instruments and other devices disturbs the heat plume so that the principal method of infection control remains the high air change rate of well-filtered air delivered by a laminar flow system. Ongoing ASHRAE research project RP-1397 is investigating hospital operating room air distribution to verify CFD predictions of conditions that sustain the thermal plume.

2.13 EFFECT OF INFECTION CONTROL ON HVAC DESIGN

Figure 2-5 shows how the infection control measures described in this chapter affect the design of HVAC systems by influencing the following HVAC design parameters:

- Outdoor air quantity, including natural ventilation
- Type and location of filters
- Humidification
- UV radiation
- Chilled-water temperature
- Supply air conditions
- Supply air change rates in individual rooms
- Air distribution and velocity
- Locations of return air grilles
- Balance of supply and return/exhaust air for pressurization (including anterooms)

REFERENCES

ASHRAE. 2007. *Method of testing general ventilation air-cleaning devices for removal efficiency by particle size.* ANSI/ASHRAE Standard 52.2-2007, Atlanta: ASHRAE.

ASHRAE. 2008. *Ventilation of health care facilities.* ANSI/ASHRAE/ASHE Standard 170-2008, Atlanta: ASHRAE.

CDC. 2003. Guidelines for environmental infection control in health-care facilities. *Morbidity and Mortality Weekly Report*, Vol. 52/No. RR-10, June 6, 2003. Atlanta: Centers for Disease Control and Prevention. Available at http://www.cdc.gov/mmwr/pdf/rr/rr5210.pdf/.

Edwards, J.R. et al. 2008. National Healthcare Safety Network (NHSN) report, data summary for 2006 through 2007. *American Journal of Infection Control*, November.

FGI. 2010. *Guidelines for design and construction of health care facilities*. Dallas, TX: Facility Guidelines Institute.

Hambraeus, A. 1988. Aerobiology in the operating room—A review. *Journal of Hospital Infection*.

Horan, T.C. et al. 1992. CDC definitions of nosocomial surgical site infections, 1992: A modification of CDC definitions of surgical wound infections. *Infection Control and Hospital Epidemiology*.

Klauss, A.K. 2011. Hall of fame feature: History of the changing concepts in ventilation requirements. *ASHRAE Journal* 53(2).

Kosar, D. 2002. The answer is 3. *Engineered Systems* 9(6).

Kurz, A., D.I. Sessler and R. Lenhardt. 1996. Perioperative normothermia to reduce the incidence of surgical wound infection and shorten hospitalization. *New England Journal of Medicine* 358:876.

Memarzadeh, F. 2011a. *The environment of care and health care-associated infections, an engineering perspective*. Chicago, IL: American Society for Healthcare Engineering.

Memarzadeh, F. 2011b. Literature review of the effect of temperature and humidity on viruses. *ASHRAE Transactions* 117(2).

Memarzadeh, F. and A. Manning. 2003. Reducing risks of surgery. *ASHRAE Journal* 45(2).

Memarzadeh, F. and W. Xu. 2012. Role of air changes per hour (ACH) in possible transmission of airborne infections. *Building Simulation* 5:15 –28.

Short, C.A. and S. Al-Maiyah. 2009. Design strategy for low energy ventilation and cooling of hospitals. *Building Research and Information* 37(3): 1-29.

USP. 2012 (annual). Pharmaceutical compounding—Sterile preparations. USP–NF General Chapter 797. Rockville, MD: United States Pharmacopoeial Convention.

WHO. 2007. *Infection prevention and control of epidemic- and pandemic-prone acute respiratory diseases in health care*. WHO/CDS/EPR/2007.6. Geneva: World Health Organization.

CHAPTER 3

AIR-HANDLING AND DISTRIBUTION SYSTEMS

3.1 INTRODUCTION

Air-handling and distribution systems in the health care environment provide a variety of functions that may include comfort conditioning, maintaining air quality, reducing airborne infections, odor control, and smoke ventilation. Design standards for air exchange rates, temperatures, humidity levels, and air filtration for many areas in a hospital exceed what is considered normal for many other types of buildings. This chapter focuses on how these requirements affect the design of hospital air-handling and air distribution systems and on the specialized design requirements for these systems. It is assumed the reader already has a good knowledge of basic HVAC design.

3.2 CONCEPT DESIGN

Design of air-handling and air distribution systems must start during the schematic design phase. Hospital air-handling units (AHUs) require more components than AHUs serving other types of buildings. Airflow rates are also typically higher because of large internal loads and high air exchange rate requirements; therefore, more building space is needed for mechanical rooms, chases, and above-ceiling components. More recently, new codes and standards for energy conservation require lower fan power. Designers must use lower duct and air-handler velocities to accomplish this, resulting in larger equipment and ductwork. It is essential that the designer make a thorough assessment of these requirements to ensure sufficient building space is allocated.

3.2.1 Initial Considerations

To identify the required sizes and locations of chases and mechanical rooms, the designer must make a relatively accurate assessment of airflow requirements and system zoning during the schematic design phase. The following is a list of considerations:

- *Review the preliminary life safety plan.* Align AHU and air distribution zones with smoke compartment zones. This minimizes the required number of smoke dampers and simplify smoke damper control sequences. A reduction in the number of smoke dampers saves construction costs, and reduces required fan static and maintenance over the life of the building. If a smoke ventilation system or an engineered smoke control system is required, it is even more essential that the air-handling and air distribution zoning align with the smoke compartment zones. Consider the location of areas where the installation of ductwork or piping is prohibited (e.g., stairwells, exit access corridors) when locating chases and mechanical rooms.

- *Identify areas with specialized air-handler requirements.* Some areas in the hospital, such as operating rooms, procedure rooms, bone marrow treatment areas, other special treatment areas, and telecommunications and electrical equipment rooms require additional air-handler components, increased airflow, or lower supply temperatures, because of their unique requirements. These unique requirements include smoke ventilation, redundant systems, redundant fans, higher air filtration requirements, low dew point, etc. For this reason, dedicated air handlers and air distribution zones may be desired for these spaces. Local codes may require dedicated air handlers for some specialized equipment rooms (e.g., elevator machine rooms).

- *Consider optimal air-handling unit size.* Determine the desired capacity range for AHUs. This deserves some input from the hospital engineering and operations staff. Using a large number of small-capacity units can limit the disruptions to staff and patients caused by system shutdowns for maintenance or repair, but this requires significantly more maintenance time for filter changes, lubrication, coil cleaning, and other preventive work. This design concept also tends to be less cost- or space-efficient than one using larger units. However, using very large AHUs (over 40,000 cfm [18,876 L/s]) makes a substantial area of the hospital dependent on the continuous operation of a single unit. In addition, the motors, fans, and other components for these units can be of sizes and weights that make repair work very difficult. AHUs in the 20,000 to 40,000 cfm (9438 to 18,876 L/s) range seem to be a good compromise, even though some smaller units may still be used for those areas with specialized requirements.

- *Determine airflow requirements for each air-handler zone.* Develop a room-by-room airflow summary chart, such as shown in Table 3-1. Compare the air requirements for cooling load, air exchange rate, and makeup air. The largest of the three values will determine the supply air requirements for the air handler. Designers should include some additional airflow “contingency”

to account for additional air that may be required as the building design progresses. It is very difficult to add additional space for mechanical rooms or chases once a building design progresses to the design development stage or beyond. Designers should also consider including allowances for future growth or change in use that might require additional air.

- *Consider system redundancy.* The designer should consider system redundancy early in the design process to ensure that any additional mechanical space for additional equipment or components is identified. System redundancy may be required by code or regulations or may be desired by the owner for certain mission-critical functions. Redundancy might be accomplished by interconnection of systems, or redundant equipment and/or components. The designer also needs to determine if a full "N+1" redundancy is required or if a reduced capacity emergency mode might be acceptable. "N+1" refers to a design that allows for full capacity in the event of failure of any one item of equipment or routine maintenance. A reduced-capacity approach might use parallel equipment, such as dual fans, where both fans would be required for full design capacity, but in the event of failure, one fan could support a reduced-capacity service.

- *Strategically locate mechanical rooms and chases.* Mechanical rooms housing AHUs requiring large amounts of outdoor air for ventilation, economizer cycles, or smoke ventilation need to be positioned near exterior walls or roofs to simplify air intake and relief. This decision may also be affected by aesthetic architectural considerations, such as which elevations can accommodate louvers. Consideration must be given to outdoor pollutant sources such as vehicle traffic areas (diesel fumes), kitchen exhaust, boiler stacks, and generator exhaust. Avoid locating chases and mechanical rooms next to stairwells, elevator shafts, exit access corridors, electrical rooms, and other areas where the passage of ducts is limited or prohibited. Ensuring that ducts and other services can be successfully routed from the chase or mechanical room and out to the zones is just as important as confirming that sufficient space is provided. Designers should consider how large air-handler components will be rigged and moved in and out of the mechanical room when future repairs or replacement are required. Allow sufficient room for service and repair procedures, such as coil pull. Rooftop or penthouse air handlers and mechanical spaces should have an adequate and practical method of getting repair and service materials and components to the room. Consider adding stairwell or elevator access to these areas.

- *Determine AHU configuration and components.* To accurately determine the size of AHUs, the designer must determine each AHU's required components and arrangement. Include sufficient

Table 3-1 *Typical Room-by-Room Airflow Summary (I-P version)*

Room Information			Mechanical Ventilation Code Requirements						ASHRAE Standard 170-2008 Requirements					Reqd by Code, cfm	Cooling Load, cfm	Room Pressure Reqd	Airflow Provided					
			OA					SA	OA		RA						SA	EA	RA	Offset		TA
Number/ Name	Area, ft²	Clg. height, ft	Est. No. of People (code or plan)	OA/p, cfm	OA per floor area, cfm/ft²	Tot. OA Reqd, cfm	OA (plan), %	Tot. SA Reqd, cfm	ach	Tot., cfm	ach	cfm	100% EA, cfm			+ = Pos – = Neg	cfm	100% EA, cfm	cfm	%	+ = out – = in, cfm	ach
1100-00 Caregiver Wrk	92	9.0	1	20	0	13	30	45	0	0	0	0	NR	45	77	NR	90	NR	90	20	0	7
1100-01 Prep 1	104	9.0	1	25	0	26	30	90	2	105	6	95	NR	105	52	NR	105	NR	105	20	0	7
1100-02 Prep 2 Prvt	107	9.0	1	25	0	27	30	90	2	110	6	100	NR	110	53	NR	110	NR	110	20	0	7
1100-07 Toilet	60	9.0	0	0	0	0	30	0	0	0	30	90	90	90	19	–	0	90	0	20	-90	10
1100-08 Soiled Util	78	9.0	0	0	0	0	30	0	0	0	20	120	120	120	17	–	0	120	0	20	-120	10
1100-09 Clean Supply	88	9.0	0	0	0.15	13	30	45	0	0	2	30	NR	45	26	+	70	NR	70	20	20	7
1100-10 Physician Dictation	99	9.0	1	20	0	14	30	50	0	0	0	0	NR	50	51	NR	100	NR	100	20	0	7
1100-13 Toilet	62	9.0	0	0	0	0	30	0	0	0	10	95	95	95	13	–	0	95	0	20	-95	10
1101-00 Nurse Stn	535	9.0	7	20	0	131	30	440	0	0	0	0	NR	440	137	NR	440	NR	440	20	0	3
1101-01 Recovery 1	124	9.0	1	25	0	31	30	105	2	125	6	115	NR	125	58	NR	125	NR	125	20	0	7
1101-02 Recovery 2	124	9.0	1	25	0	31	30	105	2	125	8	115	NR	125	58	NR	125	NR	125	20	0	7
1101-14 Meds	67	9.0	0	0	0.15	10	30	35	2	70	4	45	NR	70	29	+	70	NR	56	20	14	7
1101-17 Nourishmnt	98	9.0	0	0	0.15	15	30	50	2	100	4	60	NR	100	33	+	100	NR	80	20	20	7
1101-18 Equip Stor	150	9.0	0	0	0.15	29	30	100	0	0	0	0	NR	100	32	NR	100	NR	100	20	0	4
1103-00 Anesth Ofc	113	9.0	1	20	0	16	30	55	0	0	0	0	NR	55	34	NR	115	NR	115	20	0	7
1104-00 Anesth Wrk	144	9.0	1	20	0	20	30	70	0	0	0	0	NR	70	37	NR	145	NR	145	20	0	7
1105-00 Staff Lounge	308	9.0	0	15	0	139	30	465	0	0	0	0	NR	465	385	NR	465	NR	465	20	0	10

EA = exhaust air OA = outdoor air OA/p = outdoor air per person NR = not required RA = room air SA = supply air TA = total air

Table 3-1 *Typical Room-by-Room Airflow Summary (SI version)*

Room Information			Mechanical Ventilation Code Requirements						ASHRAE Standard 170-2008 Requirements					Reqd by Code, L/s	Cooling Load, L/s	Room Press. Reqd	Airflow Provided					
			OA					SA	OA		RA						SA	EA	RA	Offset		TA
Number/ Name	Area, m^2	Clg. height, m	Est. No. of People (code or plan)	OA/p, L/s	OA per floor area, L/s·m^2	Tot. OA Reqd, L/s	OA (plan), %	Tot. SA Reqd, L/s	ach	Tot., L/s	ach	L/s	100% EA, L/s			+ = Pos - = Neg	L/s	100% EA, L/s	L/s	%	+ = out – = in, L/s	ach
1100-00 Caregiver Wrk	8.6	2.7	1	9.4	0	6.2	30	21.2	0	0	0	0	NR	21.2	36.3	NR	42.5	NR	42.5	20	0	7
1100-01 Prep 1	9.7	2.7	1	11.8	0	12.3	30	42.5	2	49.6	6	44.8	NR	49.6	24.5	NR	49.6	NR	49.6	20	0	7
1100-02 Prep 2 Prvt	9.9	2.7	1	11.8	0	12.7	30	42.5	2	51.9	6	47.2	NR	51.9	25.0	NR	51.9	NR	51.9	20	0	7
1100-07 Toilet	5.6	2.7	0	0	0	0	30	0	0	0	30	42.5	42.5	42.5	9.0	–	0	42.5	0	20	-42.5	10
1100-08 Soiled Util	7.3	2.7	0	0	0	0	30	0	0	0	20	56.6	56.6	56.6	8.0	–	0	56.6	0	20	-56.6	10
1100-09 Clean Supply	8.2	2.7	0	0	0.76	6.2	30	21.2	0	0	2	14.2	NR	21.2	12.3	+	33.0	NR	33.0	20	9.4	7
1100-10 Physician Dictation	9.2	2.7	1	9.4	0	6.6	30	23.6	0	0	0	0	NR	23.6	24.1	NR	47.2	NR	47.2	20	0	7
1100-13 Toilet	5.8	2.7	0	0	0	0	30	0	0	0	10	44.8	44.8	44.8	6.1	–	0	44.8	0	20	-44.8	10
1101-00 Nurse Stn	49.7	2.7	7	9.4	0	61.8	30	207.6	0	0	0	0	NR	207.6	64.7	NR	207.6	NR	207.6	20	0	3
1101-01 Recovery 1	11.5	2.7	1	11.8	0	14.6	30	49.6	2	59.0	6	54.3	NR	59.0	27.4	NR	59.0	NR	59.0	20	0	7
1101-02 Recovery 2	11.5	2.7	1	11.8	0	14.6	30	49.6	2	59.0	8	54.3	NR	59.0	27.4	NR	59.0	NR	59.0	20	0	7
1101-14 Meds	6.2	2.7	0	0	0.76	4.7	30	16.5	2	33.0	4	21.2	NR	33.0	13.7	+	33.0	NR	26.4	20	6.6	7
1101-17 Nourishmnt	9.1	2.7	0	0	0.76	7.1	30	23.6	2	47.2	4	28.3	NR	47.2	15.6	+	47.2	NR	37.8	20	9.4	7
1101-18 Equip Stor	13.9	2.7	0	0	0.76	13.7	30	47.2	0	0	0	0	NR	47.2	15.1	NR	47.2	NR	47.2	20	0	4
1103-00 Anesth Ofc	10.5	2.7	1	9.4	0	7.6	30	26.0	0	0	0	0	NR	26.0	16.1	NR	54.3	NR	54.3	20	0	7
1104-00 Anesth Wrk	13.4	2.7	1	9.4	0	9.4	30	33.0	0	0	0	0	NR	33.0	17.5	NR	68.4	NR	68.4	20	0	7
1105-00 Staff Lounge	28.6	2.7	0	7.1	0	65.6	30	219.4	0	0	0	0	NR	219.4	181.7	NR	219.4	NR	219.4	20	0	10

EA = exhaust air OA = outdoor air OA/p = outdoor air per person NR = not required RA = room air SA = supply air TA = total air

access sections for inspection and service. The designer should work with equipment vendors to confirm sizes and determine equipment weights for the structural engineer.

- *Identify components requiring emergency power.* Many AHU components may require emergency power in order to maintain space conditions for critical areas, provide smoke ventilation, or maintain critical pressurization control. These requirements must be identified early and provided to the electrical engineer to ensure that provisions for sufficient emergency power are incorporated into the design. Remember to include any critical control components, such as pneumatic-control air compressors, control panels, and powered control devices.

3.2.2 Preliminary Design

Because of the complexity of health care HVAC systems and their larger space requirements, it is imperative to develop preliminary design concepts early in the building design process. Attempt to provide the following items as early in the process as possible to coordinate with the building's architectural and structural design.

- *AHU schematics and sequence of operation.* All too often, this is left for last. Thinking through the control sequence ensures that all necessary components have been included in the air-handling system. See Figure 3-1 for an example of an AHU control schematic.

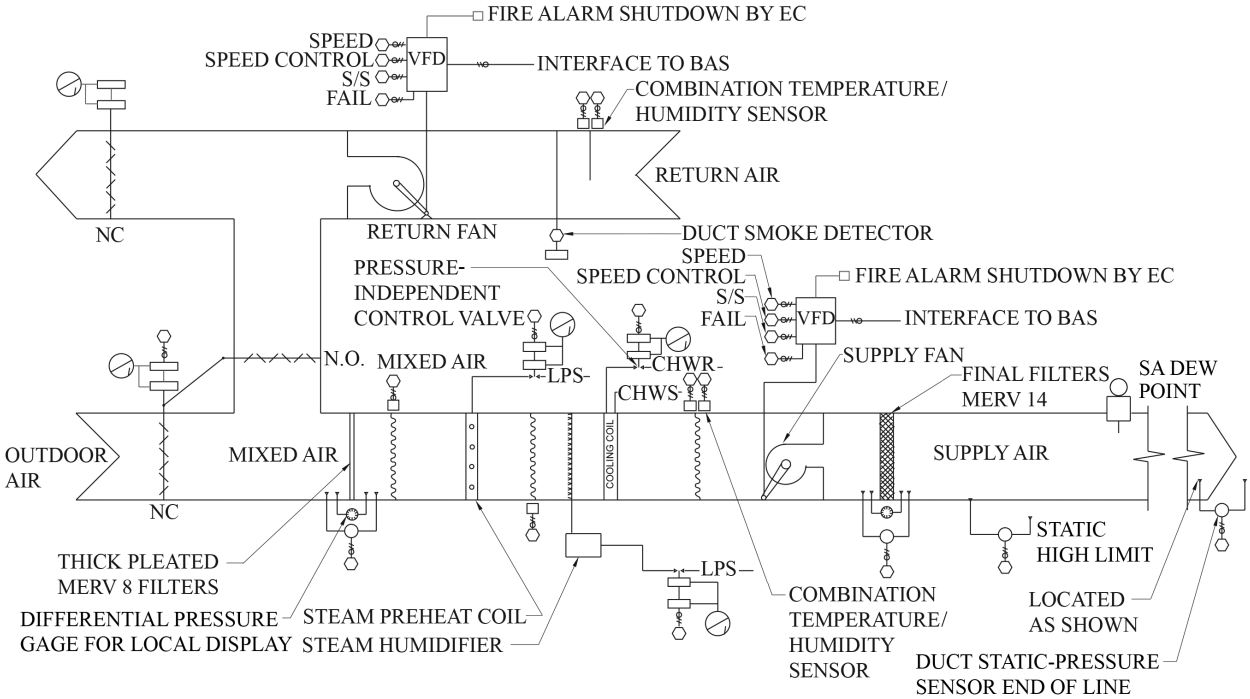


Figure 3-1 *Example AHU Control Schematic*

- *AHU plans and chase locations.* Determine AHU zones for all floors. Locate duct chases for supply, return, and exhaust risers. Develop details of chase layouts and confirm that there is sufficient room for ductwork to exit and connect to horizontal mains on the floor. Plan for piping or other systems that may share chase space. Provide sufficient space for installation and service access for any required fire/smoke dampers at the chase exit points.

- *AHU schedules, configuration details, and sizes.* Develop preliminary AHU equipment schedules and configuration plans and sections (see the example in Figure 3-2). This effort should include all needed components and sections with sizes and approximate weights.

- *Preliminary mechanical room layouts.* These layouts should include locations of all AHUs and other major equipment. Identify service clearances. Work with the electrical engineer to ensure that sufficient space is provided for electrical components such as motor control centers, starters, disconnects, or variable-speed drives.

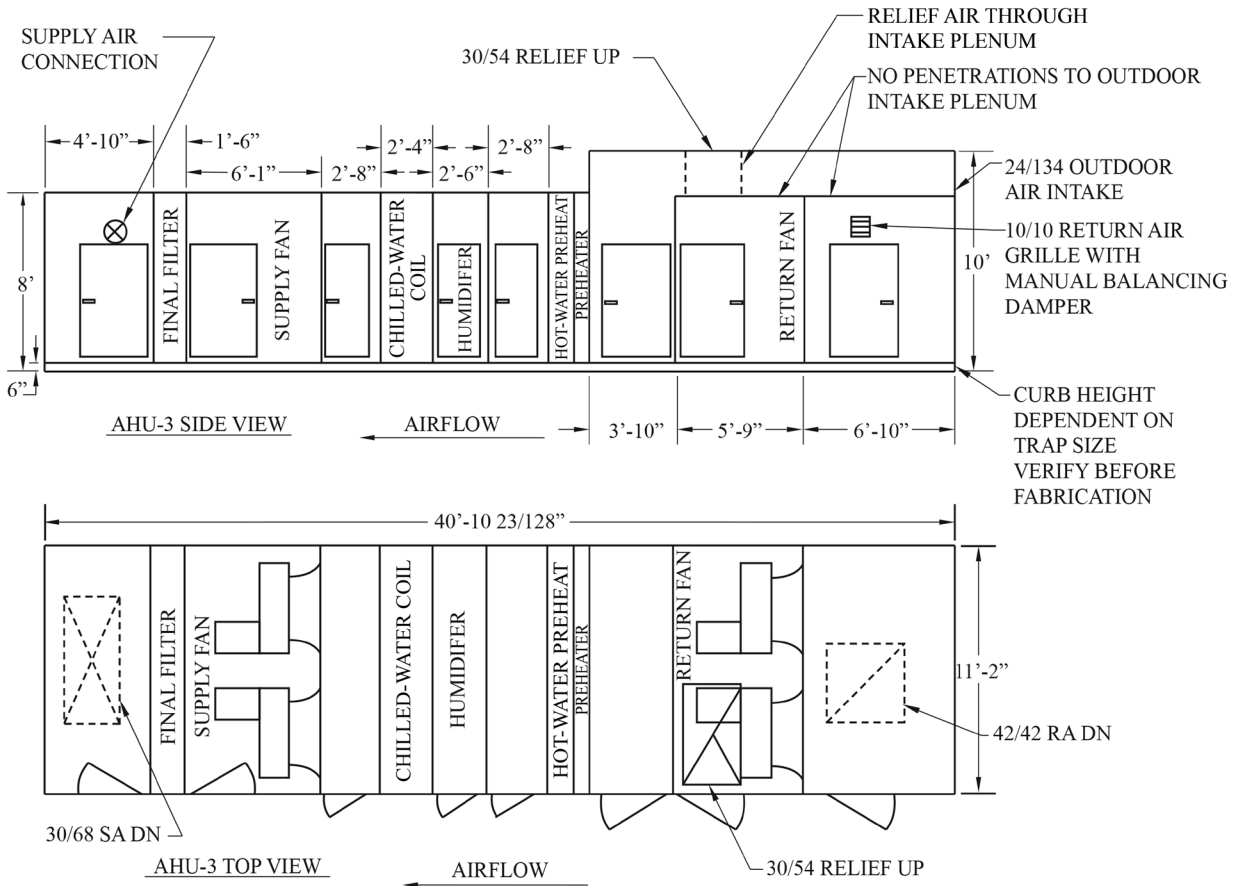


Figure 3-2 *Example AHU Configuration Plan*

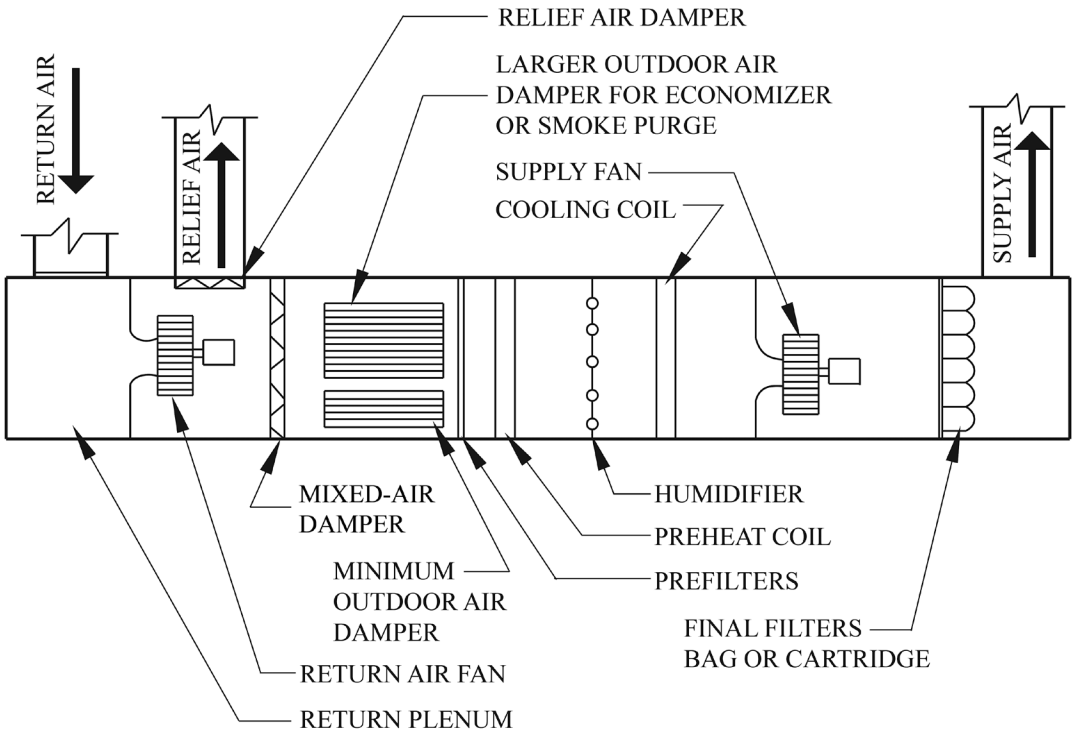


Figure 3-3 *Typical Configuration of Hospital AHU with Economizer*

- *Typical details for space zoning.* Identify the type of zone control to be used for individual spaces (e.g., variable-air-volume [VAV] reheat, constant-volume [CV] reheat, dual duct, etc.). Determine the approximate number of zone control devices (terminal boxes) and how many spaces will share a box/zone.

- *Hydronic and steam piping risers.* Develop preliminary piping risers for steam, condensate, chilled water, and hot water. Determine the paths that major routes will take to the various equipment components, and work with the building designer to plan for the necessary space and chases for pipe runs.

3.3 AIR-HANDLING UNIT COMPONENT DESIGN CONSIDERATIONS

An AHU simultaneously performs several functions in providing environmental comfort and ventilation for a facility. These include the intake of outdoor air to meet ventilation air requirements, thermal mixing of this air with recirculated air from occupied zones, thermal conditioning, moisture control, filtration to protect equipment and to remove contaminants, and attenuation of fan-generated noise to control ambient noise levels in occupied spaces. Figure 3-3 shows the configuration of a typical hospital AHU, including some of the most common components.

3.3.1 Air-Handling Unit Casing

The design intents of fundamental importance to an AHU casing are to minimize water and dirt accumulation, resist corrosion, and permit adequate access for inspection and maintenance. It is important that

no open-faced insulation be used where water accumulation is likely, such as downstream from cooling coils or humidifiers. Specifically, no lining is allowed after final filters in accordance with the FGI *Guidelines* (FGI 2010). The best design is one that uses no open-faced insulation in the system.

Fibrous AHU insulation should be isolated from the airstream using an impermeable liner (e.g., polyester film) or "sandwiched" double-wall sheet metal construction. The primary concern is that exposed fibrous insulation can collect dust and moisture to form a perfect growth environment for dangerous microorganisms—although the insulation media may be of inert material that will not of itself support microbial growth. Once contaminated, there is virtually no way of effectively cleaning or disinfecting insulation. Some manufacturers offer liner coatings, which effectively prevent fiber erosion, while still other products are available with plastic or foil coverings to exclude dirt and moisture and improve cleanability. These materials may not, however, have the long-term durability or cleanability of sheet metal. All interior AHU surfaces must be accessible for inspection and cleaning; liners or interior panels should be of a light color and interior lighting should be available to enhance the effectiveness of maintenance tasks. The panels in double-wall casings should have a "thermal-break" construction to prevent condensation on the outside surface in humid summer weather.

In recent years, foam-filled panel walls have become more common for AHU construction. These panels use rigid, foam-type insulation sandwiched between metal panels. Generally, this offers a more rigid panel with higher thermal resistance and less air leakage than the same thickness of fiber insulation. Special extruded connection members with a thermal break made of synthetic material are used for panel joints. Figure 3-4 shows a detail of this type of construction.

Designers should also consider adding casing components to the unit that will enhance ease of maintenance and service. These may include

- rigging devices (e.g., rails, lifts, winches) to assist with motor, fan or other large component removal and replacement;
- grease-fitting extensions to the exterior of the casing to allow service without entering the unit;
- inspection windows and adequate lighting (consider putting lighting on timers to prevent unnecessary usage and premature burnout); and
- pressure and temperature test ports in each section with a means for ease of opening and closing.

Designers should consider specifying on-site leakage testing of AHUs. Although such testing can be done at the factory, shipping and site assembly of some components may introduce an opportunity for

additional leakage. An on-site test can verify that the finished product meets the desired leakage specification.

3.3.2 Outdoor Air Intakes

Designers must carefully consider the location of the outdoor air intake for an AHU. Intakes must not be located near potential contaminant sources, such as boiler and generator stacks, laboratory exhaust vents, plumbing vents, cooling towers, ambulance waiting and vehicle parking areas, loading docks, and helipads. Many information sources provide generally accepted criteria for minimum separation distances from the outdoor air intake to potential contaminant sources to ensure adequate separation and dilution. These spacings vary from 10 to 75 ft [3 to 23 m], with 25 ft [7.6 m] recommended by the FGI *Guidelines* and 30 ft [9.1 m] suggested by the *ASHRAE Handbook—HVAC Applications* (ASHRAE 2011a). Designers, however, must use judgment in the application of such rules; 30 ft [9.1 m] may be insufficient separation from a given contaminant source, given the source's concentration and nature, the direction of prevailing winds, and building geometry. Certain airborne pathogens, such as

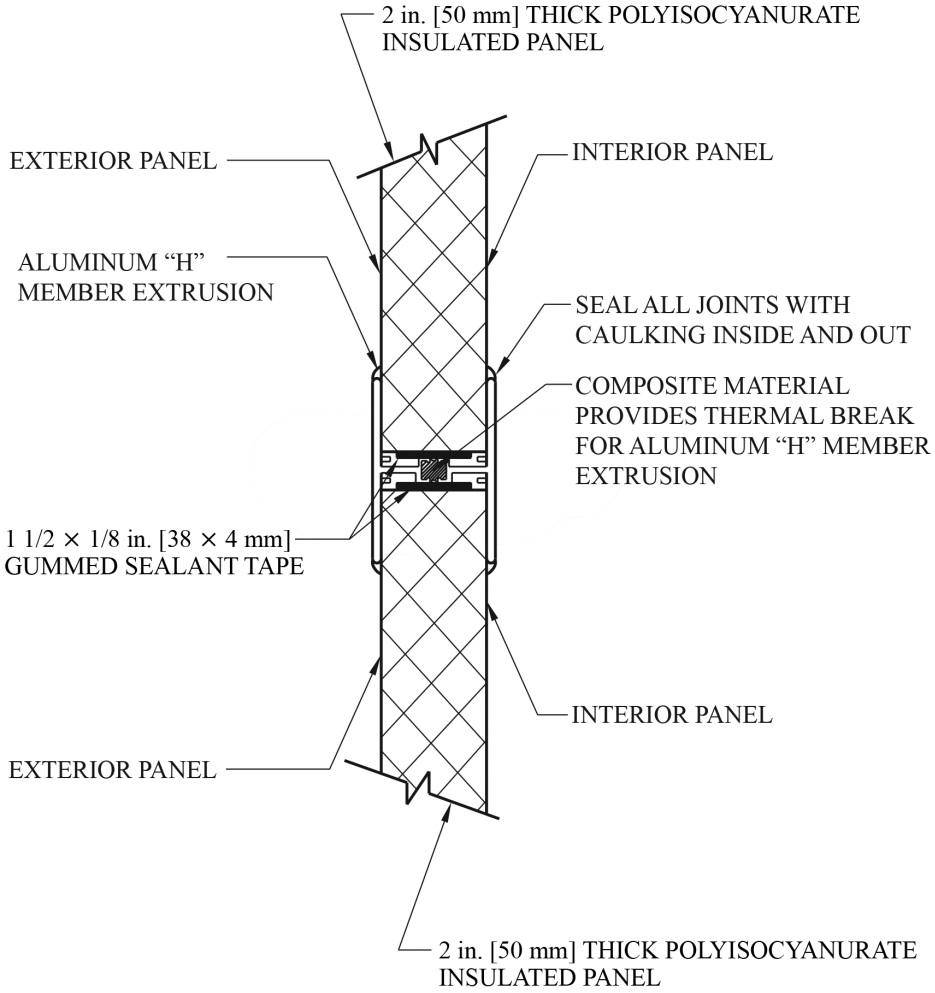


Figure 3-4 *Thermally Broken Panel Construction Detail*

Legionnaire's disease bacteria, are known to have been transmitted much longer distances from aerosolized sources such as cooling towers. Designers must apply professional judgment and, when in doubt, use analysis techniques such as those described in Chapter 24, Airflow Around Buildings, of the 2009 *ASHRAE Handbook—Fundamentals* (ASHRAE 2009c). Individual circumstances may justify the use of modeling techniques or field simulation to select the best outdoor air source locations. Outdoor air intakes should be located a minimum of 8 feet [2.4 m] above grade (10 ft [3 m] according to some codes and criteria) to avoid taking in grass clippings, leaves, bird feathers, or other debris (often wet) that can clog intake louvers, screens, and filters and provide a reservoir for microbial growth. When located atop buildings, intakes should be located well above roof level (a minimum of 3 ft [0.9 m] according to most codes) to avoid intake of debris from the roof. In cold regions, designers must consider locations for air intakes that will avoid the possibility of snow drifts. All intakes should be equipped with a factory-fabricated louver designed to exclude wind-driven precipitation and a bird screen to exclude birds or small mammals. Avoid placing an intake near horizontal surfaces, such as a shelf or ledge, that can cause rain splash to penetrate horizontally through the louver or can become a dangerous microbe growth source as a result of collected bird droppings or other organic debris.

3.3.3 Air Mixing

Once outdoor air entry to an AHU has been successfully addressed, the designer's attention should focus on the air-mixing arrangement to ensure that the outdoor and recirculated (where permitted) airflows are adequately mixed to avoid the impingement of stratified air at subfreezing temperature on downstream equipment. Achievement of a uniform mixed-air temperature is a function of physical blending (diffusion) and heat transfer. Physical manipulation of the outdoor and recirculated airstreams is required to overcome the natural tendency for air layers of differing temperature to stratify. Manufactured air-mixing boxes are available from all major AHU manufacturers, who normally provide guidance as to their performance limitations. In severe climates, or where the percentage of outdoor air is relatively high, designers should consider supplemental air-mixing equipment or arrangements. Factory-fabricated air blenders are available from a number of manufacturers who offer airflow-mixing performance data. If installed with proper inlet and outlet conditions, and with adequate airflow velocity as recommended by their manufacturers, they can significantly improve airstream mixing. These components generate additional pressure drop that must be considered in fan selection and will also increase AHU length.

3.3.4 Prefiltration

A "roughing" prefilter of minimum efficiency reporting value (MERV) 7 per ANSI/ASHRAE Standard 52.2-2007 (see Tables 2-3 and 2-4) should be provided within or immediately downstream of the mixing box and upstream from the heating and cooling coils. This filter removes lint, dust, and other large particles from the airstream before they can collect on or clog coils or other components. Throw-away, replaceable cartridge filters require less maintenance than cleanable or

roll-up filters and are usually specified for this reason. All filters should be provided with differential pressure gages mounted on the AHU, showing differential static pressure across the filter to indicate when the filter should be changed. When the facility is provided with a central direct digital control system (DDC), energy management and control system (EMCS), or building management system (BMS), filter pressure indication should also be available for monitoring and alarm generation on the system.

3.3.5 Heat Recovery

Heat recovery may be used to capture some of the heat from the exhaust or relief air stream to precondition outdoor air. Rotary heat exchangers (wheels) are one option for this type of system and have the advantage over desiccant options (which can transfer both sensible and latent heat). Some disadvantages to wheel devices are that the leaving exhaust or return airstream must be close to the outdoor air, the transfer media can be difficult to clean, and air leakage may occur from exhaust to intake (manufacturers typically indicate 1% to 5% leakage). Other air-to-air heat exchangers include heat pipes and plate style exchangers. Some design guidelines have banned integral air-to-air energy recovery units unless there is a neutral zone between the exhaust and intake ducts. Plate devices are only capable of sensible heat transfer, but some plate-style heat exchangers are made of a membrane that allows latent heat recovery.

"Run-around" heat exchanger loops that have coils and a circulation loop with a glycol mix are one method to transfer energy from an exhaust or relief airstream that is not close to the outdoor air intake or AHU. This system also has the advantage of no possibility of cross-contamination between the two airstreams. Run-around loops are only capable of transferring sensible heat.

When using heat recovery systems as part of the AHU design, the designer must consider the criticality of the AHU when deciding if the unit's preheat coil and cooling coil capacities should be based on the preconditioning provided by a heat recovery system. Although doing so may reduce chilled-water, hot-water, or steam peak demand for the AHU, a failure or poor performance of the heat recovery system could compromise space conditions. For critical systems, it may be prudent to design for a "worst case" and select preheat and cooling coils that can support the space design conditions in the event of heat recovery system failure or reduced performance.

3.3.6 General Considerations for Heating and Cooling Coils

The upstream and downstream faces of all coils must be accessible for cleaning and "combing" (straightening bent fins). Access panels or doors are normally required for this purpose. The panel and panel door should be large enough to enable a maintenance person to access and work on the entire face of the coil. Coils must be constructed of noncorrosive metals, typically copper tubing with aluminum fins. Consider specifying other noncorrosive components, such as stainless steel headers, drain pans, coil casings, and coil frames. Consider the

air vent discharge location and direction of automatic and manual air vents so that entrained water does not leak into the AHU during air bleeding. To enable necessary testing and balancing of the coil, ensure that pressure gages and thermometers (or ports for these instruments), flow measurement devices and manual balancing valves are provided on the piping connections. Upstream and downstream air temperature sensors or sensor ports are also beneficial for unit performance monitoring and troubleshooting. Pressure and temperature ports on pipe inlets and outlets can also be useful for monitoring and troubleshooting. Differential air pressure gages across coils can be helpful in indentifying fouled coil fins that require cleaning. Provide isolation valves and unions to facilitate coil replacement. Use caution in locating coils relative to the suction or discharge of the fan; if located too close, an uneven velocity distribution across the coil face can result in loss of capacity, moisture carryover, or freeze-up problems. Generally, the flow distribution across the coil face should not vary more than 10%.

As mentioned in section 3.2, many energy codes and standards are now requiring significant reductions in fan power. To accomplish this, pressure drops must be reduced by lowering air velocities, thereby decreasing friction loss in the AHU, ductwork, and fittings. Typical coil design velocities in the past have been 450 to 550 fpm [2.3 to 2.8 m/s]. To meet some of the latest energy codes or standards, design velocities as low as 250 fpm [1.3 m/s] may be necessary. This must be determined early in the design process, because it will require a much larger AHU cross section. One additional benefit to low-velocity coil selection is improved coil performance and better temperature approach. This can be especially beneficial when trying to reach low dew points for spaces such as operating rooms. Figure 3-5 illustrates the relationship between chilled-water velocity, air velocity, and temperature approach. Note that increasing chilled-water velocity and/or reducing air velocity results in a closer temperature approach and generates the lowest leaving-air temperatures.

3.3.7 Preheating Coil and Freeze Protection

Burst coils or automatic unit shutdown caused by exposure to sub-freezing temperatures are frequent occurrences in buildings and result from a number of factors: inadequate air mixing, unintended exposure of coils to 100% outdoor air (after failure of economizer controls), condensate backup in steam coils, and improperly located or installed freezestats. The time required to replace a damaged coil and clean up the flooded AHU casing (with possible contamination from treatment chemicals) can put an AHU out of service for a long time—and during the most critical environmental conditions. Water leakage in a casing from a damaged cooling coil can provide an environment suitable for microbial growth and may go undetected for an extended time. The potential impact on a health care facility under such conditions can be very serious and costly. This section discusses some general freeze-prevention considerations and practices. It is particularly recommended that the design engineer pay serious attention to wintertime

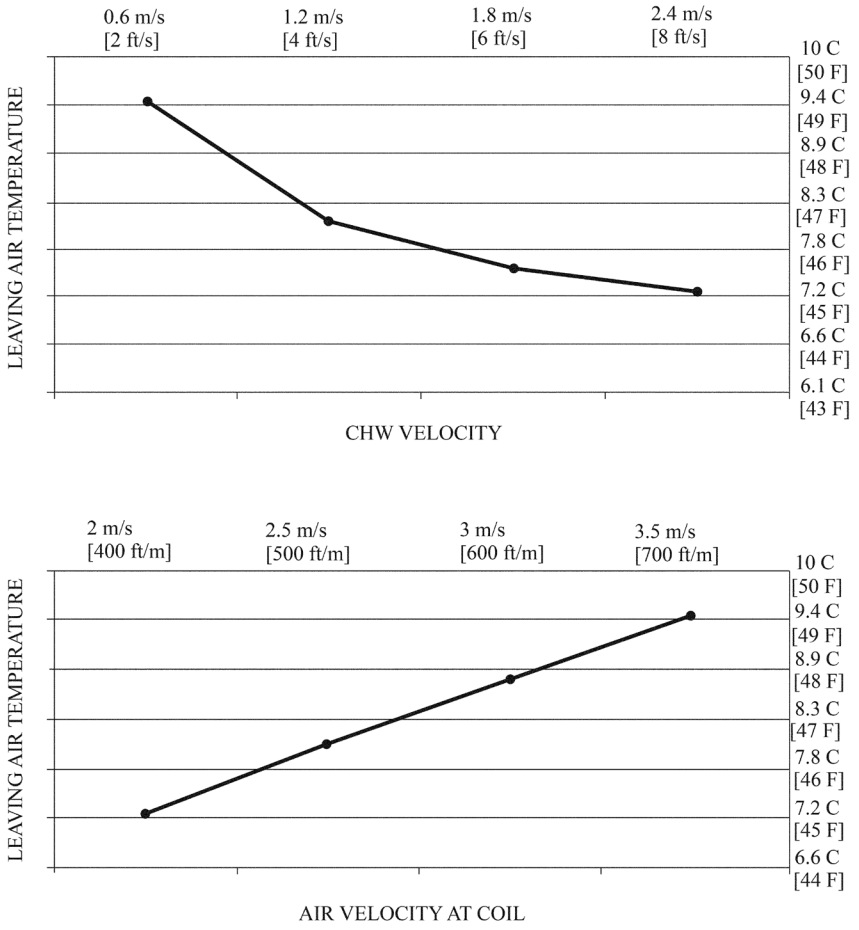
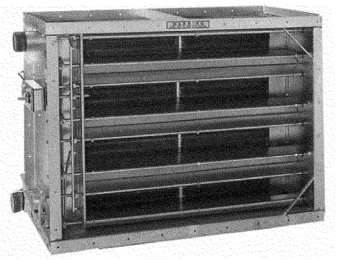


Figure 3-5 *Maximizing Chilled-Water Coil Performance*

unit operation to ensure accurate prediction of the conditions to which the unit will be exposed—not only during normal operation but also during unoccupied, emergency, or control-failure modes.

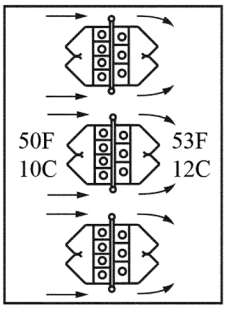
In many applications, a preheat coil is located downstream from the prefilter and before the cooling coil. Preheat coils may use hot water or steam and are normally provided when the mixed-air temperature is lower than the AHU's design discharge air temperature or when it is necessary to protect downstream equipment from near- or below-freezing mixed-air temperatures. If the mixed-air condition during the winter design day is sufficiently above freezing and the unit is configured to allow intake of large quantities of outdoor air (such as with a smoke ventilation or economizer system), a preheat coil may not be required. In addition to considering performance under design conditions, designers should think about how the coil should perform under the most severe conditions that it may encounter. For example, a fan that is designed to operate with 100% outdoor air during emergency smoke evacuation mode should have a preheat coil properly sized to raise the discharge air temperature above freezing. Specific coil freeze considerations include the following:



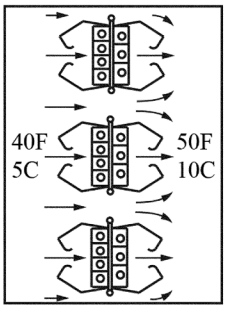
STEAM SUPPLY VALVE WOULD BE 100% OPEN FOR ANY LOAD. VALVE WOULD CLOSE FOR 0 LOAD.

BYPASS DAMPERS IN CLOSED POSITION. STEAM HEATING COILS ARE COVERED BY DAMPERS. SEE SECTIONS BELOW.

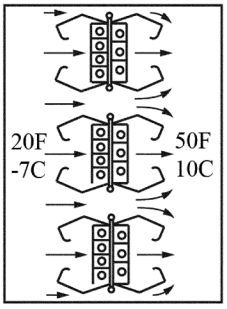
MINIMAL LOAD. DAMPERS CLOSE OVER STEAM COILS. ALL AIR BYPASSES STEAM COILS. SOME HEAT IS STILL TRANSFERED THROUGH DAMPERS.



AS LOAD INCREASES DAMPERS OPEN TO ALLOW FLOW OVER STEAM COILS.



DAMPERS CONTINUE TO MODULATE OPEN TO MEET HIGHER LOAD.



FULL HEATING. DAMPERS 100% OPEN. ALL AIR FLOWS OVER HEATING COILS.

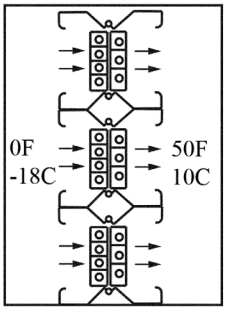


Figure 3-6 *Integral Face-and-Bypass Steam Preheat Coil*

- *Freeze considerations for steam coils.* Frequent steam coil freeze failures have resulted from exposure of the condensate-filled portions of the coil to freezing air temperatures. Designers should, therefore, pay particular attention to the manufacturer's instructions for coil installation and condensate drainage from the unit. Be aware that modulating steam control valves may cause negative atmospheric pressure in the coil, increasing the volume of condensate backup; providing a vacuum breaker will allow the condensate to drain by gravity. Many designers prefer a face-and-bypass approach for steam coil discharge temperature control, keeping the steam coil control valve fully open any time there is a need for preheat and regulating airflow around the coil to maintain discharge setpoint. Figure 3-6 shows the operation of

a steam preheat coil with integral face-and-bypass dampers. To prevent energy waste, the coil should be fitted with a two-way valve so that the coil can be turned off when preheat is no longer needed. This arrangement, while undoubtedly successful in many applications, does not necessarily eliminate the danger of condensate buildup in the coil.

- *Freeze considerations for hot water coils.* When hot-water coils are used, designers must decide whether to use an antifreeze solution in the system. A solution containing the appropriate percentage of glycol can provide freeze protection to well below 0°F [–18°C]. In addition to reducing heat transfer and increasing the pumping energy requirement, there are significant maintenance considerations associated with the use of an antifreeze solution. Maintenance personnel must maintain the glycol/water percentage selected by the designer; often this is not handled properly and the maintenance personnel merely guess at the glycol percentage based on the color of the solution. Care must also be given to using the correct antifreeze formulation; there are several reported instances of maintenance personnel mistakenly introducing automotive antifreeze into heating systems, leading to undesirable deposits ("gumming up") in the heating coils. When properly used and designed, however, glycol systems can be a very attractive freeze protection option. When determining the amount or percentage of glycol for a system it is important to understand the difference between "burst protection" and "freeze protection." Burst protection is all that is required if the system will sit dormant at temperatures below the freezing point of the fluid, thereby putting the pipes in danger of bursting. For these situations, the system needs enough glycol to keep the fluid from freezing solid. A slushy mixture is acceptable, because the fluid will not be pumped through the system. Freeze protection is required, however, if a system is going to be pumping the fluid at the lowest anticipated temperature. This can include systems that are dormant for much of the winter but require start-up during cold weather, or systems that would be at risk if the power or pump failed. Trying to pump fluid containing ice crystals can result in damage to system components. For these situations, the system must have enough glycol present to prevent any ice crystals from forming. Because the mixture expands as it freezes, there must be enough volume available in the system to accommodate the expansion. It generally requires more glycol for freeze protection (keeping the fluid completely liquid) than it does for burst protection (where a slushy mixture is acceptable). There are several types of glycol available. Many facilities are now using food-grade antifreeze so that system draindowns can be discharged to the sanitary sewer or stormwater system. One of the more universal freeze protection approaches for heating coils, whether using antifreeze solutions or untreated water, is the use

of dedicated circulating pumps. A circulating pump maintains a continuous flow of water in the coil throughout the heating season. The combination of continuous flow and pump heat can provide a significant degree of freeze protection.

- *AHU freezestat.* A freezestat is normally located on the upstream face of the cooling coil (the location may differ, depending upon AHU design and configuration). The freezestat's function is to detect subfreezing temperatures, sound an alarm, and shut down the AHU before the coil can be damaged. Too frequently, however, improper installation of the freezestat has led to damaged coils or nuisance trips. The freezestat consists of a long length of sensor tubing that must be installed in a serpentine fashion across the entire face of the coil so as to detect any localized freezing temperatures that are caused by air stratification. When inadequate space is provided for sensor installation, the tubing is frequently placed as a coiled bundle, which greatly compromises its effectiveness. For this reason, as well as to enable cleaning the upstream face of the cooling coil, an upstream access panel must be provided, with dimensions suitable to enable a maintenance technician to access the entire face of the coil. In some areas requiring low dew points (such as operating rooms), the design may use cooling coils designed to provide supply temperature at or near 32°F [0°C]. These coils may use antifreeze to reduce the freezing point. In such instances, the preheat leaving temperature would be lower than the desired supply air temperature, so the designer must be careful to select a freezestat with a lower setpoint range.

3.3.8 Cooling Coils

In addition to providing sensible cooling, a cooling coil acts as a dehumidifier. To fulfill this purpose, it must normally have a high heat transfer surface area consisting of at least six tubing rows with relatively tightly spaced fins. Because the heat transfer surfaces essentially remain continuously wet, cooling coils easily collect dust and can become a microbe growth site. For this reason, the ability to clean the coil is extremely important. A large number of coil rows and close fin spacing make cleaning difficult; therefore, it is normally recommended that coils not exceed 6 rows and/or more than 10-12 fins per inch [10-12 fins per 25 mm]. When additional rows are required, the cooling coil should be split into two separate coils (in the direction of airflow, as shown in Figure 3-7). Both the upstream and downstream faces of the cooling coil(s) must be accessible to a maintenance worker using a power washer. To avoid carryover of droplets from the cooling coil into the AHU casing, the air velocity through the cooling coil must be limited. Designers have traditionally targeted a maximum velocity of 450 to 550 fpm [2.3 to 2.8 m/s], but this varies by manufacturer because of fin design. As mentioned in section 3.3.6, lower coil velocities, potentially as low as 250 fpm [1.3 m/s], are often used to reduce fan energy to earn green-building rating system points or to comply with new energy

codes or standards. Lower initial coil velocities have the added benefit of allowing for future growth and can improve coil performance, as shown in Figure 3-5.

3.3.9 Ultraviolet Cleaning Systems

Ultraviolet (UV) systems are becoming increasingly popular as a means to cleanse cooling coils, drain pans, and in some cases airstreams within ductwork. UV radiation disrupts the DNA of a wide variety of microorganisms, thus rendering them harmless. UV is especially effective at keeping cooling coils and drain pans free of microbial contamination. The increased cooling effectiveness of a cleaner coil should more than offset the heat gain (less than 1°F [0.5°C]) to the airstream caused by operation of the UV device. When used in air-handling systems or ductwork, safety precautions must be taken to protect maintenance staff from exposure to the harmful UV rays and to protect AHU components from damage. Access doors should be fitted with interlocks which will turn off the UV in the event the door is opened. Precaution labels should be posted near access doors to any equipment with UV systems. If purchasing the UV devices separately

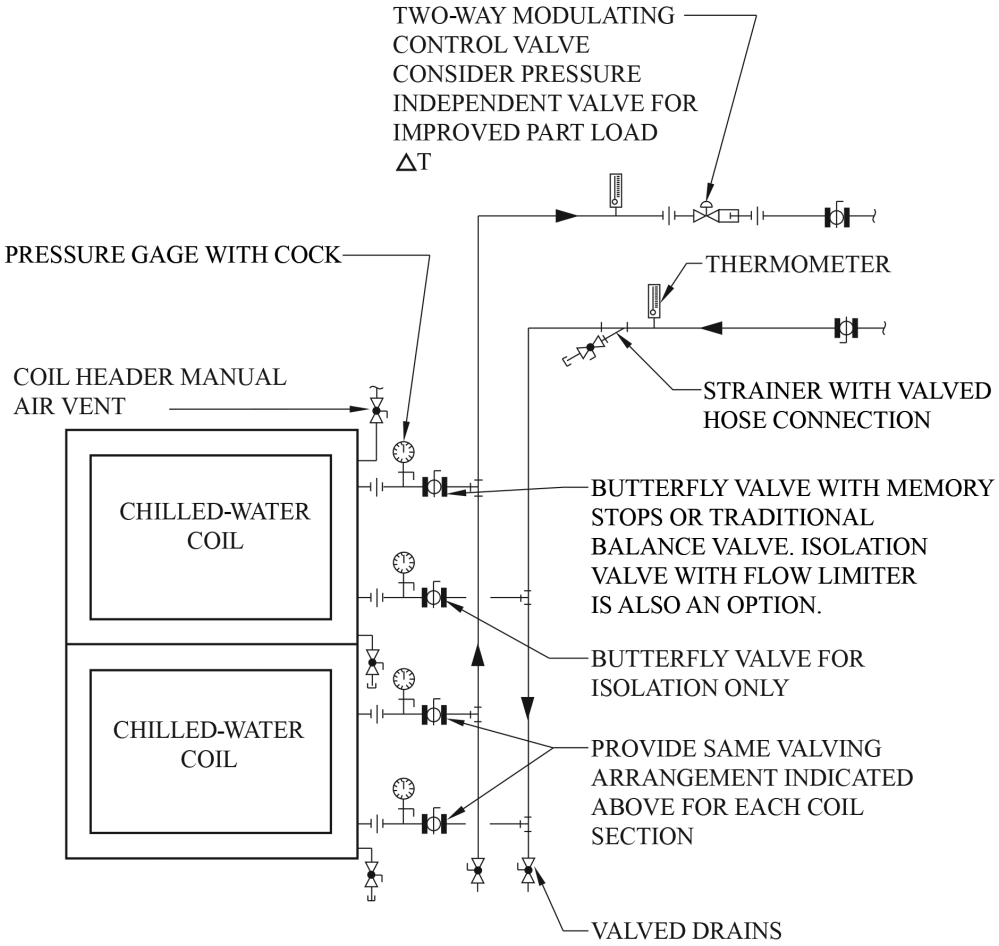


Figure 3-7 *Typical Multisection Coil Piping*

from the AHU, consult the AHU manufacturer to ensure that all components and materials exposed to UV will not sustain significant damage over time.

3.3.10 Moisture Carryover, Condensate Removal, and Drains

Cooling coils must be provided with positively draining pans constructed of noncorrosive materials (e.g., stainless steel) for collection and disposal of condensate and to avoid standing water. An oversized condensate drain pan can have an adverse effect and provide locations for microbial growth. Pans should reach entirely beneath the coil and extend approximately 12 in. (300 mm) from the discharge face. The pan should be at least 2 in. (50 mm) deep, with a drain pipe located so that the bottom of the pipe is flush with the bottom of the pan. When coils are stacked vertically, a separately trapped drain pan (as in Figure 3-8) should be provided for each coil. All drain pans must be properly trapped to ensure that the condensate continues to drain during fan operation. Trap leg dimensional and configuration requirements

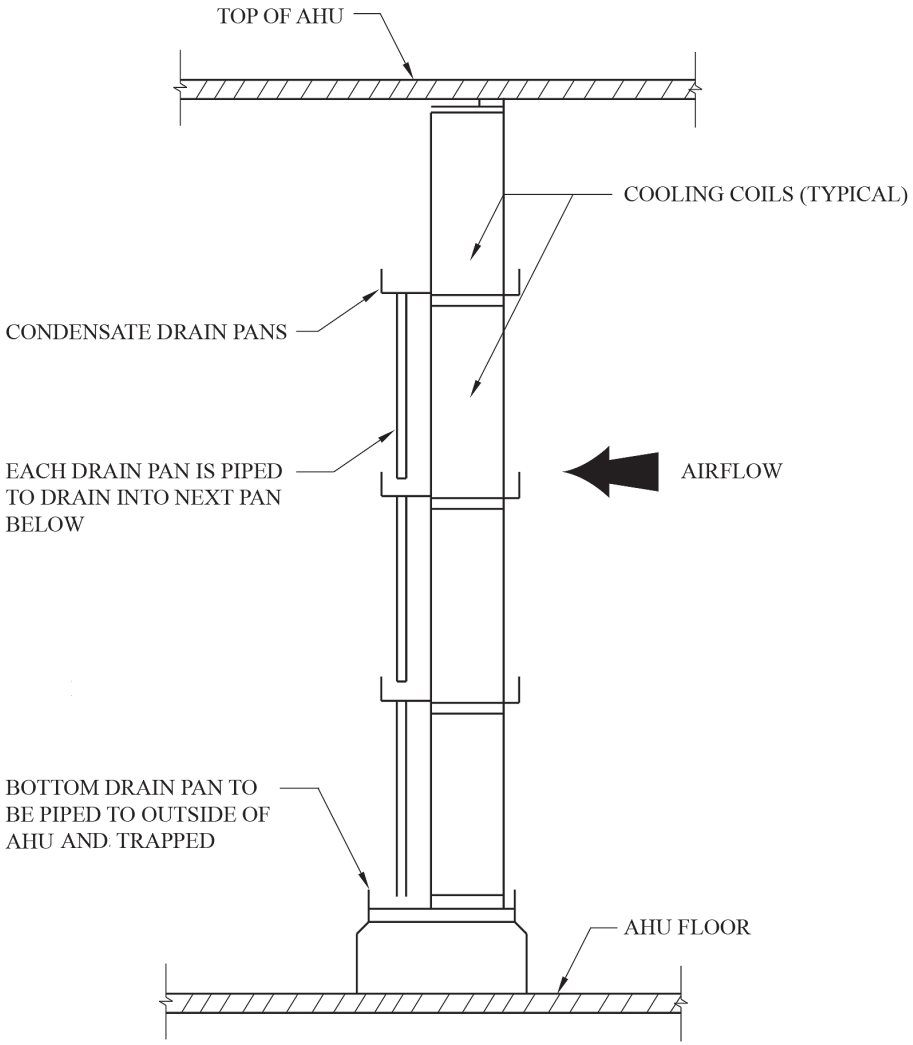


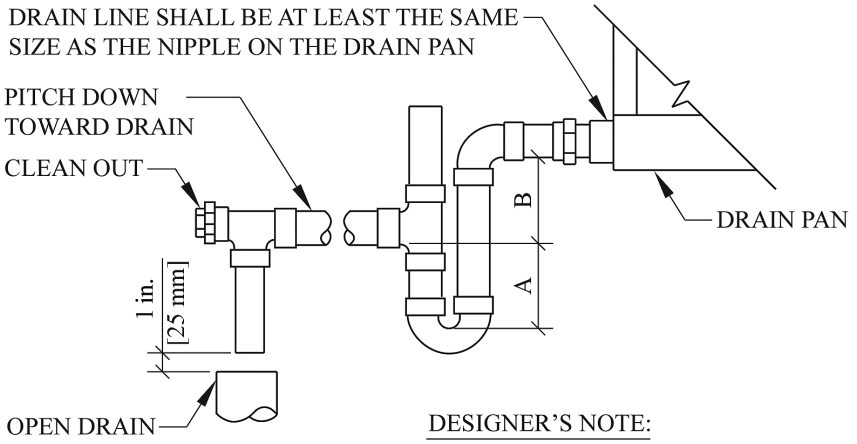
Figure 3-8 *Multiple Condensate Drain Pans*

will vary based upon whether the coil is under negative pressure (draw-through configuration) or positive pressure (blow-through configuration). In both cases, maintenance of the trap seal is important to avoid drawing sewage gases into the AHU.

Figure 3-9 shows condensate drain trap details for a coil subjected to negative pressure (draw-through) and for a coil subjected to positive pressure (blow-through). For coils subjected to negative pressure, unless the trap is properly constructed to provide a positive gravity head on the pan-inlet side (such head exceeding the negative pressure imposed by the unit fan) condensate will not drain from the unit. For coils under positive pressure, the outlet leg of the trap must be high enough to offset the positive static pressure on the inlet side, which would otherwise blow out the trap seal. Where possible, the designer may consider bottom outlet drains for improved performance. For wide units. the designer may consider dual drains. For taller coil banks, the designer should consider multiple drain pans as indicated in Figure 3-8. Such an arrangement prevents excessive condensate buildup on the lower sections of the coil where carryover may occur.

3.3.11 Supply Fans

Designers should consider operation and maintenance during the selection of an AHU supply fan to help achieve satisfactory long-term usage. The as-constructed air system pressure-flow characteristics, and, therefore, the fan operating point, often differ from the calculated values. It is a good idea to ensure that the specified fan motor power is sufficient to provide for fan operation along a broad range of the fan operating curve. Select fans so that their normal operating point will not



DESIGNER'S NOTE:

UNIT TYPE	A	B
DRAW-THROUGH	2 in. [51 mm] PLUS X	X
BLOW-THROUGH	1 in. [25 mm] MINIMUM	2X

WHERE X = STATIC PRESSURE IN PAN

Figure 3-9 *Condensate Trap Details*

be within the surge range. Consider the need to attenuate fan-generated noise that may be transmitted through the distribution system to occupied spaces. Airfoil-bladed centrifugal fans and plenum-style fan arrangements tend to be less noisy than other alternatives. When final filters or coils are located downstream of the fan discharge, a discharge air diffuser may be required (depending upon conditions and type of fan) to equalize the outlet velocity profile and avoid excessive pressure losses or velocities in the downstream components. Other fan selection considerations include the following:

- *System effect.* Catalog fan performance data are normally based upon laboratory conditions at the fan inlet and outlet, which often cannot be duplicated in the field and which maximize the performance of the fan. When conditions are less ideal, fan performance will be lower. The term "system effect" is used to describe the loss of performance resulting from nonideal inlet or outlet conditions. Typically, system effect is expressed in inches of water [Pa] pressure loss or in multiples of the "velocity head" at the fan discharge. On the suction side, system effects can result from factors such as restricted inlets, flow obstructions (such as bearings or inlet vanes), and air prespin caused by improperly designed elbow connections. On the discharge side, system effects may result from obstructions by fittings or equipment (e.g., coils, elbows, takeoffs) located too close to the fan connection or by discharge into an open plenum. Most AHU manufacturers, and several industry references and standards, provide guidelines for estimating the system effect resulting from various inlet and outlet arrangements—one source being *AMCA 201-02, Fans and Systems* (AMCA 2011). It is very important for the design engineer to read the AHU manufacturer's literature when selecting a fan to understand the conditions under which the fan was tested, so that the appropriate system effects can be estimated. Several manufacturers test their air handling unit fan performance according to *AHRI Standard 430: Central Station Air Handling Units* (AHRI 2009), which tests the fans within the factory housing (suction plenum). This better accounts for the impact of the AHU casing on fan performance, but does not account for system effects related to the connected ductwork. Some AHU manufacturers may perform the test with several diameters of straight ductwork connected at the discharge, while others may not (Page 2011). The designer can help reduce system effect by avoiding hard bends, poorly designed turning vanes, improperly designed branch flows, and abrupt AHU inlets or discharge take-offs. Also, using discharge plenums provided and tested by the AHU manufacturer can avoid elbows or transitions located too close to the fan discharge. The HVAC designer should make the building designer aware that inadequate AHU mechanical room space and shaft location can create problems and reduce system performance and energy efficiency.

- *Belt losses.* The laboratory conditions used to test fans normally involve the fan being driven by a direct-drive dynamometer. Therefore, the fan power information published in manufacturers' catalogs will often not include the effects (when applicable) of belt losses, which can be up to 3 to 5% of total motor output, according to one AHU manufacturer, depending upon belt drive characteristics, belt tension, etc.

Fan selection for a given application requires designer consideration of the performance characteristics and space requirements of the various fan types or variants available. Table 3-2 compares some of the fan types frequently used in hospital AHUs. Phased projects where fans may have to operate at an initial flow condition much lower than the final design point can offer additional challenges. The designer must review both the initial operating point on the fan curve as well as the final design point to confirm that both conditions are within a stable operating zone for the fan. Figure 3-10 shows how an initial operating point could fall into an unstable region if there is not a careful review of the fan selection and curves.

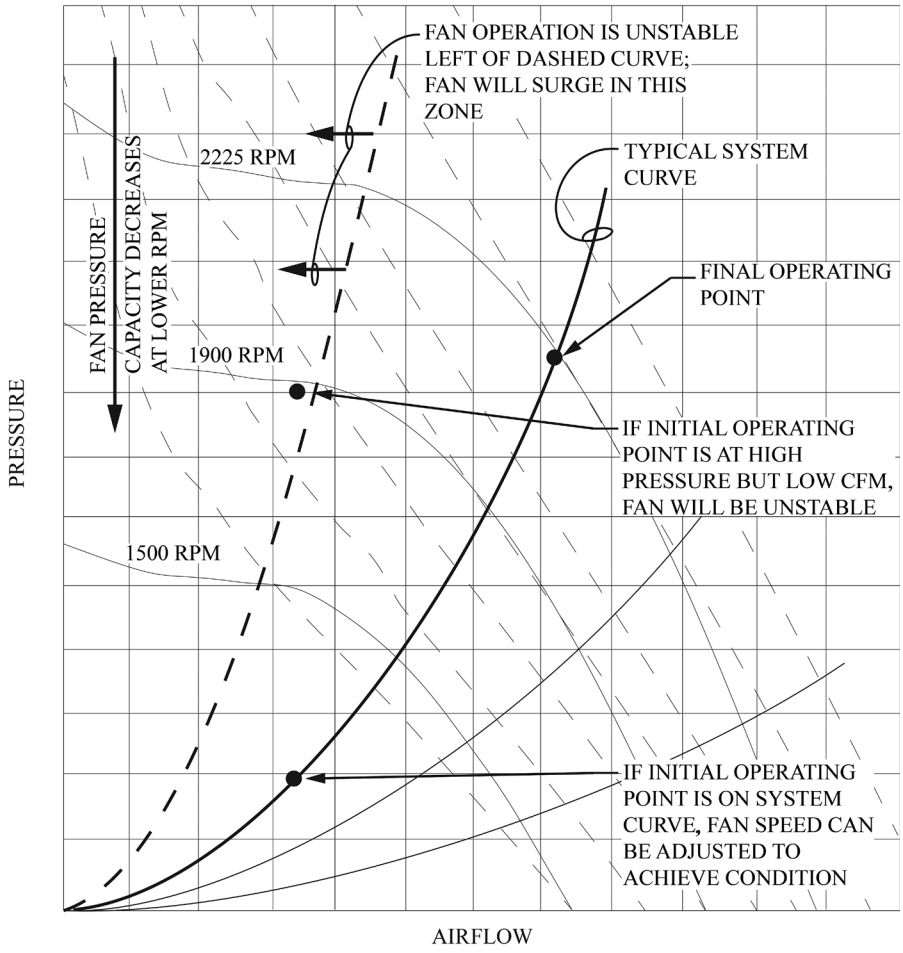


Figure 3-10 *Fan Curve Considerations*

Most of the diagrams in this chapter show the fan in the "draw-through" position, which is downstream of the coils. Note that some system designs use a "blow-through" arrangement where the supply fan is upstream of the coils, and air blows through the coils. Blow-through arrangements are typically seen in dual-duct system or multizone AHUs. One benefit of the draw-through arrangement is that the fan motor heat is added after the coil, providing some "free" reheat.

3.3.12 Return Fans

Return fans are often required for AHUs that have a ducted return air path (see Figure 3-11). A return fan may also be used for AHUs that are part of a smoke evacuation system or smoke ventilation system that requires the AHU to operate in 100% outdoor air and/or 100% exhaust mode. As with the supply fan, consideration must be given to fan noise generation and the need for attenuation to reduce sound transmitted through the return ductwork to occupied spaces. Ensure that adequate space is available for personnel access to all parts of the return fan that require inspection or periodic maintenance. As with supply fans, the design engineer will need to evaluate the "system effect" (reduced fan performance) resulting from inlet and outlet conditions. Fan type selection must consider required performance and equipment space availability for each application.

3.3.13 Relief Fans

Another option for AHUs requiring 100% outdoor air and 100% exhaust for economizer, smoke purge/evacuation, or smoke ventilation is to provide a relief air fan. Figure 3-12 illustrates the location of a

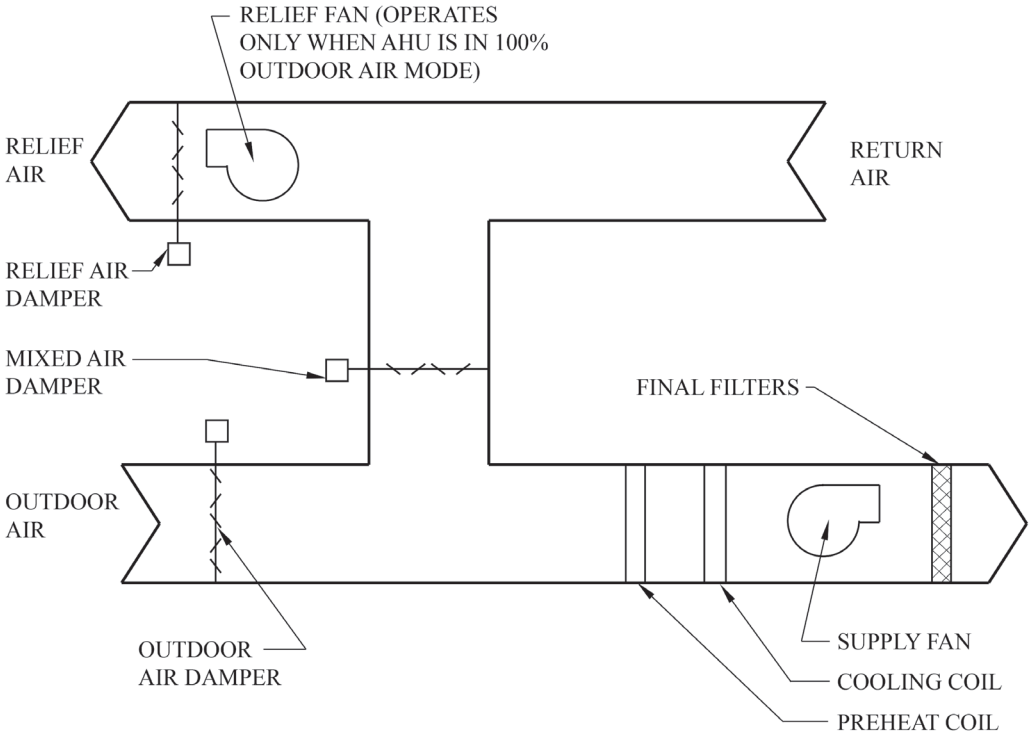


Figure 3-11 *Return Fan Location*

Table 3-2 *Types of Fans (continues across opposite page)*

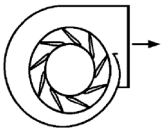
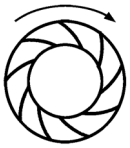
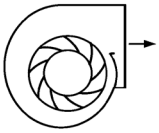
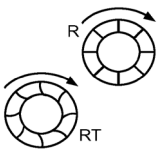
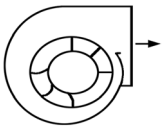
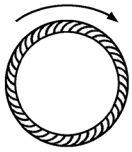
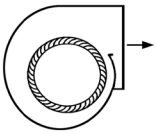
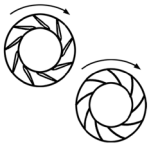
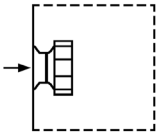
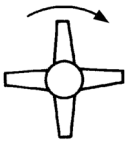
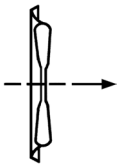
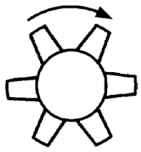
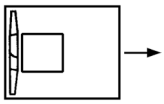
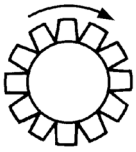
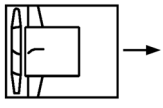
Type		Impeller Design		Housing Design	
Centrifugal Fans	Airfoil		Blades of airfoil contour curved away from direction of rotation. Deep blades allow efficient expansion within blade passages. Air leaves impeller at velocity less than tip speed. For given duty, has highest speed of centrifugal fan designs.		Scroll design for efficient conversion of velocity pressure to static pressure. Maximum efficiency requires close clearance and alignment between wheel and inlet.
	Backward- Inclined Backward- Curved		Single-thickness blades curved or inclined away from direction of rotation. Efficient for same reasons as airfoil fan.		Uses same housing configuration as airfoil design.
	Radial (R) Radial Tip (Rt)		Higher pressure characteristics than airfoil, backward-curved, and backward-inclined fans. Curve may have a break to left of peak pressure and fan should not be operated in this area. Power rises continually to free delivery.		Scroll similar to and often identical to other centrifugal fan designs. Fit between wheel and inlet not as critical as for airfoil and backward-inclined fans.
	Forward- Curved		Flatter pressure curve and lower efficiency than the airfoil, backward-curved, and backward-inclined. Do not rate fan in the pressure curve dip to the left of peak static pressure. Power rises continually toward free delivery.		Scroll similar to and often identical to other centrifugal fan designs. Fit between wheel and inlet not as critical as for airfoil and backward-inclined fans.
	Plenum/ Plug		Plenum and plug fans typically use airfoil, backward inclined, or backward curved impellers in a single inlet configuration. Relative benefits of each impeller are the same as those described for scroll housed fans.		Plenum and plug fans are unique in that they operate with no housing. The equivalent of a housing, or plenum chamber (dashed line), depends on the application. The components of the drive system for the plug fan are located outside the airstream.
Axial Fans	Propeller		Low efficiency. Limited to low-pressure applications. Usually low-cost impellers have two or more blades of single thickness attached to relatively small hub. Primary energy transfer by velocity pressure.		Simple circular ring, orifice plate, or venturi. Optimum design is close to blade tips and forms smooth airfoil into wheel.
	Tubeaxial		Somewhat more efficient and capable of developing more useful static pressure than propeller fan. Usually has 4 to 8 blades with airfoil or single-thickness cross section. Hub is usually less than half the fan tip diameter.		Cylindrical tube with close clearance to blade tips.
	Vaneaxial		Good blade design gives medium- to high-pressure capability at good efficiency. Most efficient have airfoil blades. Blades may have fixed, adjustable, or controllable pitch. Hub is usually greater than half fan tip diameter.		Cylindrical tube with close clearance to blade tips. Guide vanes upstream or downstream from impeller increase pressure capability and efficiency.

Table 3-2 *Types of Fans*

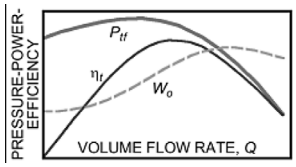
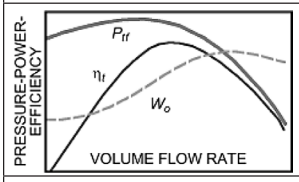
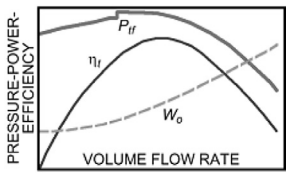
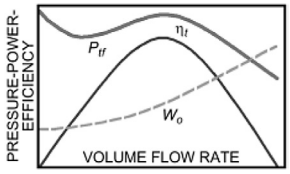
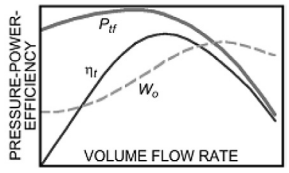
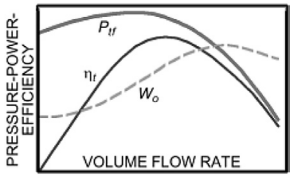
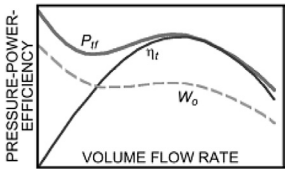
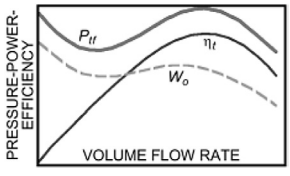
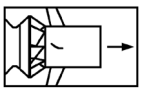
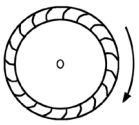
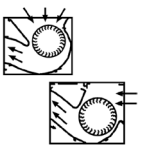
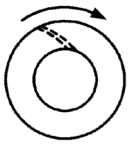
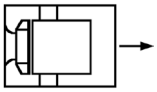
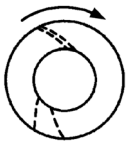
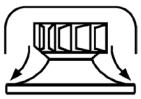
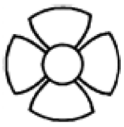
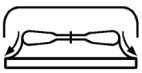
Performance Curves*	Performance Characteristics	Applications
	Highest efficiency of all centrifugal fan designs and peak efficiencies occur at 50 to 60% of wide-open volume. Fan has a non-overloading characteristic, which means power reaches maximum near peak efficiency and becomes lower, or self-limiting, toward free delivery.	General heating, ventilating, and air-conditioning applications. Usually only applied to large systems, which may be low-, medium-, or high-pressure applications. Applied to large, clean-air industrial operations for significant energy savings.
	Similar to airfoil fan, except peak efficiency slightly lower. Curved blades are slightly more efficient than straight blades.	Same heating, ventilating, and air-conditioning applications as airfoil fan. Used in some industrial applications where environment may corrode or erode airfoil blade.
	Higher pressure characteristics than airfoil and backward-curved fans. Pressure may drop suddenly at left of peak pressure, but this usually causes no problems. Power rises continually to free delivery, which is an overloading characteristic. Curved blades are slightly more efficient than straight blades.	Primarily for materials handling in industrial plants. Also for some high-pressure industrial requirements. Rugged wheel is simple to repair in the field. Wheel sometimes coated with special material. Not common for HVAC applications.
	Pressure curve less steep than that of backward-curved fans. Curve dips to left of peak pressure. Highest efficiency occurs at 40 to 50% of wide-open volume. Operate fan to right of peak pressure. Power rises continually to free delivery which is an overloading characteristic.	Primarily for low-pressure HVAC applications, such as residential furnaces, central station units, and packaged air conditioners.
	Plenum and plug fans are similar to comparable housed airfoil/backward-curved fans but are generally less efficient because of inefficient conversion of kinetic energy in discharge air stream. They are more susceptible to performance degradation caused by poor installation.	Plenum and plug fans are used in a variety of HVAC applications such as air handlers, especially where direct-drive arrangements are desirable. Other advantages of these fans are discharge configuration flexibility and potential for smaller-footprint units.
	High flow rate, but very low pressure capabilities. Maximum efficiency reached near free delivery. Discharge pattern circular and airstream swirls.	For low-pressure, high-volume air-moving applications, such as air circulation in a space or ventilation through a wall without ductwork. Used for makeup air applications.
	High flow rate, medium pressure capabilities. Pressure curve dips to left of peak pressure. Avoid operating fan in this region. Discharge pattern circular and airstream rotates or swirls.	Low- and medium-pressure ducted HVAC applications where air distribution downstream is not critical. Used in some industrial applications, such as drying ovens, paint spray booths, and fume exhausts.
	High-pressure characteristics with medium-volume flow capabilities. Pressure curve dips to left of peak pressure. Avoid operating fan in this region. Guide vanes correct circular motion imparted by impeller and improve pressure characteristics and efficiency of fan.	General HVAC systems in low-, medium-, and high- pressure applications where straight-through flow and compact installation are required. Has good downstream air distribution. Used in industrial applications in place of tubeaxial fans. More compact than centrifugal fans for same duty.

Table 3-2 *Types of Fans (continues across opposite page)*
– concluded –

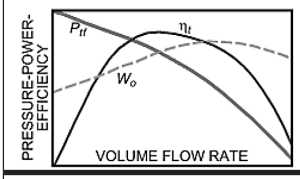
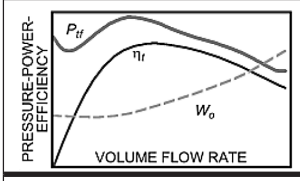
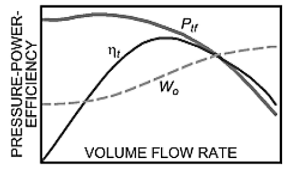
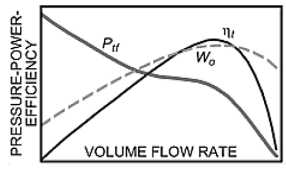
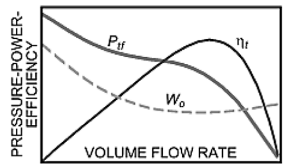
Type			Impeller Design		Housing Design	
Mixed-Flow	Mixed-Flow			Combination of axial and centrifugal characteristics. Ideally suited in applications in which the air has to flow in or out axially. Higher pressure characteristic than axial fans.		The majority of mixed-flow fans are in a tubular housing and include outlet turning vanes. Can operate without housing or in a pipe and duct.
Cross-flow	Cross-flow (Tangential)			Impeller with forward-curved blades. During rotation the flow of air passes through part of the rotor blades into the rotor. This creates an area of turbulence which, working with the guide system, deflects the airflow through another section of the rotor into the discharge duct of the fan casing. Lowest efficiency of any type of fan.		Special designed housing for 90°or straight through airflow.
Other Designs	Tubular Centrifugal			Performance similar to backward-curved fan except capacity and pressure are lower. Lower efficiency than backward-curved fan. Performance curve may have a dip to the left of peak pressure.		Cylindrical tube similar to vaneaxial fan, except clearance to wheel is not as close. Air discharges radially from wheel and turns 90° to flow through guide vanes.
	Power Roof Ventilators	Centrifugal		Low-pressure exhaust systems such as general factory, kitchen, warehouse, and some commercial installations. Provides positive exhaust ventilation, which is an advantage over gravity-type exhaust units. Centrifugal units are slightly quieter than axial units.		Normal housing not used, because air dis- charges from impeller in full circle. Usually does not include configuration to recover velocity pressure component.
		Axial		Low-pressure exhaust systems such as general factory, kitchen, warehouse, and some commercial installations. Provides positive exhaust ventilation, which is an advantage over gravity-type exhaust units. Hood protects fan from weather and acts as safety guard.		Essentially a propeller fan mounted in a supporting structure. Air discharges from annular space at bottom of weather hood.

relief fan. In this application, the relief fan may be able to operate only when the AHU goes into an increased or 100% outdoor air mode. For normal operation, the relief fan can often remain off, and the supply fan provides the pressure differential for both return and supply ductwork.

3.3.14 Humidifiers

Humidifiers are often required in health care facility air-handling systems to maintain a minimum level of relative humidity in the occupied spaces. Most criteria establish a 20% rh minimum, with possibly higher levels in critical spaces. The complexities of humidifier design and maintenance are often underestimated by designers, with the result that the devices are frequently disconnected by maintenance personnel or cited as a cause of contamination and corrosion within the AHU or ductwork. Leaks and other malfunctions resulting in oversaturated air are common. Designers must carefully consider the selection, location, and control of humidifiers within AHUs or ductwork to avoid moisture accumulation in downstream components, including filters and insulation. Humidifier design considerations include the following:

Table 3-2 *Types of Fans*
– concluded –

Performance Curves*	Performance Characteristics	Applications
	Characteristic pressure curve between axial fans and centrifugal fans. Higher pressure than axial fans and higher volume flow than centrifugal fans.	Similar HVAC applications to centrifugal fans or in applications where an axial fan cannot generate sufficient pressure rise.
	Similar to forward-curved fans. Power rises continually to free delivery, which is an overloading characteristic. Unlike all other fans, performance curves include motor characteristics. Lowest efficiency of any fan type.	Low-pressure HVAC systems such as fan heaters, fireplace inserts, electronic cooling, and air curtains.
	Performance similar to backward-curved fan, except capacity and pressure are lower. Lower efficiency than backward-curved fan because air turns 90°. Performance curve of some designs is similar to axial flow fan and dips to left of peak pressure.	Primarily for low-pressure, return air systems in HVAC applications. Has straight-through flow.
	Usually operated without ductwork; therefore, operates at very low pressure and high volume.	Centrifugal units are somewhat quieter than axial flow units. Low-pressure exhaust systems, such as general factory, kitchen, warehouse, and some commercial installations. Low first cost and low operating cost give an advantage over gravity-flow exhaust systems.
	Usually operated without ductwork; therefore, operates at very low pressure and high volume.	Low-pressure exhaust systems, such as general factory, kitchen, warehouse, and some commercial installations. Low first cost and low operating cost give an advantage over gravity-flow exhaust systems.

*These performance curves reflect general characteristics of various fans as commonly applied. They are not intended to provide complete selection criteria, because other parameters, such as diameter and speed, are not defined.

Source: Chapter 21, Fans, of the 2012 *ASHRAE Handbook—HVAC Systems and Equipment* (ASHRAE 2012).

- *Humidifier types.* ANSI/ASHRAE/ASHE Standard 170-2008 requires steam injection type humidifiers for health care facility applications. Steam is sterile and, therefore, eliminates the risk of introducing viable microorganisms, such as *Legionella*, into the building airstream. Steam may be generated centrally (using a boiler or heat exchanger) or locally at the humidifier by a separate electrical or steam-to-steam generator. Small gas-fired units are also available. Regardless of the steam source, care must be taken to ensure that only dry steam is supplied to the steam injector. Consult manufacturer's recommendations for appropriate condensate trapping and drainage provisions and ensure that appropriate details and instructions are communicated via construction drawings.

- *Avoiding wetting of air handler or duct components.* When saturated dry steam is injected into the airstream, a portion of the steam is immediately condensed and forms a mist or "vapor trail"

of water particles. Unless a suitable expanse of downstream duct or AHU casing is provided to allow for reevaporation, the mist will impinge on downstream equipment and cause water buildup. Filters, exposed insulating materials, and even sheet metal can easily become microbe growth sites in these circumstances, and fans and other steel AHU and ductwork components will quickly rust. The distance required for reevaporation is a function of air temperature, relative humidity, velocity, casing or duct dimensions, and the design of the humidifier components; it can vary from a few inches (several mm) to more than 12 ft [3.6 m].

- *Humidifier location.* Consider placing the humidifier upstream of the cooling coil. The supply air is warmer at this point, which will improve absorption. This location also allows the cooling coil fins to act as an eliminator blade section and provide an additional safeguard to prevent wetting of downstream components such as fans and filters. The control measuring point should be located downstream from the cooling coil to prevent oversaturation of the air entering the coil. Sensors and controls must be kept in proper working order and calibration to prevent energy waste by oversaturation of the air and subsequent dehumidifying with the cooling coil. Note that, although dehumidification occurring in the cooling coil could result in wasted energy, this is better than potentially wetting a downstream filter section that would compromise infection control. The humidifier steam discharge relative to the airflow direction depends on the particular manufacturer. Designers should consult the manufacturer's installation instructions to confirm proper humidifier orientation.

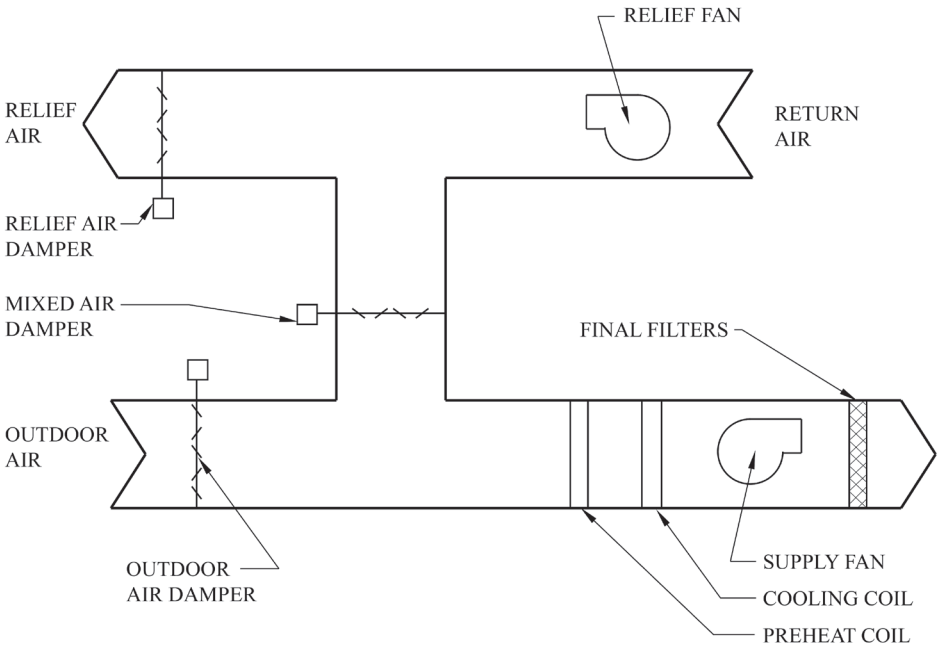


Figure 3-12 *Relief Fan Location*

- *Humidifier control.* Humidifiers are often controlled by a space humidistat or a return air sensor. Such a control approach can introduce the opportunity for oversaturation of supply air. Designers should consider controlling the humidifier from a supply air sensor instead. The control sequence can then have a setpoint limit of 80% to 90% to prevent oversaturation of the supply air. Room humidistats or return air sensors can still be used but would not directly control the humidifier. A call for additional humidity from a room humidistat or return air sensor would instead increase the supply air humidity setpoint. Users should not be given control of humidity from room humidistats.

3.3.15 Final Filtration

Many of the spaces in a health care facility require a higher level of filtration than is provided by a prefilter alone. The FGI *Guidelines*, for example, recommend a filtration level of MERV 14 for all patient care areas, whether in clinics or in full-service hospitals. Some codes require HEPA filtration for inpatient applications, especially where patients are particularly vulnerable to infection, such as protective isolation rooms for immunocompromised patients and orthopedic operating rooms. Designers must provide (and require in contract documents) adequate space for replacing filters. All filters should be provided with a differential pressure indicating manometer, mounted on the AHU, to indicate when replacement is required. Electronic monitoring through the building automation system is highly desirable. Automatic alarms can be included to alert maintenance personnel of the need for a filter change. The size of the second filter, normally the final filter installed in the AHU, along with the cooling coil's dimensions, is a determining factor in establishing the overall dimensions of the AHU. The design air velocity for health care facility AHU filters should not exceed 500 fpm [2.5 m/s] for filters of MERV 15 and below. HEPA and higher efficiency filters (MERV 17 and above) should be designed with a 300 fpm [1.5 m/s] velocity limit. Note that the use of "Z" and "V" filter configurations increases the filter area, allowing the filter velocities to be lower than the coil velocities for the same AHU cross-sectional area. To ensure adequate airflow throughout the range (from clean to dirty) of filter resistance, designers should use the filter manufacturer's recommended final resistance when calculating fan pressure require-ments. If no final resistance recommendation is available, a value of 1.4 in. of water [350 Pa] is recommended for MERV 13 to 15 filters. Be aware that when filters are clean, resulting in system resistance lower than the fan selection point, the fan motor must be adequately sized to accommodate the higher power requirements at that operating condition. One advantage of using variable-speed drives on fans is that fan speed can be increased as filters begin to load so the AHU maintains a constant airflow. Figure 3-13 shows a typical relationship of pressure drop versus air velocity for a MERV 14 filter.

A filter's effectiveness is only as good as the filter rack strength and gasket integrity. It is essential, especially for filters with MERV ratings 14 and up, that the AHU include filter racks and gaskets designed for

the filters to be used. Improper filter racks allow air to leak past and bypass the filters. MERV 14 and up filters are available in both bag and cartridge style. Cartridge filters are becoming very popular because of their increased durability.

3.3.16 Noise Control

In many cases, attenuation of fan noise (supply, return, or both) will be neededto achieve the room background noise levels required by design criteria. This is often a concern with the double-walled AHUs required for health care facilities, because the interior sheet metal wall resists noise breakout and helps to transmit the noise through the ductwork. Providing sidewall takeoffs where diffusers connect to ductwork and adding flexible ductwork with at least one elbow at final diffuser or grille connections can offer significant attenuation. When additional attenuation is required, the designer's options include active electronic silencers or factory-fabricated sound attenuators. Packless type attenuators and active silencers have limited application and efficacy, often leaving packed-type liners and attenuators as the only practical choice. This chapter has already discussed concerns regarding water-permeable, unsealed insulation surfaces exposed to the airstream. Several manufacturers, however, offer double-walled attenuating ductwork or fabricated attenuators with perforated inner sheet metal housings and impermeable foil or plastic liners, which probably offer the best compromise between durability/sanitation concerns and the need for noise attenuation. Such foil or plastic liners do not drastically reduce attenuation performance. Their flame spread/smoke generation characteristics, however, should be checked against the limiting requirements of NFPA 90A and applicable codes. Because of installation space limitations, and to improve the inspectability and cleanability of airflow surfaces, fabricated attenuators are often chosen over attenuating ductwork.

Attenuator inlet and outlet conditions must also be considered. The noise-attenuating properties and pressure-flow characteristics cataloged by attenuator manufacturers (and available in their literature) are based

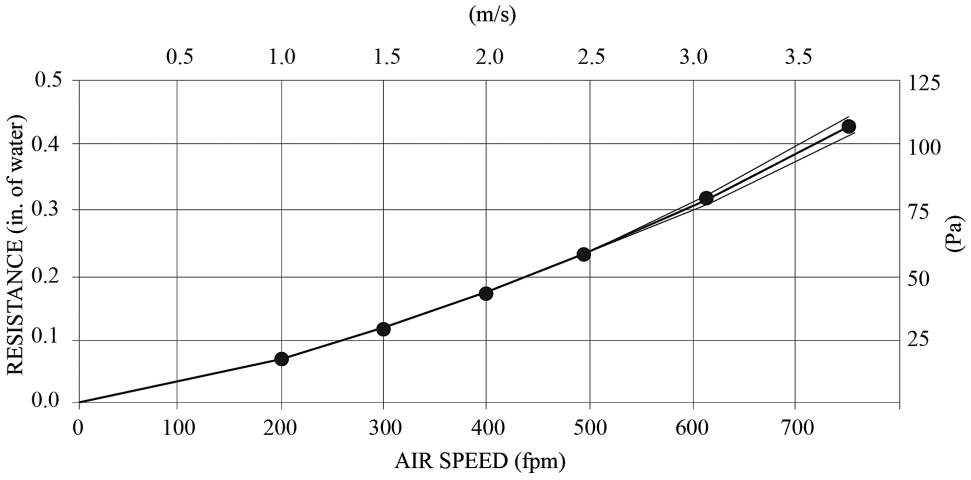


Figure 3-13 *Filter Pressure Drop versus Air Velocity*

upon smooth inlet and outlet duct transitions. Many designers do not realize that, without proper transitions, the pressure loss across a sound attenuator can be several times the catalog value and the device can actually generate more noise than it attenuates. The designer needs to include suitable transition space and provide appropriate details and instructions for the contractor.

3.3.17 Vibration Control

Chapter 48, Noise and Vibration Control, of the 2011 *ASHRAE Handbook—HVAC Applications* (ASHRAE 2011b) is an excellent resource for information on equipment and system vibration control. As indicated in that chapter, many of the most sensitive areas can be found in the health care environment. Such areas include operating rooms, microsurgery areas (such as eye surgery), labs using electron microscopes, and laser equipment locations. In addition to the methods covered in the Handbook chapter, the designer can follow some simple practical design guidelines to avoid potential vibration issues. These include the following:

- Do not locate air handlers, chillers, pumps, compressors, or other moving equipment directly over highly sensitive areas, such as operating rooms.
- Select fans for stable operation, and provide smooth duct transitions to avoid fan surging (see section 3.3.11), which can introduce vibration .
- Coordinate with the structural engineer so that the structure supporting moving equipment is designed to limit transmission of vibration.
- Consider inertia pads for larger equipment or when equipment is near highly sensitive areas; refer to the ASHRAE Handbook for additional information on when the use of inertia pads is recommended.

3.3.18 Airflow Monitors

Airflow-monitoring arrays are often provided in the return and supply airstreams for variable-air-volume (VAV) systems to enable differential supply/return fan flow control. In addition, they are frequently used in both VAV and constant-volume (CAV) systems, to monitor flow of outdoor air. This monitoring can help the owner confirm that minimum ventilation rates are being maintained and alarm the owner of potential energy waste when excessive outdoor air is being introduced because of malfunctioning dampers or controls. To accurately measure velocity (and therefore flow volume), monitoring arrays require a reasonably uniform entering velocity profile. Establishing that profile normally requires a certain extent of straight upstream ductwork (usually specified by the device manufacturer in terms of unit diameters) and a smoothly transitioning discharge arrangement. Designers should consult manufacturer's recommendations, ensure that the space requirements are taken into account in laying out the fan room, and reflect the requirements in the construction documents. Designers also need to consider the range of flow that they intend the device to measure to ascertain that it is not

only sufficiently accurate over that range but can physically sense flow at lower velocities (a particular concern with pitot-type velocity sensing).

3.3.19 Dehumidification Equipment

Dehumidification by the primary cooling coil is often sufficient to limit relative humidity to the maximum values permitted by codes. Very stringent upper limit relative humidity requirements may, however, dictate supplemental dehumidification using mechanical refrigeration or desiccant equipment. Some designers address this issue by providing automatic controls to reset the cooling coil discharge temperature below that required for cooling as a means of providing dehumidification; such a strategy requires reheat of the air supply for comfort conditioning. This control strategy can be difficult to accomplish with a nonmodulating cooling system, such as traditional direct-expansion (DX) systems. When such a control strategy is needed, and chilled water is not available, the designer should consider special DX systems that are designed to operate in a reheat mode. Several manufacturers offer such systems, which use hot-gas bypass or variable-speed compressors to modulate the cooling capacity and maintain fixed discharge temperatures. Refer to section 3.9 for information on additional dehumidification strategies for areas, such as operating rooms, requiring low dew points.

3.3.20 System Redundancy

AHU shutdowns for repairs or service can be especially challenging in the hospital environment. Most areas operate 24 hours per day. Shutdown of an AHU not only compromises patient and staff comfort but also compromises infection control because of loss of pressure relationships for critical spaces. In some critical areas, such as operating rooms, central sterile supply, isolation rooms, and areas accommodating immunocompromised patients (such as a bone marrow unit), even a momentary loss of supply air presents a problem. For such areas, the designer should consider redundant equipment. Dual units operating in parallel might be considered. Figure 3-14 illustrates a configuration often used with hospital AHUs. A single unit is split into two "modules" that can operate independently. High-pressure dampers are provided to isolate one side and prevent backflow of air through that section when it is down for service.

3.4 AIR DISTRIBUTION SYSTEM ALTERNATIVES

The following sections note some specific considerations when applying HVAC systems in the health care environment. For all of the systems listed below, terminal boxes or devices should have double-wall construction or insulation lined with foil or polyester film to avoid exposed insulation in the airstream. Factory-mounted access doors (to inspect dampers and coils) are a relatively low-cost option and are useful for maintenance and troubleshooting. Access doors should include gaskets and good locks for a tight seal. Adding a supply air temperature sensor in the leaving airstream provides a very useful monitoring point for diagnosing system problems. Locate terminal boxes where they can be easily accessed for service and maintenance. Avoid locations above light fixtures, walls, work areas, patient care areas, or other spaces that will restrict access. Consider the controller location as well and maintain sufficient clearance for service.

3.4.1 Variable-Air-Volume (VAV) Systems

Variable-air-volume systems without reheat have limited applications in the hospital environment. Although some interior locations may not, in theory, require heating, the designer should consider including reheat for rapid warm-up when thermostat settings are raised. Consider that patients are often sensitive to low room temperatures and drafts. When using VAV systems, minimum airflow settings must be sufficient to meet minimum air exchange rates for both outdoor and supply air. For areas that must maintain positive or negative room pressure, VAV terminal boxes are required on both supply and return/exhaust. VAV terminal boxes without reheat are a good solution for spaces such as equipment rooms, electrical rooms, and other typically unoccupied areas that have continuous internal loads and do not require heat. Because these spaces do not have required minimum air exchange rates or outdoor ventilation air requirements, minimum airflow can be set to zero, thereby eliminating the need for reheat.

3.4.2 Variable-Air-Volume Terminal Reheat (VAVTR) Systems

Variable-air-volume systems with reheat are common in hospital spaces. Reheat coils should be sized to provide rapid warm-up as well as to meet the steady-state load. This is especially true in areas, such as operating rooms, where very rapid temperature changes are desired. In some cases, operating rooms may require high room temperatures during surgical procedures. In such situations, the designer may need to use a constant-temperature hot-water supply system rather than a

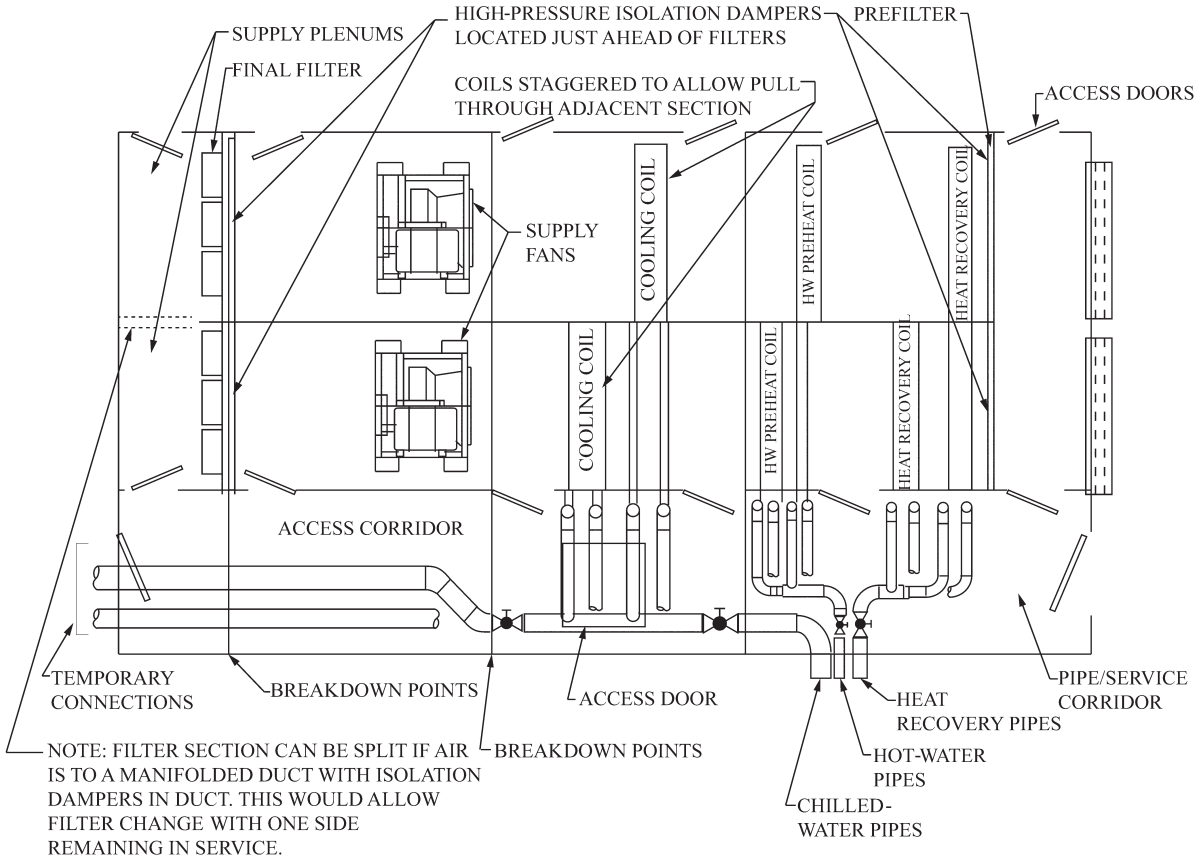


Figure 3-14 *Dual-Section AHU*

hot-water reset control strategy. Two-row heating coils for reheat will also provide more capacity for rapid warm-up and to meet high room temperature requirements. As with VAV systems, VAVTR systems must also maintain minimum airflow settings sufficient to meet minimum air exchange rates for both outdoor and supply air. For areas that must maintain positive or negative room pressure, VAV terminal boxes are required on the return/exhaust in addition to the VAVTR boxes on the supply.

3.4.3 Constant-Air-Volume (CAV) Systems

Constant-air-volume systems without reheat are not very common in the hospital environment. Although room pressure requirements or high air exchange requirements may suggest a CAV system, there must be a means to maintain temperature when cooling loads in the various spaces are lower than peak design. For this reason, CAV terminal reheat systems are more common in the hospital environment.

3.4.4 Constant-Air-Volume Terminal Reheat (CAVTR) Systems

Constant-air-volume systems with reheat are often used in the hospital environment. Airflow for many areas in hospitals is often dictated by air exchange requirements rather than by load. In such areas, there may not be an opportunity to use a VAVTR system, or the amount of peak airflow that can be varied may be too low to justify the added complexity of a VAVTR system. A CAVTR system may be a reasonable choice for such spaces. CAVTR systems may also be considered for areas where maintaining room pressure is critical (e.g., isolation rooms, operating rooms). While VAV systems can also be used in such areas by controlling both supply and return/exhaust, the effect of this added complexity on reliability should be considered. As with a VAVTR system, reheat coils in CAVTR systems should be sized to provide rapid warm-up as well as meeting the steady-state load (see section 3.4.2).

3.4.5 Dual-Duct Systems

Dual-duct systems were once very common in hospitals. This is no longer the case for new hospitals because of the additional cost and space requirements of dual primary air supply ducts. Many older systems are still in place, and the hospital designer may be tasked with renovations or expansions of these systems. A problem frequently encountered in older dual-duct systems is poor control, or leaking of air from the primary air source that is being set back. For example, with a dual-duct terminal box in full cooling mode where the hot-duct air should be at minimum or zero, a poorly functioning diverting damper or hot-duct damper may cause unwanted hot air to continue flowing, thus significantly reducing cooling capacity. When renovating or expanding such systems, the designer may want to consider repair or replacement of existing terminal boxes. AHU repairs or modifications such as variable-speed fan drives or discharge dampers will reduce overpressurization of ductwork and assist in preventing this leakage.

3.4.6 Other Systems

Many older hospitals may still have fan coil units or induction units in place. These were particularly popular in patient rooms. While not expressly prohibited for use in patient care areas, it can be difficult to meet many of the current codes and standards with these systems.

Typical fan coils or induction units are not able to accommodate the higher pressure drops of MERV 14 filters, which are required in many patient care areas. There is considerable disagreement, but ANSI/ASHRAE/ASHE Standard 170-2008 (ASHRAE 2008) allows recirculating room-HVAC units in some areas, including patient rooms. In such cases, the minimum 2 ach (air changes per hour) must be filtered to MERV 14 while the remaining 4+ ach does not require filtration, because it may be recirculated.

Many state and local codes require that these units be noncon–densing. In such circumstances, additional systems must be used to provide latent cooling for the spaces. ANSI/ASHRAE/ASHE Standard 170-2008 lists specific areas where the use of room recirculating units is prohibited.

Chilled beams are another type of room recirculating terminal unit. Chilled beams consist of two types, passive and active. Passive beams use only a heat exchanger coil; there is no connection for a primary air system. Air movement through the cooling coil in the beam is induced by natural convection. A separate system must be used for ventilation. Active beams work much like an induction unit. Primary air is supplied to the unit and discharged through high-velocity nozzles that induce airflow through the terminal. A heat exchanger coil in the beam provides heating or cooling. This coil must be kept clean to maximize performance.

The heat exchange coils in both active and passive beams must be designed for noncondensing operation to prevent condensation from forming in the chilled beams and dripping to the space below. This is typically achieved by supplying higher chilled-water temperatures to the beams, which means that the heat exchangers in the beams cannot provide latent cooling to the space. All latent cooling loads must be met by primary air supplied to an active chilled beam or by supplemental systems. Designers may also need to provide supplemental systems to meet minimum air exchange rates and filtration requirements.

Chilled beams are most suitable in areas that do not have high air exchange requirements or latent loads. They can be especially effective in areas with high sensible heat loads from equipment such as that found in laboratories, data centers, and medical records and storage areas.

Fan-coil units, induction units, fan-powered boxes, chilled beams, and packaged terminal air conditioners (PTAC) all have similar drawbacks:

- Poor humidity control
- Possible condensation in the unit
- Limited filtration, not better than MERV 8
- Potential for buildup of contamination
- Cleaning difficulty

3.5 DUCTWORK

3.5.1 General Design Consideration

Duct systems for health care facilities may be designed using any of the major duct-sizing approaches (including the equal friction, static regain, T-method, and other approaches) described in the *ASHRAE Handbook—Fundamentals* or in publications from the Sheet Metal and Air Conditioning Contractors' National Asociation (SMACNA) and others in the industry. The 2009 *ASHRAE Handbook—Fundamentals* (ASHRAE 2009b) provides guidance as to velocity and pressure loss limitations, as well as economic considerations for the several methods. Designers should be aware that careful attention to duct system velocity limitations is especially warranted in health care facility design, due to the common imposition of background noise level criteria. Considering the variety of building systems required for health care service, ductwork design must be carefully coordinated with the electrical, fire protection, plumbing and HVAC piping, and other building services, as well as with architectural and structural elements, to ensure sufficiency of space. Most designers recommend fully ducted installations, using all-metal duct construction, particularly for inpatient facilities, and the avoidance of duct liner except when absolutely necessary to attenuate ductborne noise. Other health care facility ductwork considerations are as follows:

- *Pressure losses.* Various organizations, including ASHRAE and SMACNA, publish guidelines for selection of fittings and determining pressure losses. The manufacturers of distribution equipment (such as diffusers, sound attenuators, fire dampers, and inlet louvers) normally publish pressure loss characteristics. Designers must be cautious, however, because the published pressure losses (as well as noise output values) often correspond to specific, idealized inlet or connection arrangements that may not be possible in actual building situations.

- *Pressure class.* Designers should be careful to show or specify the duct pressure classes for supply, return, and exhaust ductwork to ensure adequate construction and sealing according to SMACNA standards.

- *Fittings.* Designers must ensure that specifications or drawings include provisions for the necessary fittings to enable testing and balancing. Splitters (when allowed and permitted) and balancing dampers must be shown or detailed wherever required. Designers should provide suitable ductwork configurations to enable accurate pitot traverses in main and branch ductwork.

- *Access.* Access openings should be provided where required for system maintenance and inspection. This involves not only suitably framed and gasketed (as required) openings in the duct, but architectural design coordination to ensure that corresponding ceiling access is provided. Duct access doors should be provided at fire and smoke dampers, on both sides of duct-mounted coils,

at humidifiers, and as required by the client or codes to facilitate duct cleaning.

- *Elbows.* Whenever allowed by space conditions, use long-radius elbows to minimize pressure losses and improve performance and cleanliness. "Square" elbows with turning vanes should be avoided, especially in exhaust and return systems, because they collect dust and debris, leading to reduced airflow performance.

- *Flexible ductwork.* Use of flexible ductwork should be limited because of its higher pressure losses, particularly when crimped or coiled, and its greater susceptibility to abuse or damage. Many designers limit flexible duct connections to a maximum length of 5 to 6 ft [1.5 to 1.8 m].

3.5.2 Fully Ducted versus Plenum Returns

Most designers prefer fully ducted return systems in health care facilities, including outpatient clinics, largely because of their inherently superior sanitary characteristics. Some codes mandate fully ducted systems for all inpatient facilities. Ducted returns protect the airstream from direct exposure to such potential plenum conditions as accumulated dust, microbes or odors generated by wet materials (from piping leaks, roof leaks, or floor leaks in multistory facilities); rodent droppings; fibers from deteriorated flame proofing or equipment; and smoke produced by smoldering wiring insulation or other sources during a fire. To minimize the latter possibility, NFPA codes require that electrical cables installed in plenums used for air movement must be of the plenum-rated type. Above-ceiling plenums, in particular, are prone to disturbance by maintenance activities that could release opportunistic fungi or allergens into a return airstream. Ducted returns, in addition, can be designed to minimize "cross-talk" wherein audible conversations are transmitted between rooms via open return connections, particularly when room partitions do not extend above the ceilings. Table 3-3 lists positive or negative pressure relationship requirements for many spaces in a hospital. Without a ducted return system, it is impossible to balance return airflows and maintain these pressure differentials.

3.5.3 Duct Insulation

External duct insulation is considered best practice for the hospital environment as opposed to internally insulated or lined ductwork. Externally insulated ductwork is preferred for reasons of infection control and reduced system static-pressure loss. Reducing system static-pressure loss has become more important with recent energy code updates that place more stringent limits on fan power. If internal insulation is used, the insulation should be covered with polyester film or other material to prevent fibers from entering the airstream. Nonfibrous insulation, such as closed-cell foam or other materials, could also be considered. With externally insulated ductwork, the designer must consider acoustics and use measures other than liner to reduce duct noise. Reducing duct velocities to provide better acoustics, rather than

relying on lined ductwork, will also help with energy code compliance. Exhaust and return ducts above ceilings do not need to be insulated.

3.5.4 Duct Cleaning

Ductwork collects deposits of dust and can become contaminated with microbial colonization. The extent of this problem varies with the level of filtration, HVAC system maintenance, geographic location, climate, and other factors. Some scientific studies have implicated accumulated dust in ductwork with increased occupant health complaints, such as itchy eyes, cough, and allergic reactions (Brosseau et al. 2000). Numerous studies also attribute hospital nosocomial infection outbreaks to microbes growing in ductwork or air-handling equipment. In addition, excessive dust buildup in ducts can result in significantly reduced air system performance, including underventilation. In recent years, large numbers of companies that specialize in ductwork cleaning have emerged, and the National Air Duct Cleaners Association has published guidelines and specifications for this work (NADCA 2006). Cleaning processes require access into the interior of the ductwork and involve placing the duct under a vacuum in combination with mechanical or power brushing, air washing, contact vacuuming, and sometimes steam cleaning. Microbial biocides and encapsulants may also be used. For new construction, requirements for the delivery, storage, and installation of ductwork should be specified. At a minimum, these should include the following:

- Ductwork should be shipped to site adequately covered or wrapped to prevent dust and dirt buildup.
- Ductwork stored on site should be stored in a dry area.
- Stored ductwork should be wrapped or covered to prevent buildup of construction dust and dirt.
- Ductwork should be stored on pallets or other means to keep materials off the floor.
- Once installed, ductwork should be cleaned, wiped, and inspected for dust; completed sections should be sealed with plastic or other means to keep out construction dust.
- Air-handling systems should not be run until filters are in place and construction work is complete to the point that dusty operations (e.g., gypsum board sanding) are no longer occuring.
- If air-handling systems must be operated during construction activities, all return inlets should be covered with filter material to prevent dust from entering the return duct system.

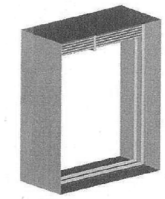
3.5.5 MRI Room Ductwork

All materials in the MRI scan room must be nonferrous. Aluminum ductwork is typically used. The designer must be careful to make sure that not only the ductwork—but all duct components—are of nonferrous construction. Screws and connectors must be aluminum, brass, or other nonferrous metals. The metal helix used in flexible ductwork must be aluminum or other nonferrous metal. All ductwork and into the room must pass through an RF shield. The HVAC engineer must coordinate

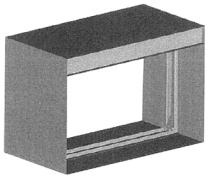
with the magnetic shield designer to determine where duct penetrations will be located and what size ducts are required. MRI machines also require specially constructed and insulated quench vent ducting to the outdoors. Refer to Chapter 8 for additional information on MRI systems.

3.5.6 Fire/Smoke Dampers

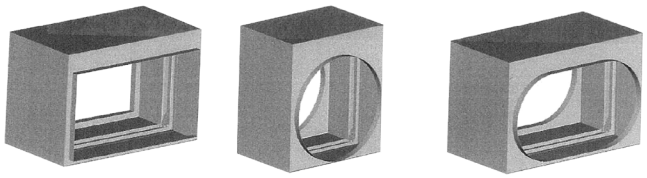
Figure 3-15 illustrates the three types of traditional curtain-style fire dampers. Most hospitals are required to conduct frequent testing of fire and smoke dampers to comply with accrediting agencies. For this reason, the designer should select duct routes that minimize the number of dampers required. Care must be taken to maintain sufficient



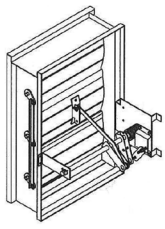
TYPE A FIRE DAMPER
The Type A fire damper is generally used in applications where the blade stack intrusion in the airstream is not a consideration. Typical installations are in a low-pressure system.



TYPE B FIRE DAMPER
The Type B fire damper is generally used where the duct height is nominal and/or where air speed is high enough. It will be beneficial to have the blade stack out of the airstream. Having the blade stack out of the airstream maximizes free area and reduces the pressure drop.



TYPE C FIRE DAMPER
The Type C fire damper is generally used where velocities are medium to high and free area is a consideration. Type C dampers can be ordered with low-pressure or with medium-/high-pressure ratings. The Type C fire damper has a collar (or transition collar) for duct attachment. The collar is available in three configurations: round, square/rectangular, and oval.



MULTIBLADE FIRE DAMPER
Fire damper is reset and closed by spring operator and linkage can be reset from outside of duct. Easier to test and reset but substantially higher pressure drop.

Figure 3-15 *Fire Damper Types*

clearance and access for testing and resetting of dampers. Multiblade dampers are often the easiest type to reset and test, because damper operation is controlled by a spring assembly on the outside of the duct. Unfortunately, multiblade dampers often have significantly higher static-pressure losses. A typical multiblade fire damper assembly and a comparison of pressure loss for various types of fire dampers are shown in Figure 3-16.

3.6 TERMINAL UNITS

3.6.1 Single-Duct Terminal Units

A single-duct terminal unit (Figure 3-17) consists of an air inlet assembly, flow sensor, housing, and a discharge outlet. Typical accessories include a variety of liners, discharge attenuators, access doors, and multiple outlet plenums. Low-profile configurations can be used where plenum space is restricted.

Single-duct terminal units are typically used to provide either a constant air volume or constant discharge pressure. Figure 3-18 shows a common cooling-only control sequence where the zone temperature is controlled by varying the volume of cooling air based upon the thermostat demand.

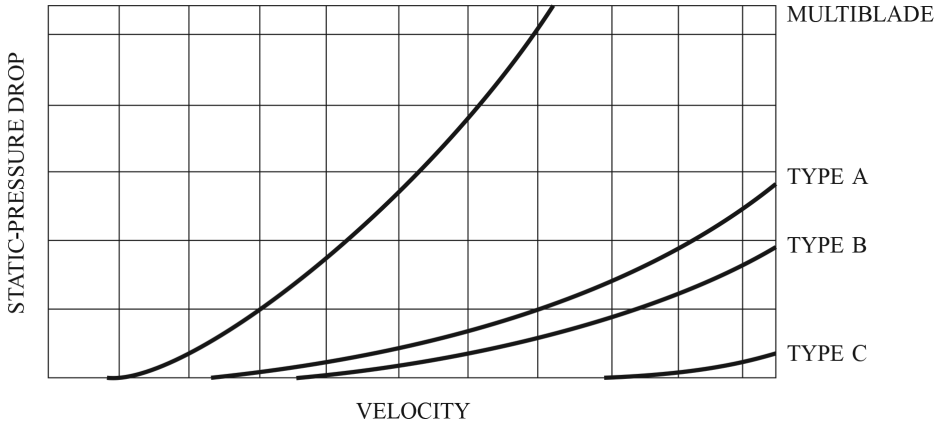


Figure 3-16 *Multiblade Fire Damper and Pressure Loss through Fire Dampers*

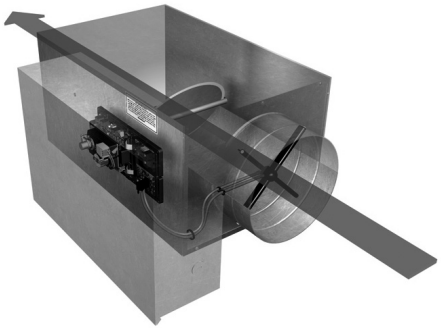


Figure 3-17 *Single-Duct Terminal Unit*
(Courtesy Price Industries)

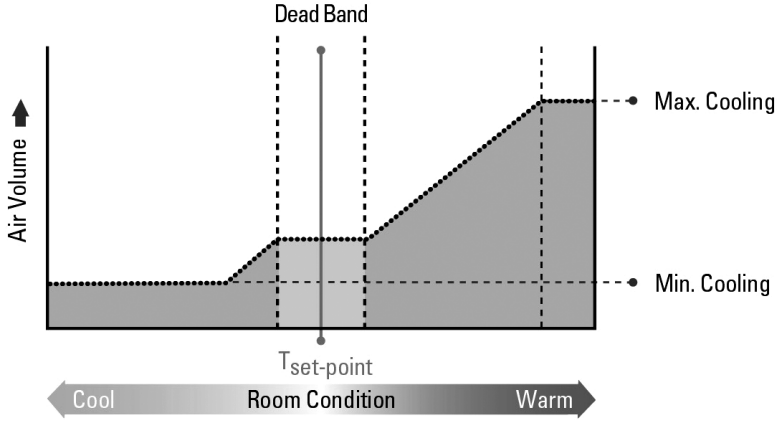


Figure 3-18 *Common Sequence of Operation for Single-Duct Terminal Unit*
(Courtesy Price Industries)

Single-duct terminal units can be used with either hot water or electric reheat coils when required.

3.6.2 Exhaust Single-Duct Terminal Units

A single-duct terminal that is configured to control exhaust air has the same basic components as a standard single-duct terminal; the airflow direction, however, is reversed and there typically is an inlet attenuator section to reduce the sound generation of the valve when it is operating in a less than full-open position. The exhaust single-duct terminal is often used in spaces that require either exhaust air volume control or space pressurization. These units are also used in applications that use a supply-exhaust tracking control scheme.

3.6.3 Dual-Duct Terminal Units

A dual-duct terminal unit (Figure 3-19) has an integral mixing section between the two supply valves and the discharge duct connections. Different levels of mixing performance are available. A standard-mixing unit will provide a uniform discharge temperature profile (±1°F [0.5°C]) at a downstream distance of three equivalent duct diameters from the terminal. A high-mixing-performance unit will provide, at a discharge distance of 6 in. [150 mm], a uniform discharge air temperature profile (±1°F [1°C]).

Dual-duct systems are used in both interior and exterior zones in buildings (such as hospitals) where the use of auxiliary reheat, such as hot-water or electric coils, is not desirable.

Figure 3-20 shows a typical VAV sequence of operation for a dual-duct terminal unit in a single-fan, dual-duct system. In this control scheme, the zone air volume is allowed to vary based on thermostat demand while maintaining a minimum flow to the zone. Other sequences of operation, such as constant-volume-to-the-zone or dual-fan, dual-duct systems, are also possible.

3.6.4 Fan-Powered Terminal Units

The basic series-fan-powered terminal unit (Figure 3-21), some–times referred to as a constant-volume unit, consists of an air inlet assembly (similar to a single-duct unit), a housing, a blower/motor

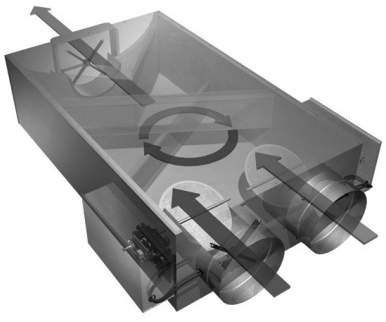


Figure 3-19 *Dual-Duct Terminal Unit (Courtesy Price Industries)*

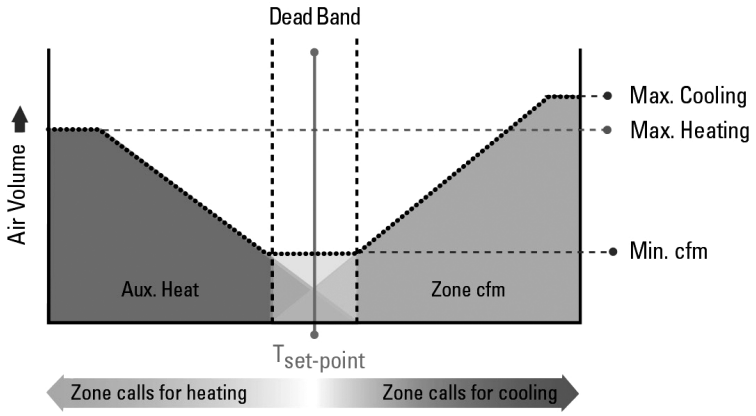


Figure 3-20 *Common Sequence of Operation for Dual-Duct Terminal Unit (Courtesy Price Industries)*

assembly, a return air opening, and a high-voltage connection. All discharge air from the series-fan-powered terminal goes through the blower/motor assembly. The discharge air is a mixture of the supply air from the air inlet assembly and the return air opening. The percentage of supply air and percentage of return/plenum air varies based on the regulation of the supply air inlet valve from room cooling calls by the thermostat. A common sequence of operation is shown in Figure 3-22.

Parallel-Flow Variable-Volume

The basic parallel-fan-powered terminal, sometimes referred to as an intermittent- or variable-volume unit, consists of an air inlet assembly (similar to a single-duct unit), a housing, a blower/motor assembly with backdraft damper, a mixing chamber, a return air opening/plenum opening, and a high-voltage connection.

The discharge air from the parallel-fan-powered terminal is a combination of primary air and plenum air. During cooling operation, the fan is not in operation and only the primary air is discharged. During heating operation, the fan is energized,pumping plenum air into the mixing chamber, where it is mixed with the primary air and then discharged from the unit. Generally, fan-powered boxes are used only with ceiling plenum returns, thus not in patient care areas where pressure relationships are required.

3.7 ROOM AIR DISTRIBUTION

3.7.1 Room Distribution Design Approach

Room airflow rates in the health care environment must be sufficient to meet cooling and heating loads, required air exchange rates, and makeup air requirements. The designer must determine the necessary airflow rates to meet each condition and design for the worst case. A room-by-room airflow summary chart (such as in Table 3-1) should be developed.

3.7.2 Air Exchange Rates and Ventilation

Minimum air exchange rates for the various types of spaces should comply with ANSI/ASHRAE/ASHE Standard 170-2008 (see Table 3-3). This standard lists minimum air exchange rates for both ventilation air

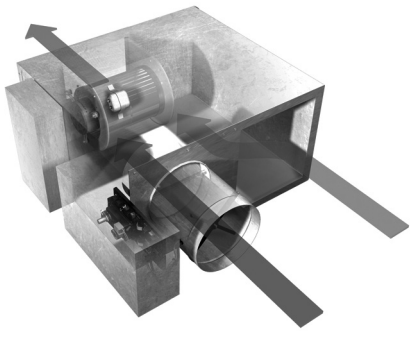


Figure 3-21 *Series-Fan-Powered Terminal Unit*
(Courtesy Price Industries)

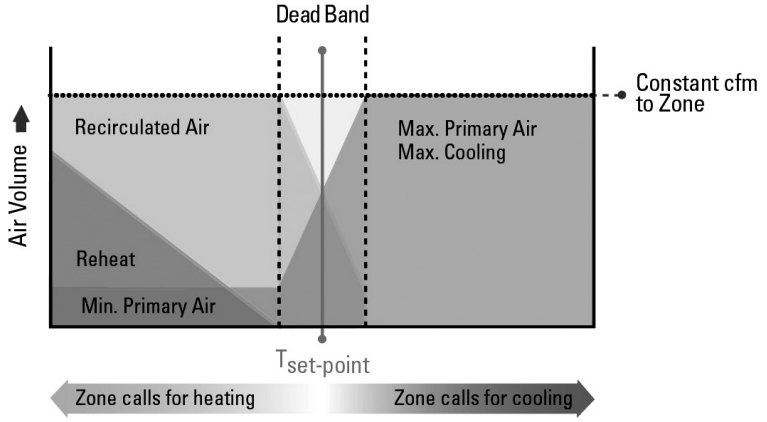


Figure 3-22 *Common Sequence of Operation for Series-Fan-Powered Terminal Unit*
(Courtesy Price Industries)

Table 3-3 *Ventilation Design Parameters*

Function of Space	Pressure Relationship to Adjacent Areas (n)	Minimum Outdoor ACH, ach	Minimum Total ACH, ach	All Room Air Exhausted Directly to Outdoors (j)	Air Recirculated by Means of Room Units (a)	RH (k) (%)	Design Temperature (l), (°F/°C)
SURGERY AND CRITICAL CARE							
Class B and C Operating room, (m),(n) (o)	Positive	4	20	N/R	No	20-60	68-75/20-24
Operating/surgical cystoscopic rooms, (m), (n) (o)	Positive	4	20	N/R	No	20-60	68-75/20-24
Delivery room (Caesarean) (m),(n), (o)	Positive	4	20	N/R	No	20-60	68-75/20-24
Substerile service area	N/R	2	6	N/R	No	N/R	N/R
Recovery room	N/R	2	6	N/R	No	30-60	70-75/21-24
Critical and intensive care	N/R	2	6	N/R	No	30-60	70-75/21-24
Intermediate case (s)	N/R	2	6	N/R	N/R	max 60	70-75/21-24
Wound Intensive Care (Burn Unit)	N/R	2	6	N/R	No	40-60	70-75/21-24
Newborn intensive care	Positive	2	6	N/R	No	30-60	72-78/22-26
Treatment room (p)	N/R	2	6	N/R	N/R	20-60	70-75/21-24
Trauma room (crisis or shock) (c)	Positive	3	15	N/R	No	20-60	70-75/21-24
Medical/Anesthesia gas storage (r)	Negative	N/R	8	Yes	N/R	N/R	N/R
Laser Eye Room	Positive	3	15	N/R	No	20-60	70-75/21-24
ER Waiting Rooms (q)	Negative	2	12	Yes	N/R	max 65	70-75/21-24
Triage (q)	Negative	2	12	Yes	N/R	max 60	70-75/21-24
ER Decontamination	Negative	2	12	Yes	No	N/R	N/R
Radiology waiting rooms (q), (w)	Negative	2	12	Yes	N/R	max 60	70-75/21-24
Class A Operating/Procedure room (o) (d)	Positive	3	15	N/R	No	20-60	70-75/21-24
INPATIENT NURSING							
Patient room (s)	N/R	2	6	N/R	N/R	max 60	70-75/21-24
Toilet room	Negative	N/R	10	Yes	No	N/R	N/R
Newborn nursery suite	N/R	2	6	N/R	No	30-60	72-78/22-26
Protective environment room (t)	Positive	2	12	N/R	No	max 60	70-75/21-24
AII room (u)	Negative	2	12	Yes	No	max 60	70-75/21-24
Combination AII/PE room	Positive	2	12	Yes	No	max 60	70-75/21-24
AII anteroom (u)	(e)	N/R	10	Yes	No	N/R	N/R
PE anteroom (t)	(e)	N/R	10	N/R	No	N/R	N/R
Combination AII/PE anteroom	(e)	N/R	10	Yes	No	N/R	N/R
Labor/delivery/recovery/postpartum (LDRP) (s)	N/R	2	6	N/R	N/R	max 60	70-75/21-24
Labor/delivery/recovery (LDR) (s)	N/R	2	6	N/R	N/R	max 60	70-75/21-24
Patient Corridor	N/R	N/R	2	N/R	N/R	N/R	N/R
Nourishment are or room	N/R	N/R	2	N/R	N/R	N/R	N/R

Table 3-3 *Ventilation Design Parameters*
– continued –

Function of Space	Pressure Relationship to Adjacent Areas (n)	Minimum Outdoor ACH, ach	Minimum Total ACH, ach	All Room Air Exhausted Directly to Outdoors (j)	Air Recirculated by Means of Room Units (a)	RH (k) (%)	Design Temperature (l), (°F/°C)
NURSING FACILITY							
Resident Room	N/R	2	2	N/R	N/R	N/R	70-75/21-24
Resident Gathering/Activity/Dining	N/R	4	4	N/R	N/R	N/R	70-75/21-24
Physical Therapy	Negative	2	6	N/R	N/R	N/R	70-75/21-24
Occupational Therapy	N/R	2	6	N/R	N/R	N/R	70-75/21-24
Bathing Room	Negative	N/R	10	Yes	N/R	N/R	70-75/21-24
RADIOLOGY (v)							
X-ray (diagnostic and treatment)	N/R	2	6	N/R	N/R	max 60	72-78/22-26
X-ray (surgery/critical care and catheterization)	Positive	3	15	N/R	No	max 60	70-75/21-24
Darkroom(g)	Negative	2	10	Yes	No	N/R	N/R
DIAGNOSTIC AND TREATMENT							
Dialysis treatment area	N/R	2	6	N/R	N/R	N/R	72-78/22-26
Dialyzer reprocessing room	Negative	N/R	10	Yes	No	N/R	N/R
Nuclear medicine hot lab	Negative	N/R	6	Yes	No	N/R	70-75/21-24
Nuclear medicine treatment room	Negative	2	6	Yes	N/R	N/R	70-75/21-24
Bronchoscopy, sputum collection, and pentamidine administration (n)	Negative	2	12	Yes	No	N/R	68-73/20-23
Laboratory, general (v)	Negative	2	6	N/R	N/R	N/R	70-75/21-24
Laboratory, bacteriology (v)	Negative	2	6	Yes	N/R	N/R	70-75/21-24
Laboratory , biochemistry (v)	Negative	2	6	Yes	N/R	N/R	70-75/21-24
Laboratory, cytology (v)	Negative	2	6	Yes	N/R	N/R	70-75/21-24
Laboratory, glasswashing	Negative	2	10	Yes	N/R	N/R	N/R
Laboratory, histology (v)	Negative	2	6	Yes	N/R	N/R	70-75/21-24
Laboratory, microbiology (v)	Negative	2	6	Yes	N/R	N/R	70-75/21-24
Laboratory, nuclear medicine (v)	Negative	2	6	Yes	N/R	N/R	70-75/21-24
Laboratory, pathology (v)	Negative	2	6	Yes	N/R	N/R	70-75/21-24
Laboratory, serology (v)	Negative	2	6	Yes	N/R	N/R	70-75/21-24
Laboratory, sterilizing	Negative	2	10	Yes	N/R	N/R	70-75/21-24
Laboratory, media transfer (v)	Positive	2	4	N/R	N/R	N/R	70-75/21-24
Autopsy room (n)	Negative	2	12	Yes	No	N/R	68-75/20-24
Nonrefrigerated body-holding room (h)	Negative	N/R	10	Yes	No	N/R	70-75/21-24
Pharmacy (b)	Positive	2	4	N/R	N/R	N/R	N/R

Table 3-3 *Ventilation Design Parameters*
– continued –

Function of Space	Pressure Relationship to Adjacent Areas (n)	Minimum Outdoor ACH, ach	Minimum Total ACH, ach	All Room Air Exhausted Directly to Outdoors (j)	Air Recirculated by Means of Room Units (a)	RH (k) (%)	Design Temperature (l), (°F/°C)
Examination room	N/R	2	6	N/R	N/R	max 60	70-75/21-24
Medication room	Positive	2	4	N/R	N/R	max 60	70-75/21-24
Gastrointestinal endoscopy procedure room	Positive	2	6	N/R	No	20-60	68-73/20-23
Endoscope Cleaning	Negative	2	10	Yes	No	N/R	N/R
Treatment room	N/R	2	6	N/R	N/R	max 60	70-75/21-24
Hydrotherapy	Negative	2	6	N/R	N/R	N/R	72-80/22-27
Physical therapy	Negative	2	6	N/R	N/R	Max 65	72-80/22-27
STERILIZING							
Sterilizer equipment room	Negative	N/R	10	Yes	No	N/R	N/R
CENTRAL MEDICAL AND SURGICAL SUPPLY							
Soiled or decontamination room	Negative	2	6	Yes	No	N/R	72-78/22-26
Clean workroom	Positive	2	4	N/R	No	max 60	72-78/22-26
Sterile storage	Positive	2	4	N/R	N/R	max 60	72-78/22-26
SERVICE							
Food preparation center (i)	N/R	2	10	N/R	No	N/R	72-78/22-26
Warewashing	Negative	N/R	10	Yes	No	N/R	N/R
Dietary storage	N/R	N/R	2	N/R	No	N/R	72-78/22-26
Laundry, general	Negative	2	10	Yes	No	N/R	N/R
Soiled linen sorting and storage	Negative	N/R	10	Yes	No	N/R	N/R
Clean linen storage	Positive	N/R	2	N/R	N/R	N/R	72-78/22-26
Linen and trash chute room	Negative	N/R	10	Yes	No	N/R	N/R
Bedpan room	Negative	N/R	10	Yes	No	N/R	N/R
Bathroom	Negative	N/R	10	Yes	No	N/R	72-78/22-26
Janitor's closet	Negative	N/R	10	Yes	No	N/R	N/R
SUPPORT SPACE							
Soiled workroom or soiled holding	Negative	2	10	Yes	No	N/R	N/R
Clean workroom or clean holding	Positive	2	4	N/R	N/R	N/R	N/R
Hazardous Material Storage	Negative	2	10	Yes	No	N/R	N/R

Source: Table and following notes adapted from ANSI/ASHRAE/ASHE Standard 170-2008 (ASHRAE 2008), including Addenda a, b, c, d, e, f, g, h, i, j, k, l, m, n, o, p, q, r, s, t, and v.
Note: N/R= no requirement

Notes:

a. Except where indicated by a "No" in this column, recirculating room HVAC units (with heating or cooling coils) are acceptable for providing that portion of the minimum total air changes per hour which is permitted by Section 7.1 (subparagraph 1-e). Because of the cleaning difficulty and the potential for buildup of contamination, recirculating room units shall not be used in areas marked "No". Recirculating devices with HEPA filters shall be permitted in existing facilities as interim, supplemental environmental controls to meet requirements for the control of airborne infectious agents. The design of either portable or fixed systems should prevent stagnation and short circuiting of airflow. The design of such systems shall also allow for easy access for scheduled preventative maintenance and cleaning.

b. Pharmacy compounding areas may have additional air change, differential pressure, and filtering requirements beyond the minimum of this table depending on the type of pharmacy, the regulatory requirements (which may include adoption of USP 797), the associated level of risk of the work (see USP 797), and the equipment utilized in the spaces.

c. The term trauma room as used herein is a first aid room and/or emergency room used for general initial treatment of accident victims. The operating room within the trauma center that is routinely used for emergency surgery is considered to be an operating room by this Standard.

d. Pressure relationships need not be maintained when the room is unoccupied.

e. See Section 7.2 and its subsections for pressure-relationship requirements.

f. This letter is not used in this table.

g. Exception: All air need not be exhausted if darkroom equipment has a scavenging exhaust duct attached and meets ventilation standards regarding NIOSH, OSHA, and local employee exposure limits.2, 3

h. A nonrefrigerated body-holding room is applicable only to facilities that do not perform autopsies on-site and use the space for short periods while waiting for the body to be transferred.

i. Minimum total air changes per hour (ach) shall be that required to provide proper makeup air to kitchen exhaust systems as specified in ANSI/ASHRAE Standard 154.4 In some cases, excess exfiltration or infiltration to or from exit corridors compromises the exit corridor restrictions of NFPA 90A,5 the pressure requirements of NFPA 96,6 or the maximum defined in the table. During operation, a reduction to the number of air changes to any extent required for odor control shall be permitted when the space is not in use. (See AIA [2006] in Informative Annex B: Bibliography.)

j. In some areas with potential contamination and/or odor problems, exhaust air shall be discharged directly to the outdoors and not recirculated to other areas. Individual circumstances may require special consideration for air exhausted to the outdoors. To satisfy exhaust needs, constant replacement air from the outdoors is necessary when the system is in operation.

k. The RH ranges listed are the minimum and/or maximum allowable at any point within the design temperature range required for that space.

l. Systems shall be capable of maintaining the rooms within the range during normal operation. Lower or higher temperature shall be permitted when patients' comfort and/or medical conditions require those conditions.

m. National Institute for Occupational Safety and Health (NIOSH) criteria documents regarding occupational exposure to waste anesthetic gases and vapors, and control of occupational exposure to nitrous oxide7 indicate a need for both local exhaust (scavenging) systems and general ventilation of the areas in which the respective gases are utilized. Refer to NFPA 99.8 for other requirements

n. If pressure monitoring device alarms are installed, allowances shall be made to prevent nuisance alarms. Short term excursions from required pressure relationships shall be allowed while doors are moving or temporarily open. Simple visual methods such as smoke trail, ball-in-tube, or flutterstrip shall be permitted for verification of airflow direction.

o. Surgeons or surgical procedures may require room temperatures, ventilation rates, humidity ranges, and/or air distribution methods that exceed the minimum indicated ranges.

p. Treatment rooms used for bronchoscopy shall be treated as bronchoscopy rooms. Treatment rooms used for procedures with nitrous oxide shall contain provisions for exhausting anesthetic waste gases.

q. In a recirculating ventilation system, HEPA filters shall be permitted instead of exhausting the air from these spaces to the outdoors provided that the return air passes through the HEPA filters before it is introduced into any other spaces. The entire Minimum Total Air Changes per Hour of recirculating airflow shall pass through HEPA filters. When these areas are open to larger, non-waiting spaces, the exhaust air volume shall be calculated based on the seating area of the waiting area. (Informative Note: The intent here is to not require the volume calculation to include a very large space (e.g. an atrium) just because a waiting area opens onto it.)

r. See NFPA 99 for further requirements.8

s. For patient rooms, intermediate care, labor/delivery/recovery rooms, and labor/delivery/recovery/postpartum rooms, four total ach shall be permitted when supplemental heating and/or cooling systems (radiant heating and cooling, baseboard heating, etc.) are used. For single-bed patient rooms using Group D diffusers, a minimum of six total air changes per hour shall be provided and calculated based on the volume from finished floor to 6 ft. (1.83 m) above the floor.

t. The protective environment airflow design specifications protect the patient from common environmental airborne infectious microbes (i.e., Aspergillus spores). Recirculation HEPA filters shall be permitted to increase the equivalent room air exchanges; however, the outdoor air changes are still required. Constant volume airflow is required for consistent ventilation for the protected environment. The pressure relationship to adjacent areas shall remain unchanged if the PE room is utilized as a normal patient room. Rooms with reversible airflow provisions for the purpose of switching between protective environment and AII functions shall not be permitted.

u. The AII room described in this standard shall be used for isolating the airborne spread of infectious diseases, such as measles, varicella, or tuberculosis. Supplemental recirculating devices using HEPA filters shall be permitted in the AII room to increase the equivalent room air exchanges; however, the minimum outdoor air changes of Table 7-1 are still required. AII rooms that are retrofitted from standard patient rooms from which it is impractical to exhaust directly outside may be recirculated with air from the AII room, provided that the air first passes through a HEPA filter. When the AII room is not utilized for airborne infection isolation, the pressure relationship to adjacent areas, when measured with the door closed, shall remain unchanged and the minimum total air change rate shall be 6 ach. Switching controls for reversible airflow provisions shall not be permitted.

v. When required, appropriate hoods and exhaust devices for the removal of noxious gases or chemical vapors shall be provided in accordance with NFPA 99.8

w. This requirement applies only to radiology waiting rooms programmed to hold patients who are waiting for chest x-rays for diagnosis of respiratory disease.

(outdoor air) and total supply air. Some state and local codes may have minimum air exchange rates that differ from the ASHRAE standard. In such instances, the designer should design for the higher value. In some cases, the designer may also have to demonstrate compliance with ANSI/ASHRAE Standard 62.1. Under this scenario, the designer must evaluate the outdoor air requirements for both standards and use the higher of the two requirements.

3.7.3 Supply Air Diffusers

The proper selection of air outlets is important to efficient space comfort conditioning. A wide range of supply air outlets are suitable for use in health care facilities. These range from square cone or square plaque diffusers for use in less-critical areas to radial flow and laminar diffusers for more-critical spaces. Patients can be especially sensitive to cool air currents from a supply diffuser; this requires care on the part of the designer in diffuser placement relative to the bed or care area. The designer may want to consider diffusers with adjustable patterns to allow field adjustments when performance issues arise. Figure 3-23 shows an example of an adjustable-pattern supply diffuser.

Ease of cleaning and sterilizing of all surfaces of the outlet is an important consideration when selecting supply air outlets, in addition to sound, pressure drop, and throw distance. Operating rooms, procedure rooms, pharmacy compounding cleanrooms, and other specialized clean areas (such as protective isolation rooms) may require low-velocity, laminar-flow supply diffusers. The construction of a laminar-flow supply diffuser is shown in Figure 3-24. These diffuser types are also available with integral high-efficiency filters.

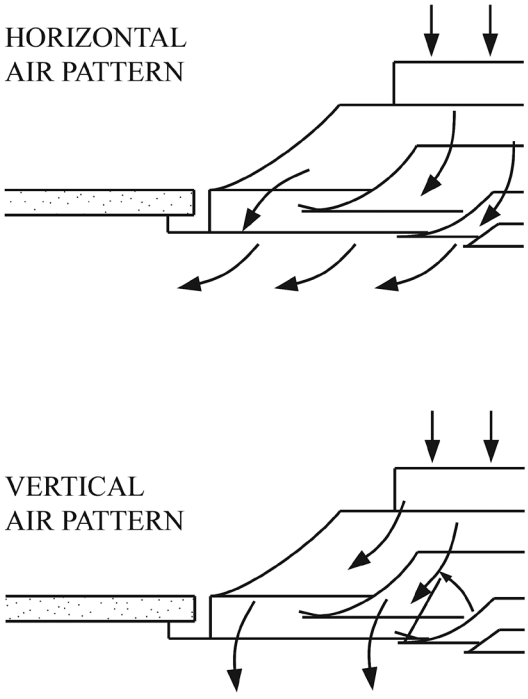


Figure 3-23 *Adjustable-Pattern Supply Diffuser*

3.7.4 Return and Exhaust Air Grilles

Return and exhaust air inlets have very little effect on room air diffusion, regardless of inlet type or location. Return air inlets, however, should be located a sufficient distance from the supply outlet so that short-circuiting of supply air does not occur. Depending upon the type of room, the return and exhaust inlets may be located high or low in the room, or perhaps a combination of the two. See Chapter 20, Space Air Diffusion, of the *ASHRAE Handbook—Fundamentals* (ASHRAE 2009a) as well as manufacturers' guidelines for more information on return and exhaust air inlet selection and location.

3.7.5 MRI Room Air Distribution

Because of the strong magnetic fields present in MRI rooms, all ductwork and air distribution components must be completely free of ferrous metals. Aluminum is often the material of choice. Designers must also make sure that fasteners and other components are nonferrous. A standard aluminum supply grille or return grille, for example, may contain steel screws or rivets. Many manufacturers offer products specifically designed for the MRI environment that are completely free of ferrous metals. Ductwork penetrations through the specially shielded walls or ceiling of the MRI imaging room must pass through a special RF filter. The HVAC designer should consult with the room-shielding designer to coordinate such penetrations.

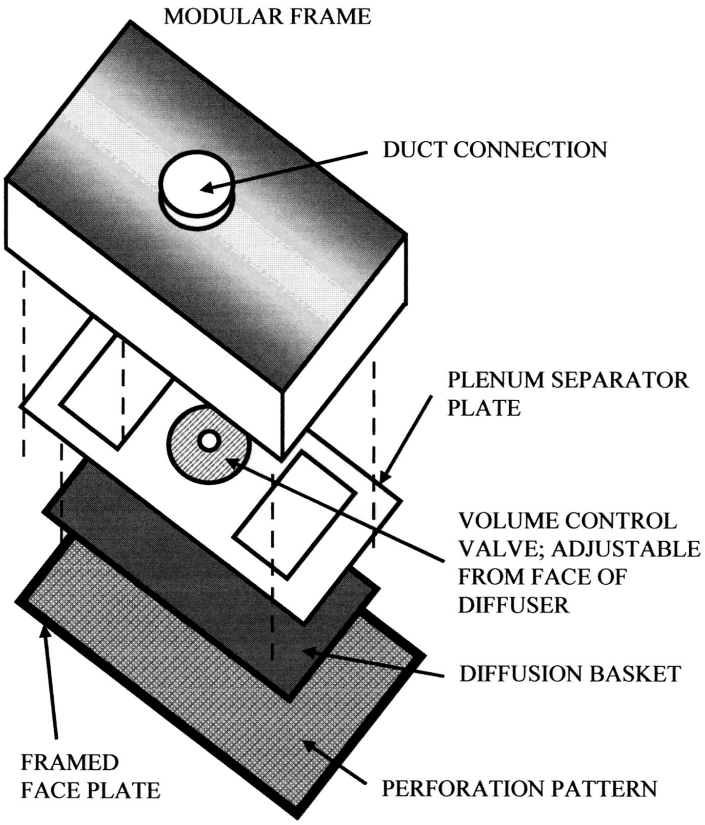


Figure 3-24 *Laminar-Flow Supply Diffuser*

3.8 DEHUMIDIFICATION

3.8.1 The Standard Cooling Cycle

Figure 3-25 illustrates the psychrometrics of a standard cooling cycle. Return air is mixed with outdoor air, which yields the mixed air condition. Mixed air is cooled to the supply air temperature, typically 50°F to 55°F [10.0°C to 12.8°C]. As the air is cooled below the dew point of the entering mixed-air condition, the excess water vapor condenses; thus, dehumidification or latent cooling occurs in addition to sensible cooling. The supply air to the room must have a dew point below the room dew-point temperature to offset latent loads in the room. For most spaces with temperatures in the 70°F to 75°F [21.1°C to 23.9°C] range, moderate-to-low internal latent loads, and 50% to 60% rh requirements—this standard cooling cycle provides sufficient dehumidification. In the example shown in Figure 3-25, the room condition is 72°F [22.2°C] db and 50% rh, with a dew point of approximately 52°F [11.1°C]; thus, 50°F [10.0°C] supply air is sufficient to condition this space as long as internal latent loads are moderate.

Spaces requiring conditions with very low dew points and/or high internal latent loads can be more challenging. Such spaces may require less-traditional systems to provide the necessary dehumidification. These are discussed in the following sections and Chapter 8.

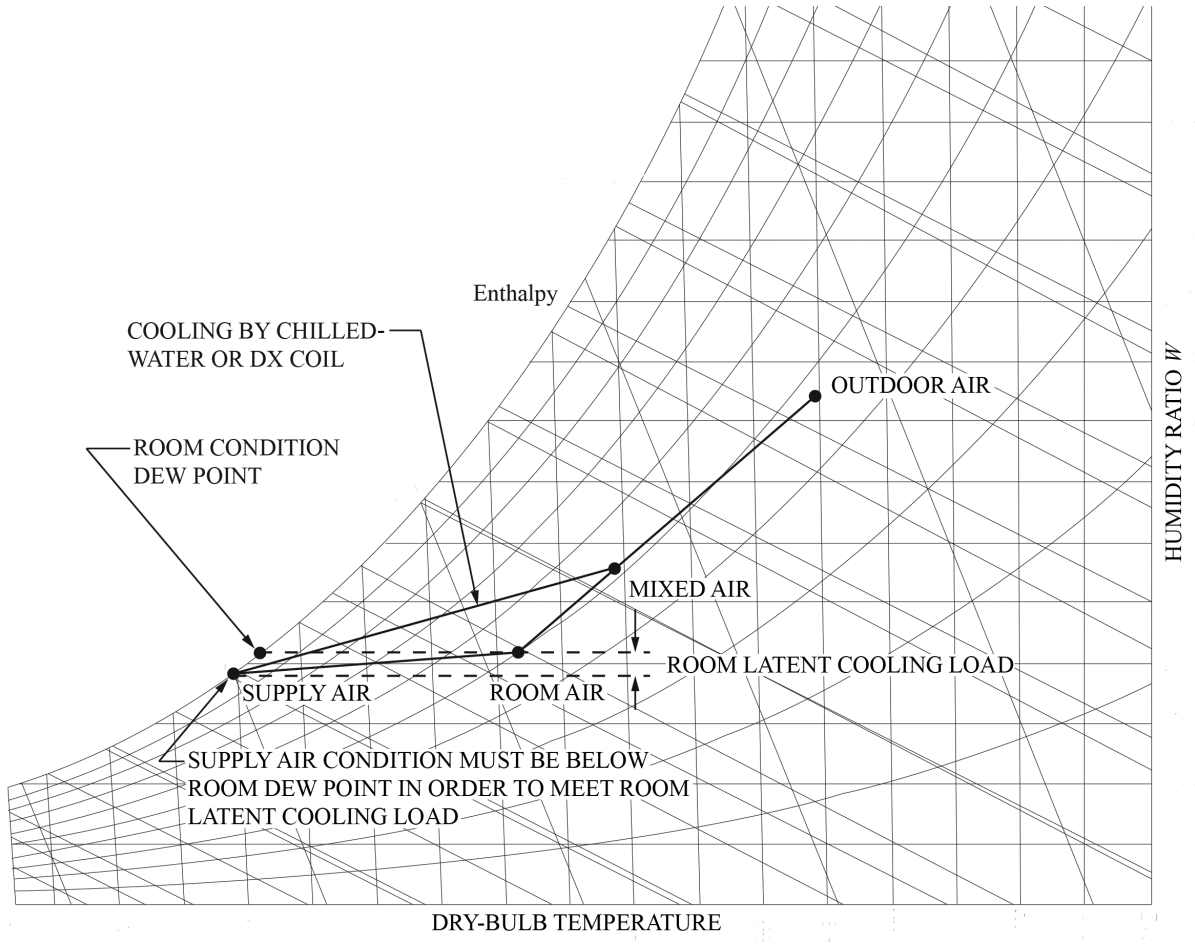


Figure 3-25 *Psychrometrics of Standard Cooling Cycle*

3.8.2 Psychrometric Analysis and Dew Point

Selected areas of a hospital require room temperatures lower than the typical design values. If relative humidity in these spaces is to be maintained at levels not exceeding 50% to 60% rh, the resulting dew point can be very low. It may not be possible to produce supply air temperatures below this dew point with a chilled-water coil using typical chilled water supplied at 42°F to 44°F [5.6°C to 6.7°C]. Design of such spaces requires a thorough psychrometric analysis to determine if the space requirements are achievable with a traditional cooling system or if a specialized system is required. Such specialized systems may introduce more project cost and complexity; therefore, this should be explored early in the design process.

Areas requiring low temperatures and/or low relative humidity may include (but are not limited to) operating rooms, procedure rooms, pharmacy compounding, autopsy rooms, sterile processing rooms, and computer rooms. Some of the most challenging conditions are often in the operating room. Surgeons and staff often request temperatures and relative humidities that are significantly below ANSI/ASHRAE/ASHE Standard 170-2008 design values.

Figure 3-26 shows the dew-point temperature for several different room conditions. Remember that the dew point of the supply air to these spaces must be below the room dew-point temperature. A room condition of 75°F [23.9°C] db and 50% rh (point A) has a dew point (point B) of 55.1°F [12.8°C], which could easily be accomplished with 50°F to 52°F (10.0°C to 11.1°C) supply air. Room conditions of 70°F [21.1°C] db and 50% rh (point C) or 65°F [18.3°C] db and 60% rh (point F) have a dew point (point E) of 50.5°F [10.3°C]. Assuming supply air near saturation, this would require supply air of less than 50°F [10.0°C]. With proper coil selection and/or lower chilled-water temperatures, such as 41°F to 42°F [5.0°C to 5.6°C], this is still achievable with traditional systems. The other room conditions noted on Figure 3-26 illustrate more extreme conditions and demand supply air dew points below the space dew points of 45.9°F [7.7°C] and 41.3°F [5.2°C], respectively. Such conditions require specialized systems such as those discussed in the following sections. Point D is 65°F [18.3°C] and 60% rh; Point G is 65°F [18.3°C] and 60% rh; Point H is 45.9°F [7.7°C] dew point; Point I is 60°F [15.6°C] and 50% rh; Point J is 55°F [12.7°C] and 60% rh; and Point K is 41.3°F [5.2°C] dew point.

3.8.3 Conventional Systems

As noted earlier, a conventional system with chilled-water coils can achieve some of the moderately low dew point conditions. By lowering chilled-water supply temperatures to 41°F to 42°F [5.0°C to 5.6°C] and selecting coils for close approach, supply air temperatures as low as 46°F to 48°F [7.8°C to 8.9°C] can be achieved with room dew points as low as 47°F to 49°F [8.3°C to 9.4°C].

Achieving such a close coil temperature approach requires more rows and fins and maintaining higher coil water velocities (lower ΔT), which increases energy use because of increased fan and pumping

energy requirements. Lowering chilled-water temperature also reduces chiller efficiency and increases heat gains to piping systems. However, pumping energy may be lower. Therefore, before considering more costly and complex add-ons, lower the chilled-water temperature as far as possible and determine if conditions can be met.

3.8.4 Secondary Glycol Chiller

Figure 3-27 shows how a secondary glycol chiller can be used for low-dew-point applications. A dedicated chiller and pump are provided for AHUs supplying areas with low dew-point requirements. By using a glycol mix in the secondary chiller, AHU coil, and piping, the chilled-water supply temperature can be lowered to 32°F [0°C] and even lower. The designer will need to coordinate with the chiller manufacturer to determine what conditions are possible. This will allow the AHU coil to produce extremely low supply air temperatures.

The traditional chilled-water system can be used to cool the condenser of a secondary, water-cooled chiller. This allows the secondary chiller to be installed in an internal mechanical room near the AHU and eliminates the need for a cooling tower. This also provides lower condenser water temperatures to the secondary glycol chiller, which

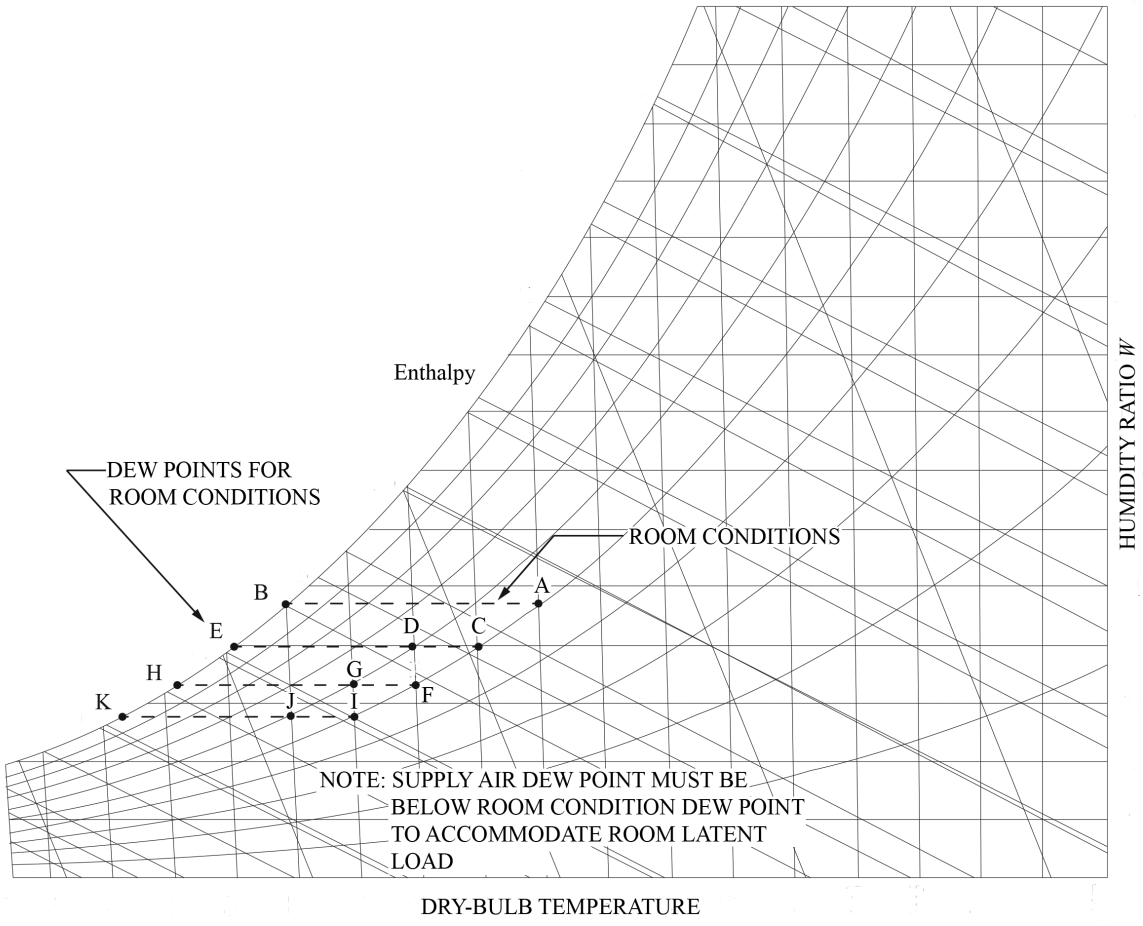


Figure 3-26 *Psychrometric Chart Showing Dew Point Requirements*

may be required for it to operate at such low chilled-water supply temperatures. Again, the designer will need to consult with the chiller manufacturer to determine the necessary operating conditions. A mixing valve arrangement (as indicated in Figure 3-28) can be used to provide the correct condensing water temperature.

3.8.5 Multistage DX Dehumidifiers

Figure 3-28 shows a schematic diagram of a DX dehumidifier system. Such systems typically utilize multistage refrigerant compressors capable of producing lower evaporator coil temperatures. After the air passes through the low-temperature evaporator and is dehumidified, the condenser coil provides reheat to replace some of the sensible heat that was removed. Refrigerant can be diverted from the reheat coil condenser to an auxiliary condenser when room sensible cooling requirements increase. The auxiliary condenser may be a self-contained, air-cooled unit or a water-cooled heat exchanger cooled by the facility's chilled-water system.

3.8.6 Desiccant Systems

Figure 3-29 shows a schematic diagram for a desiccant system. A desiccant dehumidification wheel is used to adsorb moisture from the air that is to be supplied to the space. To continue this process, the

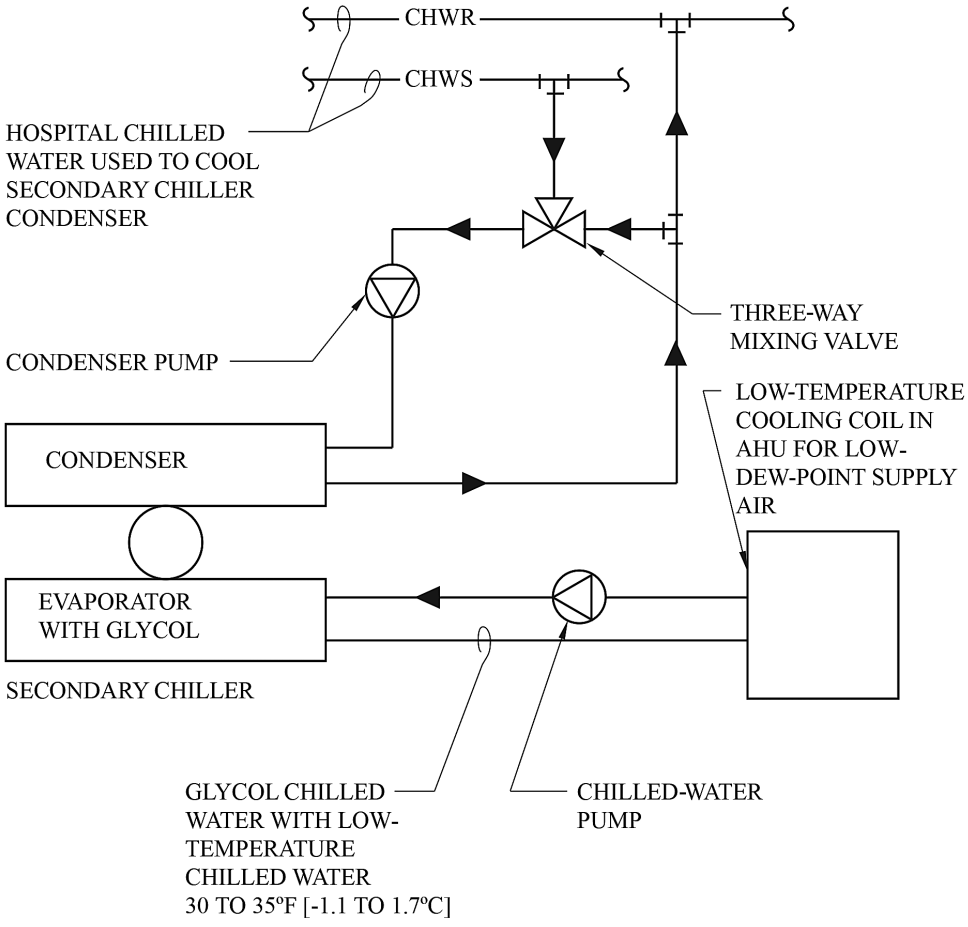


Figure 3-27 *Secondary Glycol Chiller for Low-Dew-Point Systems*

desiccant wheel must be continually regenerated (dried), so that the supply air side of the wheel will continue to absorb moisture. The temperature required to drive this regeneration process depends upon the type of desiccant used on the wheel. In some cases, the air is heated before entering the regeneration side of the wheel. A byproduct of this adsorption process is sensible heat that is transferred to the supply air. Depending on the process, cooling in the form of a chilled-water or DX coil may be needed to remove this unwanted sensible heat and cool the supply air back to the desired temperature.

The psychrometrics of this process are shown in Figure 3-30. Desiccant systems can achieve extremely low dew points (less than 25°F [–3.9°C]). Note that achieving such low dew points remains an energy-intensive process. To reach the very low dew points, heat likely must be added to the regeneration air, and excess sensible heat must be removed from the supply air. This can result in high summer steam (or other heat source) loads and extremely high chilled-water or other cooling-source loads. Before selecting such a system, the designer should consider this additional load and determine if that will be feasible.

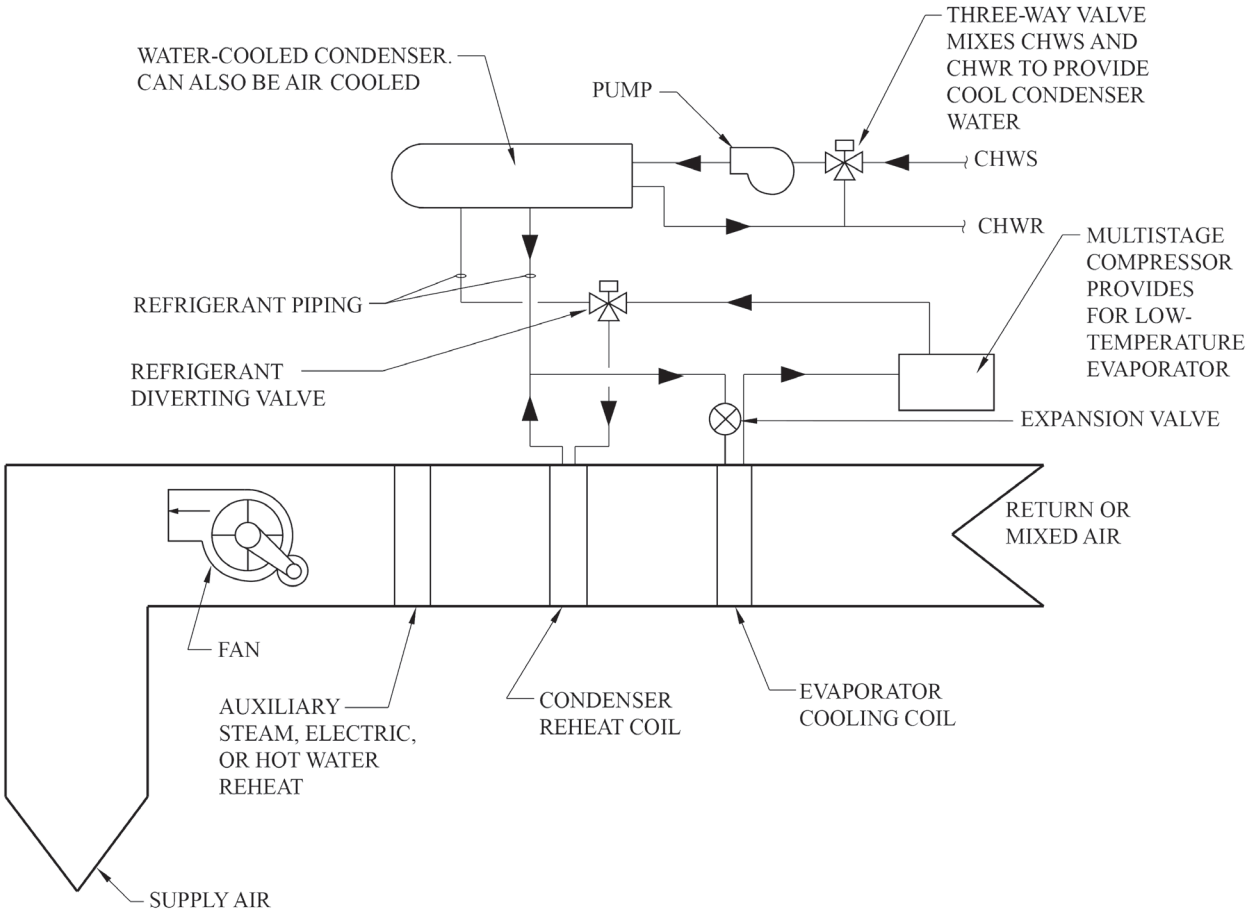


Figure 3-28 *DX Dehumidifier*

There are concerns regarding air leakage (exhaust to supply) and cross contamination with energy wheels. This should be discussed with the infection control department.

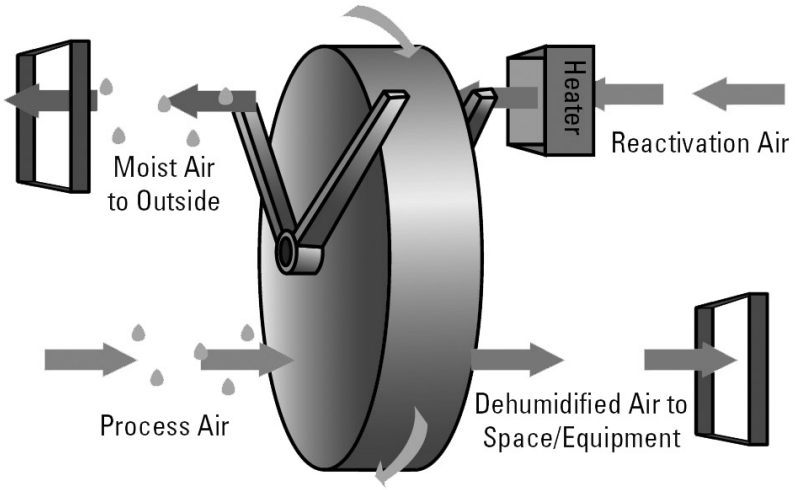


Figure 3-29 *Desiccant Systems*
(Courtesy Price Industries)

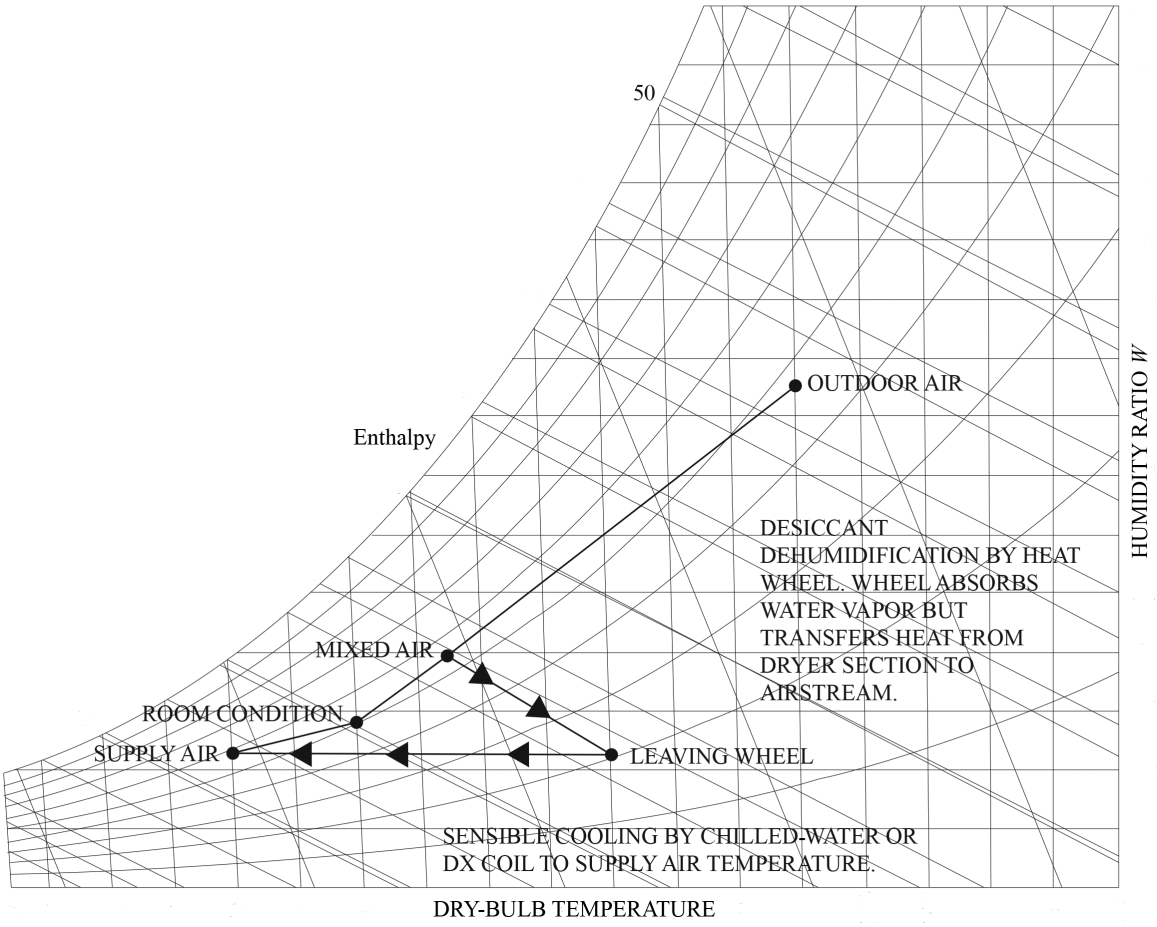


Figure 3-30 *Desiccant System Psychrometrics*

Other desiccant system configurations are able to achieve relatively low dew points without the need for high-temperature regeneration heat (Murphy 2006). These systems can be well suited for various spaces in health care facilities that require lower supply air dew points, but not so low as to require high-temperature regeneration heat.

REFERENCES

AHRI. 2009. *Central station air handling units.* ANSI/AHRI Standard 430-2009. Arlington, VA: Air-Conditioning, Heating, and Refrigeration Institute.

AMCA. 2011. *Fans and systems.* AMCA Publication 201-02 (R2011). Arlington Heights, IL: Air Movement and Control Association International.

ASHRAE. 2003. *Ventilation for commercial cooking operations.* ANSI/ASHRAE Standard 154-2003. Atlanta: ASHRAE.

ASHRAE. 2008. *Ventilation of health care facilities.* ANSI/ASHRAE/ASHE Standard 170-2008. Atlanta: ASHRAE.

ASHRAE. 2009a. Chapter 20, Space air diffusion. *ASHRAE Handbook—Fundamentals.* Atlanta: ASHRAE.

ASHRAE. 2009b. Chapter 21, Duct design. *ASHRAE Handbook—Fundamentals.* Atlanta: ASHRAE.

ASHRAE. 2009c. Chapter 24, Airflow around buildings. *ASHRAE Handbook—Fundamentals.* Atlanta: ASHRAE.

ASHRAE. 2011a. Chapter 45, Building air intake and exhaust design. *ASHRAE Handbook—HVAC applications.* Atlanta: ASHRAE.

ASHRAE. 2011b. Chapter 48, Noise and vibration control. *ASHRAE Handbook—HVAC Applications.* Atlanta: ASHRAE.

ASHRAE. 2012. Chapter 21, Fans. *ASHRAE Handbook—HVAC Systems and Equipment.* Atlanta: ASHRAE.

Brosseau, L.M., D. Vesley, T.H. Kuehn, J. Melson, and H.S. Han. 2000. Methods and criteria for cleaning contaminated ducts and air-handling equipment (RP-759). *ASHRAE Transactions* 106(1):188–99.

FGI. 2010. *Guidelines for design and construction of health care facilities.* Dallas, TX: Facility Guidelines Institute.

Murphy, J. 2006. Temperature & humidity control in surgery rooms. *ASHRAE Journal* 48(6).

NADCA. 2006. *ACR 2006: Assessment, cleaning and restoration of HVAC systems.* Washington, DC: National Air Duct Cleaners Association.

NFPA. 2012. *NFPA 90A: Standard for the installation of air-conditioning and ventilating systems.* Quincy, MA: National Fire Protection Association.

NFPA. 2011. *NFPA 96: Standard for ventilation control and fire protection of commercial cooking operations.* Quincy, MA: National Fire Protection Association.

NFPA. 2005. *NFPA 99: Standard for health care facilities.* Quincy, MA: National Fire Protection Association.

NIOSH. 2012. Criteria Documents. Atlanta: National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention. Available at http://www.cdc.gov/niosh/pubs/criteria_date_desc_nopubnumbers.html

NIOSH. 1994. Controlling exposures to nitrous oxide during anesthetic administration. Publication 94-100 (NIOSH Alert). Atlanta: National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.

OSHA. 1994. Computerized information system. Washington, DC: Occupational Safety and Health Administration, U.S. Department of Labor.

Page, S. 2011. System effect: To believe it is to see it. *ASHRAE Journal* 53(6).

CHAPTER 4

UTILITIES

4.1 INTRODUCTION

Central utility plants for health care facilities can offer economic and maintenance advantages over decentralized systems and represent a significant first-cost investment by the owner. Health care facility utility plants can include cooling, heating, sterilization, humidification, emergency generation, medical gases, and domestic water services. Most hospital (institutional) health care facilities have one or more central plants, while smaller clinics generally have decentralized packaged equipment with one or two central utilities for building heating or domestic water. This chapter focuses on the HVAC&R aspects of central utility plants and the design considerations specific to health care facilities. The chapter is organized into four subsections discussing the following topics:

- General considerations
- Central cooling plants
- Central heating plants
- Other utilities

4.2 GENERAL CONSIDERATIONS

In general, owners of health care facilities tend to prefer equipment that is reliable, is easily accessible/serviceable, and has a low cost of maintenance. General considerations that should be evaluated early in a project to provide a central utility plant design that meets the needs of the owner include

- location,
- on-site backup emergency operation,
- redundancy,
- service and maintenance,
- seismic restraints, and
- future capacity and expansion.

4.2.1 Location

Location of the central utility plant in a health care facility has many impacts on the long-term cost and flexibility of the facility and represents a critical design decision. For a more general discussion of central cooling and heating plants, refer to Chapter 3 of the 2012 *ASHRAE Handbook—HVAC Systems and Equipment.* The most important of the numerous considerations for locating a central utility plant are

- location relative to other physical elements,
- vibration and acoustics,
- aesthetic considerations,
- equipment maintenance and replacement, and
- future expansion.

Centralized mechanical equipment offers many benefits over decentralized systems: greater opportunity for higher energy efficiency, taking advantage of diversity, reduced maintenance, and equipment redundancy. Locating centralized equipment close to and equidistant from the primary loads served by the equipment reduces the system's first cost by minimizing distribution piping and improves energy efficiency by reducing energy for fluid circulation. Despite these obvious advantages, the core of a hospital may not be the ideal location for central utility plant equipment because of considerations such as stack exhaust and cooling tower plumes that may negatively affect patient care.

Cooling towers, generators, and air-cooled condensers/chillers can impact the visual aesthetic of a facility and the patient atmosphere if equipment is located in sight of patient windows. Byproducts of heating and cooling processes, such as cooling tower plumes or boiler flue exhaust, may also negatively impact patient views. In addition to aesthetic concerns for patients, consider the impact to adjacent property and local code constraints, which may preclude locating equipment adjacent to roadways, along property lines, or adjacent to residential areas.

Central-plant equipment (generators, cooling towers, chillers, etc.) located near the core of a health care facility may create unacceptable noise and vibration that negatively affect the patient experience, health care workers, or medical equipment. Vibrations from central equipment can impact the reliability of laboratory, imaging, and other sensitive medical equipment located near a central plant. Acousticians may need to determine what mitigation is necessary to make central-plant equipment proposed for a given location acoustically acceptable to the owner. The design process should include a review of the impacts on adjacent property, which may preclude equipment locations near the property line and roadways.

Indoor air quality can be negatively impacted by central utility equipment (e.g., generator engine exhaust, vacuum exhaust, boiler flue

exhaust, etc.). Cooling towers have been linked to the outbreak of some airborne diseases, such as legionellosis. Distances from outdoor air intakes to contaminant sources will likely need to exceed code minimums to ensure that poor quality air does not enter the intakes. It may even be necessary to study and/or model the effects of wind currents on exhaust plumes in relation to outdoor air intakes. Models will clarify the probability of recirculation, but the designer should remember that, over time, a wide variety of wind patterns will occur.

Central utility plants located at the core of a health care facility may also negatively affect the owner's ability to maintain or replace equipment. Consider the path that will be available to bring large equipment to and from the central plant. Easily removable wall or roof openings may be needed, along with access for cranes and other heavy equipment. Mechanical space built above grade level should have adequate elevator access for large equipment maintenance and replacement. A fully accessible stairway to the roof is desirable for roof-mounted equipment and should be provided when feasible. Ship ladders and roof hatches for access cost less in the short term, but are bound to result in additional long-term operating expense. Central plants located near core services may not be accessible for large equipment moves except during evenings or at night when patient volumes are lighter. To minimize patient disruption, central plants should ideally not be located near spaces that have consistent around-the-clock operation, such as emergency centers and patient rooms.

Future expansion of the central plant should be considered and understood by the engineer when sizing equipment, distribution piping, and equipment rooms, and should be documented for future reference. It is important to have enough space in or around equipment rooms to allow for the replacement of existing equipment while it is still in operation and for the addition of future equipment to accommodate expansion. In new buildings, central plants located near core areas may require additional floor-to-floor height because of large distribution piping and a need to maintain desirable ceiling heights. In consideration of the many factors that go into locating a central plant, many owners have decided to locate central plants on the perimeter of, or even slightly removed from, the primary health care facility. Such a location may provide increased flexibility in lieu of the lower energy distribution costs that occur with a more central location.

4.2.2 On-Site Backup Emergency Operation

The need to operate many health care facilities during prolonged power outages makes the selection of equipment and fuel sources a critical element of the design process. The fuel options available for central utility plants include electrically driven equipment, fossil-fuel-driven equipment, a combination of the two, or steam or chilled-water utilities that are available from a third party. Fossil-fuel-driven equipment can use direct-fired or steam absorption chillers, hot water and steam boilers, or engine-driven equipment such as generators and, less commonly, chillers and pumps. When multiple fuel sources are available,

discussions should take place to determine which sources are the most reliable. Dual-fuel boilers are discussed later in this chapter.

Because of the need to operate health care facilities during emergency situations, many health care facility central plants include the ability to provide heating and cooling to all or part of the building, even with the loss of utility services. Coordination with the owner and review of local building codes are necessary to establish what equipment must be available for operation using on-site fuel sources and the duration (typically 96 hours) of operation. Equipment selection may affect fuel choice decision making. The recent implementation of high-efficiency condensing hot-water equipment typically limits fuel choices to natural gas or propane in lieu of oil-fired boilers, although a handful of manufacturers are beginning to offer gas and fuel oil options with high-efficiency boilers. In some cases, the availability of a fuel or the cost of bringing a fuel onto the site may determine the best alternative.

Design consideration should be given to providing an on-site or backup source of water during emergency situations. Cooling towers, humidifiers and sterilization will not be able to operate if water service is lost. Cooling coil condensate recovery systems can be used during normal operation and may reduce the on-site makeup water requirements during emergency operations.

4.2.3 Redundancy

Continuous operation of the facility and the critical functions of the cooling and heating plants suggest that redundant equipment should be considered during design, and is required by ANSI/ASHRAE/ASHE Standard 170-2008. Providing key equipment in multiple, parallel configurations allows for unexpected extended maintenance on the equipment or replacement of major components during peak seasonal loads without impacting patient care and facility operation. The preferred level of redundant equipment provides sufficient standby equipment to meet peak loads after the failure of any single chiller, cooling tower, boiler, steam-to-hot-water convertor, pump, or critical steam trap in the plant; this is often referred to as N+1. Additional connections can be provided to allow for the use of temporary equipment (e.g., chillers, cooling towers, boilers, etc.) to accommodate the replacement of existing equipment or equipment failure.

A heating plant that is not fully redundant should include a minimum of two boilers, each sized (at a minimum) to serve half of the full load but not less than the heating requirements in critical care areas, patient rooms, and other critical areas of the building. Many types of health care facilities are required by code or accreditation to provide backup heat for all patient care areas. When redundant boilers are not provided, auxiliary equipment, such as pumps, traps, and convertors, can still be cost-effectively provided with backup equipment to reduce the number of potential failure points in the heating plant.

While redundancy in cooling systems is preferred, there are health care facilities that cannot (or elect not to) provide backup central cooling systems. When a plant is not fully redundant, it is desirable for the central cooling system to include a minimum of two chillers. With water-cooled equipment, the associated cooling towers should each be sized to serve at least half of the full load. Auxiliary cooling equipment such as pumps can be provided with backup as a cost-effective way to reduce the number of failure points in the cooling plant.

In a system without backup equipment, the owner should have an operational plan in place to shed heating and cooling load as necessary. At a minimum, the plan should provide heating to the critical care areas, operating rooms, patient rooms, and other critical areas of the building and reduce the quantity of heat provided to less critical areas, such as administration, when even the largest piece of equipment is down for maintenance. The facility plan and equipment sizing should allow for a safety factor to provide freeze protection to areas of the building that do not receive full heating as well as a pickup factor to bring cold areas of the building back up to temperature when full heating capacity is restored to the system. The engineer should provide guidance to the owner in developing a plan (e.g., not maintaining a hot standby boiler) that maximizes heating plant operation under reduced-capacity conditions. If a facility plan exists, it is important for the design engineer to understand and update the plan while implementing new design work.

4.2.4 Service and Maintenance

Proper space planning for a central utility plant is an important element of design typically lead by the HVAC designer. At the beginning of a project, determine the amount of space required for heating and cooling plants, and also provide adequate space for incoming water and fire suppression services, fire pumps, backflow preventers, air compressors, and vacuum systems. Manufacturer-recommended clearances around and above the equipment should be maintained, and space allocated for tube-pull clearances, motor removal, and other maintenance requirements. Space layout and access to all equipment must be planned to provide life-safety-code-required means of egress through equipment rooms, and to permit rapid repair or replacement of equipment. Adequate isolation valves should be provided to allow continued functioning of the facility while equipment is down for servicing and replacement.

The more limited the access space, the less likely it is that equipment will be properly maintained. Maintenance for boilers, chillers, and other large equipment can be relatively time intensive, sometimes requiring a single unit to be out of service for a lengthy period of time (as compared to the maintenance requirements for support equipment such as pumps). The essential nature of the services provided by general hospital facilities often means that owners and certain codes and accreditation organizations require redundant or backup equipment be provided that will allow for the continued operation of the facility

during maintenance or repair of equipment. The utility plant design should also consider the ability of the facility operating and maintenance personnel. Minor maintenance and adjustment of small equipment may be possible using the hospital facility staff; however, maintenance of major equipment like boilers and chillers will often require a contract with an outside service company.

4.2.5 Seismic Restraint

Many health care facilities serve a critical societal function following earthquakes and other natural disasters. Health care facility designs may need to incorporate seismic restraints that allow for the continued operation of the facility following a seismic event. Depending on location and soil conditions, most building codes require health care facilities to include seismic restraints for their mechanical and electrical equipment. Large central-plant equipment (boilers, chillers, and cooling towers) may also need to be seismically certified. Seismic restraint requirements for central-plant equipment may affect the space planning of mechanical rooms because larger seismic pads may be required and additional space for pipe restraints may need to be provided. Refer to Chapter 13 for additional information concerning seismic design requirements and considerations. Designers are also encouraged to review the SMACNA *Seismic Restraint Manual: Guidelines for Mechanical Systems,* ASHRAE's *Practical Guide to Seismic Restraint*, and Chapter 55 of the 2011 *ASHRAE Handbook—HVAC Applications,* as well as other ASHRAE books and resources on the subject.

4.2.6 Future Capacity and Expansion

Health care facilities regularly undergo small and major renovations that continuously affect the operation of their utility plants. When designing a new health care facility, or a major upgrade of the utility plant at an existing facility, it is important to understand the expected growth plans for the facility so that adequate future capacity can be integrated into the design. During small renovations, central systems are expected to handle small additional loads without having to add capacity. Therefore, when central-plant equipment is designed, it is often slightly oversized relative to the current load. Consider designating mechanical room space for the installation of one or more future boilers, chillers, pumps, and other major equipment. Distribution piping should also be sized to account for future loads and include valve connections for future equipment to minimize shutdowns when new equipment is installed.

4.3 CENTRAL COOLING PLANTS

Central cooling plants represent a significant initial investment for health care facilities, along with continued maintenance and energy costs. Most health care facilities require some level of cooling year-round that must be accounted for in the design and selection of equipment. This section includes discussion of the following topics:

- General considerations
- Optimizing cooling plant efficiency
- Cooling under emergency power

4.3.1 General Considerations

Central cooling plants for health care facilities involve several design considerations beyond those of the typical central-plant design. For general discussions of central cooling plant design, see Chapter 3 of the 2012 *ASHRAE Handbook—HVAC Systems and Equipment* or other resources.

Refrigeration

The life safety dangers of refrigerants are generally understood by HVAC engineers. In a health care environment, the patient population is particularly vulnerable to the risks associated with refrigerant leaks. Designers should review the requirements of ANSI/ASHRAE Standard 15-2010, *Safety Standard for Refrigeration Systems,* regarding protec–tion of building occupants from refrigerant leaks.

Control and Instrumentation

Due to the initial cost investment and continuous intensive energy use, modern central cooling plants are typically controlled electronically by direct digital control (DDC) systems to allow for continuous monitoring and optimization of energy usage. Most modern DDC systems are based upon an open control protocol such as BACnet or LONWorks. The engineer should work with the owner to determine the level of control and monitoring instrumentation to include in the project and that will fit the budget. If included as an initial part of the project, energy efficiency and monitoring can be provided to the owner without significantly increasing the cost of the central plant and can improve plant operations in a cost-effective manner. Providing a flow meter in the chilled-water piping loop and using monitored chilled-water supply and return temperatures as a part of chiller operations can serve as a cost-effective meter to calculate daily energy usage and peak cooling load. In lieu of a flow meter, a less accurate flow estimate can be obtained by measuring the pressure drop across each chiller evaporator bundle to calculate the flow across each chiller; however, fouling of the evaporator will affect the accuracy of this estimate over time. Energy input to the chiller is typically available at the equipment and additional monitoring of energy usage for pumps and cooling tower fans will allow the facility operator to calculate total cooling plant efficiency hourly and daily. Trending of this information along with outdoor air temperature can create excellent baseline performance data for the facility, encourage energy optimization, and provide data for future expansion. Metering of cooling tower makeup and blowdown water can reduce bills for sewage usage, where the water supplier allows subtraction from total consumption.

Chillers and VFDs

Many chillers use variable-frequency drives (VFDs) for energy savings. Because a health care facility has electrically sensitive medical equipment, chillers with VFDs should be specified with harmonic filters to minimize electrical interference with the building electrical system.

Building Cooling Loads

Chiller plants should be sized to meet current building and pro-cess loads and, as requested by the owner, to provide additional capacity for redundancy and future loads. When modifying or expand-ing an existing chiller plant, it may be possible to gather information

during times of peak seasonal temperatures to determine the existing system load. This can be done using temporary equipment to measure the operational parameters of an existing chilled-water plant, using information from the existing control systems and trending data, and discussing plant operations with the facilities staff. Understanding the current operating conditions of the central cooling plant during both peak and nonpeak loads is critical to a design engineer working on major renovations and additions as a means of determining the impacts on and necessary changes to the plant.

Peak cooling-load estimations for health care facilities should account for variables that include weather conditions, building envelope, internal heat gain, ventilation, reheat, process cooling, and, to a lesser extent, infiltration. The process of estimating peak cooling loads is explained thoroughly in the 2009 *ASHRAE Handbook—Fundamentals.* Because of requirements for minimum air changes, most health care facilities have a reheat load during cooling season that must be accounted for when determining the peak building cooling load. Spaces that will often contribute to reheat load include interior spaces with low internal loads and minimum air change requirements, north- and east-facing exterior zones with minimum air change requirements, and areas with high minimum air change requirements (such as surgical suites and interventional spaces). Health care facilities may also have process loads, such as kitchen refrigeration equipment and imaging equipment, that contribute to the peak cooling load.

4.3.2 Optimizing Cooling Plant Efficiency

Water Distribution Systems

Variable-speed water distribution systems are encouraged for most chilled-water plant applications because of their energy saving potential. In older or existing facilities, primary/secondary pumping systems may be advantageous over variable-speed primary pumping systems. Older chillers may not be able to handle reduced water flow through the evaporator; and primary/secondary systems can be implemented without making modifications to the chiller controls. With constant flow in the primary loop, new cooling systems can be added that provide higher cooling ΔT (14°F to 16°F [6.6°C to 7.5°C]) and lower flow rate at cooling coils without impacting the operation of the existing chillers. Variable-speed primary systems are commonly installed in new central cooling plants and may provide operational benefits over primary/secondary pumping arrangements. Variable-speed primary chiller installations require 15 to 20 ft of water [45 to 60 kPa] pressure drop across the chiller evaporator to allow for a reduction in minimum flow and also require accurate chilled-water flow measurement. Many new chillers have been designed with controls that allow reduction in flow through the evaporator to save pump energy. Both primary/secondary and variable-speed primary systems should be seriously considered as water distribution systems for new central cooling plants.

Surgical Suite Cooling

Chiller operating efficiency is improved with higher chilled-water supply temperatures and, in the case of water cooled equipment, lower entering condenser water temperatures. Operating room (surgical)

suites typically require low dew-point temperatures to achieve the desired humidity levels associated with the room air temperatures requested by doctors. To achieve these lower dew-point temperatures, lower chilled-water supply temperatures may be required. Rather than lowering the chilled-water supply temperatures for the entire facility, it may be cost effective to provide a separate chilled-water loop with a dedicated low-discharge-temperature chiller that serves only the operating rooms. Surgical suites are a core component of the hospital, and a cooling backup to the chiller may be required by the owner. Refer to Chapter 8 for additional information on surgical suite design.

Radiant Cooling Panels and Chilled Beams

Radiant cooling panels and chilled beams require that chilled-water supply temperatures be kept above the dew-point temperature of room air to prevent condensation from occurring on the devices. A secondary chilled-water loop could be provided that mixes primary supply chilled water with return water to achieve a secondary supply water temperature above the dew point. Another potential solution to providing higher chilled-water supply temperatures is to provide a dedicated chiller or chillers and a separate chilled-water loop that serves only radiant cooling panels and chilled beams. Better operating efficiency and energy savings can be achieved by supplying higher chilled-water temperatures at the chiller instead of mixing supply and return water to achieve the desired supply water temperature. See Chapter 3 for additional discussion on chilled beams.

Water-Side Economizer

A water-side economizer uses "free cooling" from the cooling tower in colder months in lieu of running a chiller or an air-side economizer for the air-handling equipment. Health care facilities have strict humidity requirements; a water-side economizer can minimize the amount of humidification required during low-humidity outdoor air conditions, compared to an air-side economizer. If a water-side economizer is used in lieu of an airside economizer, the cost of the heat exchanger and controls can be offset by installing smaller louvers and outdoor air ductwork, eliminating mixed air controls, and, in some instances, eliminating air-handling unit return fans and preheat coils. Although there are exceptions, ANSI/ASHRAE/IES Standard 90.1-2010 (ASHRAE 2010b) may require the use of water-side economizers (versus air-side economizers) when a building is humidified to a dew-point temperature higher than 35°F [1.7°C]. Many local jurisdictions have adopted ANSI/ASHRAE/IES Standard 90.1 as code minimum for building energy performance.

A water-side economizer can be developed using a plate-and-frame heat exchanger to reject heat from the chilled-water loop to the condenser water loop without the use of a compressor (see Figure 4-1). Selecting a plate-and-frame heat exchanger with a pressure drop similar to the condenser and evaporator of the chiller allows use of the existing chilled-water and condenser water pumps, avoiding the need to provide additional pumping equipment.

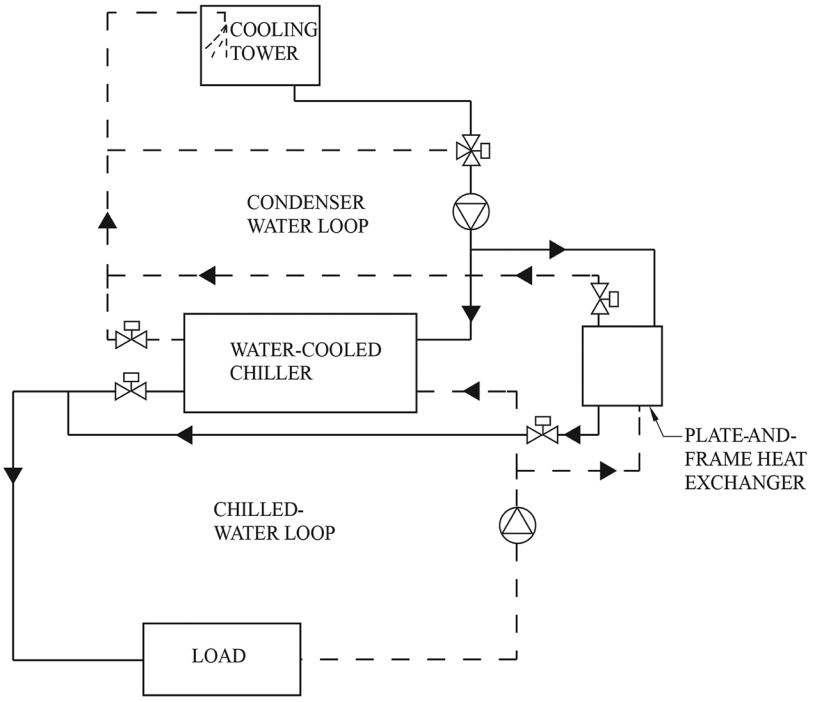


Figure 4-1 *Water-Side Economizer Using Plate-and-Frame Heat Exchanger*

A water-side economizer can be designed to operate in series with a chiller to increase the available economizer-mode operating hours (see Figure 4-2). Provisions should be made to allow for operation without the chiller when condenser water temperatures are low enough to meet the full cooling load. Careful consideration should be given to how the chiller will operate under the reduced load condition and to providing head pressure control on the chiller to allow for chiller operation at low condenser water temperatures.

A cooling tower designed with a water-side economizer should consider low-water-flow conditions during operation and provide the ability to run the cooling tower fan in reverse to protect the tower from freezing during cold temperatures. Refer to Chapter 9 of the 2012 *ASHRAE Handbook—HVAC Systems and Equipment* for additional information on water-side economizers.

Condenser Heat Recovery and Dedicated Condenser Heat Recovery Machines

Condenser heat recovery is an energy efficiency measure that utilizes the heat rejected to condenser water to preheat domestic water loads or to supplement reheat loads required for space heating. ANSI/ASHRAE/IES Standard 90.1-2010 (ASHRAE 2010b) (the prescriptive method) requires the use of heat recovery to preheat service hot water for facilities that operate 24 h/day and meet minimum load requirements. Many local jurisdictions have adopted ANSI/ASHRAE/IES Standard 90.1 as code minimum for building energy performance. With the addition of a double-wall, flat-plate heat exchanger, condenser heat recovery can be used with standard chiller condenser temperatures to preheat domestic hot water (see Figure 4-3).

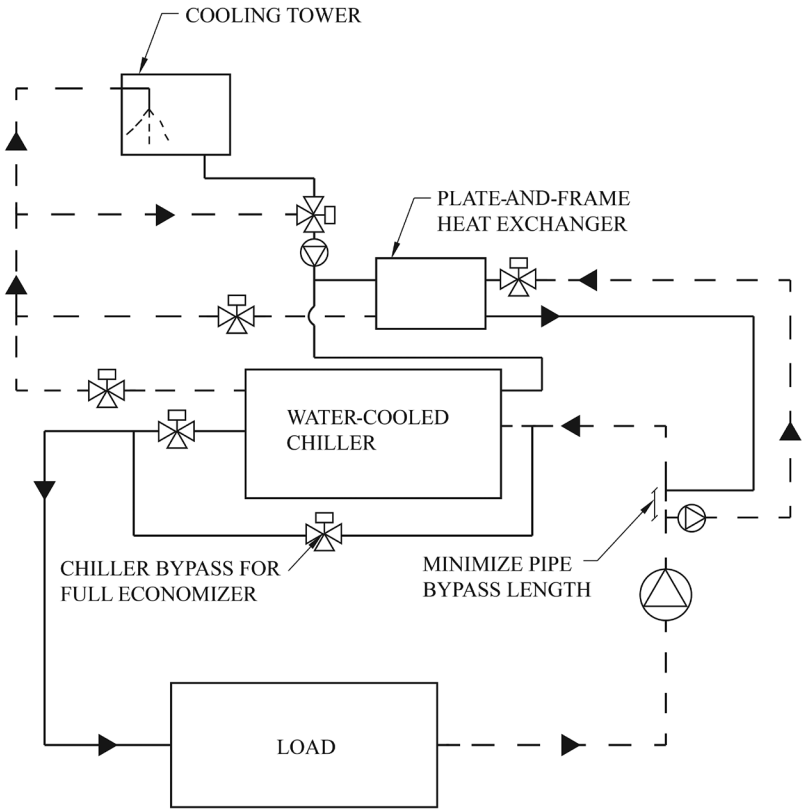


Figure 4-2 *Water-Side Economizer Operating in Series with Chiller*

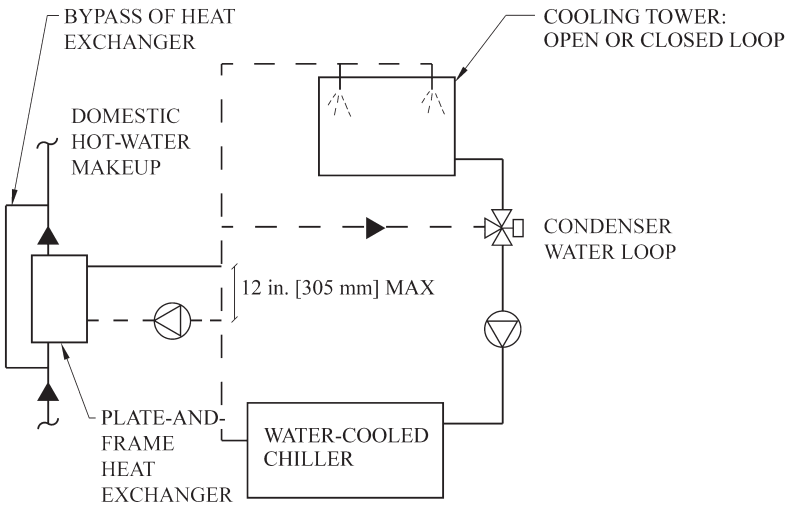


Figure 4-3 *Condenser Heat Recovery for Preheating Domestic Hot Water*

A different approach to condenser heat recovery provides a dedicated heat recovery machine that simultaneously generates chilled water for cooling and hot water for space heating or domestic water heating loads. The dedicated machine is typically installed in either a sidecar or series position with other chillers and boilers in the central utility plant. Dedicated heat recovery machines have higher condenser water

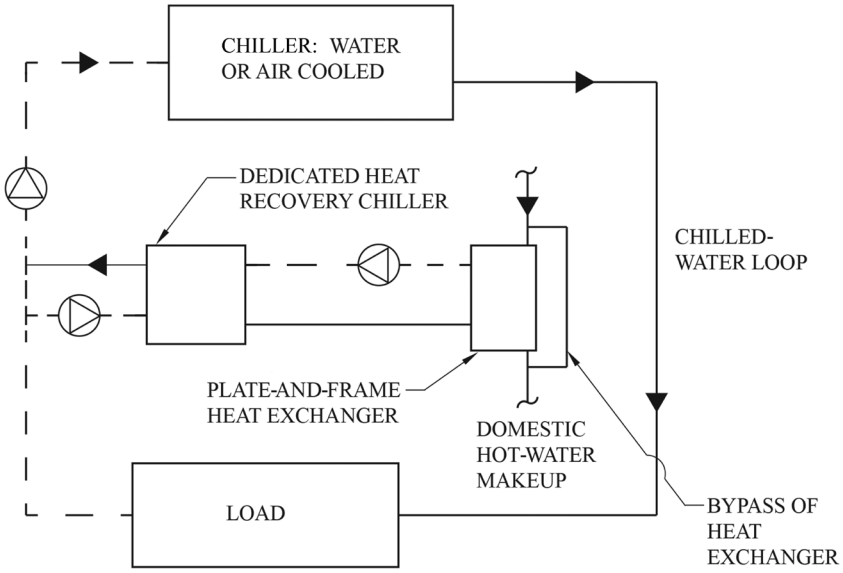


Figure 4-4 *Dedicated Heat Recovery Chiller*

discharge temperatures than typical operations (Figure 4-4), allowing for reheat usage. A dedicated heat recovery machine is optimally sized to meet winter cooling load or summer reheat load, whichever is smaller. The use of condenser heat recovery typically offers significant energy savings over normal fuel-fired heat generating systems. The full capacity of a dedicated heat recovery machine should not typically be included in analysis of the peak cooling or heating load for the central cooling and heating plant. Because of the nature of the system, its output capacity in cooling and heating will be determined by the smaller of the two loads, and the dedicated heat recovery machine may not be able to achieve full load under a peak-load condition. Building energy modeling and existing system modeling are used to optimally size the equipment.

4.3.3 Cooling Under Emergency Power

Many health care facilities do not have the emergency power capacity to operate all of their HVAC systems; many times, only 50 to 75% of total cooling capacity will be available. The HVAC and electrical system designers can assist the facility owner in developing a cooling triage plan (Koenigshofer 2009) for operating the building under emergency power. This will involve determining the amount of emergency power that is available for the HVAC system, the load requirements of cooling equipment, and the load requirements for both power and cooling capacity of all air-handling units. When determining cooling-equipment power requirements (what is to be connected to the emergency power source), consider all components necessary for the operation of the system, including pumps, compressors, fans, cooling towers, chillers, and controls. Documentation of the existing mechanical equipment, including information on the chilled-water system and HVAC controls, along with the cooling load, motor horsepower [watts], and water flow rate for each air handling unit,should be included as part of the strategy planning.

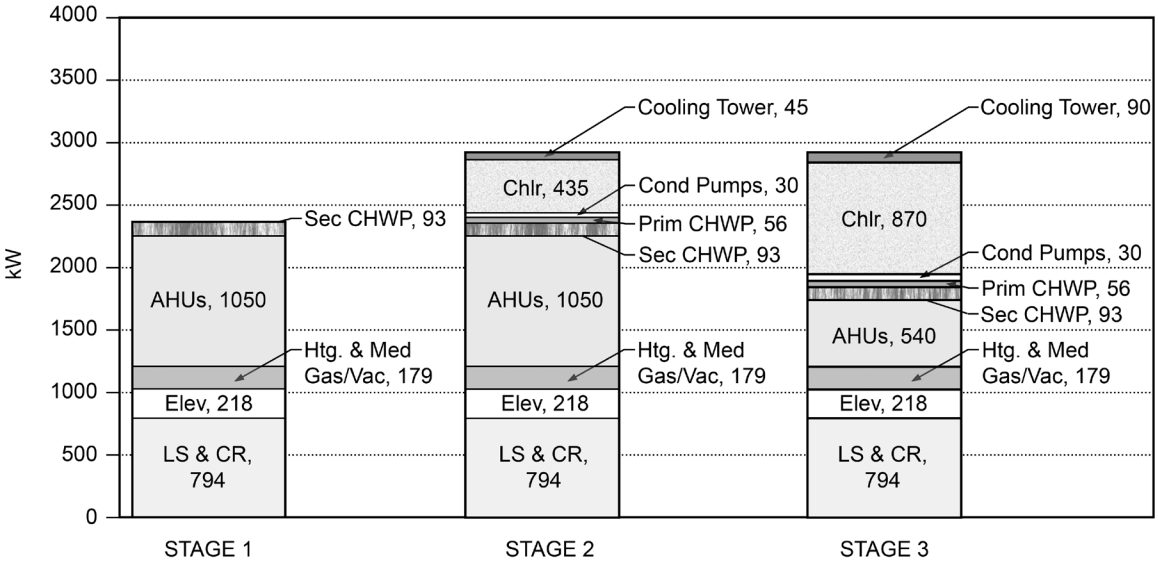


Figure 4-5 *Emergency Power Distribution*
Source: Koenigshofer (2009).

Assist the owner in prioritizing air-handling units (from most important to least important) and grouping the air-handling units into categories: those that receive full cooling, partial cooling, and no cooling. The electrical power and cooling capacity requirements of units in the full-cooling category should be less than the available emergency operation capacities. Any remaining generator or cooling plant capacity can be used for the units receiving partial cooling. Once equipment has been prioritized, develop strategies for each air-handling unit to divert cooling capacity to units in the full-cooling category, reduce load for partial cooling, and divert load from units requiring no capacity. Strategies for reducing cooling capacity include raising supply air setpoints, closing chilled-water valves (either manually or automatically), reducing airflow at air-handling units, or reducing outdoor air intake. Airflow can be reduced by commanding VFDs to lower speeds, reducing the static-pressure setpoint to slow fans, and commanding VAV boxes to lower airflow setpoints. Operation under these conditions will be complex and must be thoroughly thought out. Common considerations include accounting for 3-way valves in the chilled-water system; maintaining pressure relationships for dietary, isolation rooms, sterile processing, the emergency department, operating rooms, and procedure rooms; and dealing with VAV boxes that open wide (calling for more air because room temperature set-point is not maintained or static-pressure setpoints have been lowered). Consider how the systems are controlled. Older hospitals with pneumatic controls will have limited ability to reduce airflow in a system or adjust control valves automatically; manual shutdown of systems may be required.

Figure 4-5 shows the distribution of emergency power over three stages of an outage. Often, AHUs may need to be turned off to allow for the in-rush of large chiller currents.

After developing a strategy for every air-handling unit, a draft plan for operation should be created. The draft plan should be reviewed with high-level facility management to address required adjustments and to get approval of the plan. The final plan should be shared with facility personnel and the facility staff trained on operation under the plan.

4.4 CENTRAL HEATING PLANTS

Central heating plants represent a significant initial investment for health care facilities, along with continued maintenance and energy costs. Most health care facilities require reheat, or year-round heating, and/or steam production for sterilization and humidification, which must be accounted for in the design and selection of central utility plant equipment. This section includes discussion of the following topics:

- General considerations
- Boiler plants
- Optimizing steam plant efficiency

4.4.1 General Considerations

Dual-Fuel Heating

Fuel system redundancy options for heating plants should be discussed with the owner and investigated. Most manufacturers offer equipment with a minimum of two fuel source options that allow a facility owner to provide an on-site backup fuel source in case of an interruption of utility service. Redundant fuel sources include noninterruptible utility services (investigation into utility service requirements and acceptability by local authorities having jurisdiction is required for noninterruptible service) or providing on-site fuel in storage tanks. On-site fuel storage capacity should also be discussed with the owner. In many instances, 96 hours of on-site fuel capacity is provided to meet either owner or code requirements. Most existing systems with dual-fuel boilers use natural gas burners with Number 2 grade fuel oil as the on-site backup fuel source. Number 2 grade fuel oil has the advantage of using the same fuel source as emergency generators and can allow for some first-cost savings. Although some high-efficiency condensing boilers provide a dual-fuel option (Number 2 grade fuel oil and natural gas), most manufacturers of high-efficiency condensing boilers offer only propane and natural gas as fuel options.

Sizing the Central Heating Plant

Heating plants should be sized to meet the current building and process loads and, as requested by the owner, to provide additional capacity for redundancy and future loads. When modifying or expanding an existing boiler plant, it may be possible to determine the existing load on the system by gathering information during peak seasonal temperature conditions. This can be accomplished by using temporary equipment to measure the operational parameters of an existing heating plant, using information from existing control systems and trending data, and discussing plant operations with the facilities staff. Understanding the current operating conditions of the central heating plant during both peak and nonpeak loads is critical to a design engineer working on major renovations and additions as a means of determining impacts on and necessary changes to the plant.

Health care facilities often have one or more heating plants to serve all water heating, humidification, and sterilization loads. Load estimations for health care facilities should account for on-site laundry services, domestic water heating, ventilation, sterilization, humidification, food preparation process loads, space water heating, and, in some cases, absorption refrigeration. Space heating loads for health care facilities include heating losses through the building envelope, ventilation, infiltration, reheat load, a heating pickup factor for areas with night setback, and snowmelt systems. Each of the loads mentioned above can be served by a dedicated system or by a common system. On-site laundry services are more common in older facilities; newer health care operations typically do not include on-site laundry services.

Steam Piping Systems

Steam systems are common in hospitals, but are unfamiliar to many designers because of reduced use in other building types. Designers are encouraged to review Chapter 11 of the 2012 *ASHRAE Handbook—HVAC Systems and Equipment* for a general overview of steam systems and Chapter 22 of the 2009 *ASHRAE Handbook—Fundamentals* for information on steam and condensate pipe sizing. In a health care facility, steam piping headers and mains leaving the boiler plant should be oversized to minimize pressure losses and to allow for future capacity in the system.

Steam System Chemical Treatment

Steam and condensate systems are subject to corrosion from scale, carbonic acid, oxidation, galvanic action, and high-purity-water aggressiveness. Effects of pipe corrosion include reduced equipment life, clogging or plugging of system components, and discoloration of materials that come in contact with the steam or return condensate (such as medical instruments in sterilization). There are multiple methods that should be used to minimize and control corrosion in steam and condensate systems.

Makeup water introduced into a boiler system can include a significant number of chemical compounds (known as mineral salts) that are naturally present in potable water and can lead to the formation of scale in boilers, heat exchangers, and piping. Scale is formed when mineral salts, typically magnesium and calcium carbonate, cannot be dissolved in the water at the elevated temperatures found in a steam system and precipitate to form scale. The concentration of scale-forming compounds in water is known as hardness and is measured in parts per million (ppm) or grains per gallon [grams per cubic metre]. Makeup water with a hardness exceeding 3.5 grains per gallon [60 grams per cubic metre] should be "softened" to minimize the amount of scale that can form in the system. Sodium zeolite water-softening minimizes scale by minimizing the precipitation of magnesium and calcium carbonate. Blowdown or bleed-off cycles can also reduce the amount of scale formation in a steam system and should be automatically controlled to maintain a maximum concentration of impurities or by a timer.

Carbonic acid is formed when carbon dioxide (CO_2) is introduced into a steam system or when carbonate and bicarbonate compounds that are introduced in highalkaline makeup water break down. Carbonic acid is very corrosive to materials commonly used in steam systems, such as mild steel and copper. Free oxygen (O_2) dissolved in water can cause oxidation: the removal of iron from mild steel surfaces because of the presence of oxygen. Boiler system deaeration helps to remove most CO_2 and O_2 from a steam system, thus limiting oxidation and, to a lesser extent, carbonic acid. Deaeration removes most of the oxygen in a system; however, chemical treatment using oxygen scavengers should also be used to reduce oxidation. After deaerating the makeup water supply, introducing sodium sulfite into the system (the most common oxygen scavenger) will virtually eliminate or passivate any remaining oxygen. Stack economizers are vulnerable to oxidation and should be located downstream of the deaerator tank and the introduction point for sodium sulfite.

The most significant cause of carbonic acid is typically carbonate and bicarbonate compounds introduced as components of the naturally occurring mineral salts in makeup water, not CO_2 entering the system. A dealkalizer, typically downstream of the water softener, will remove most of the carbonate and bicarbonate compounds with chloride ions. Testing and analysis of the water should be performed during design, along with a cost analysis, to determine if a dealkalizer should be provided. The reverse osmosis (RO) process can be 95% effective in removing carbonates as well as other impurities from water; however, the process is significantly more expensive that water softening. If RO is used, serious consideration should be given to using stainless steel piping because of the high-purity water being introduced into the steam system. Chemical treatment of the system also mitigates the impact of carbonic acid and oxidation. Alkaline treatment chemicals, known as amines, are used to raise the pH or to shield piping system materials from direct corrosion agents. Amines neutralize carbonic acid that does form in a system, and although they have no impact on oxidation, they (while filming) create a molecular coating that protects the inside surface of a piping system from carbonic acid and oxidation. Additional discussion of the effect of amines on humidification systems can be found in Rabinovich (2004).

Galvanic corrosion occurs when dissimilar metals are used in steam and condensate systems. Common combinations of metals that can cause galvanic corrosion are copper/steel and steel/stainless steel. The use of dissimilar metals in piping systems should be kept to a minimum, and dielectric couplings should be used at all connections between dissimilar metals.

High-purity-water aggressiveness occurs when “clean” or “pure” steam is utilized. Clean or pure steam is most commonly defined as either not being chemically treated or where most of the impurities in the water have been removed through distillation, demineralization,

or reverse osmosis. Such steam is highly corrosive to piping and equipment in the system, including mild steels and even low-grade stainless steels. In these situations, it is highly recommended that all portions of the system that come in contact with the steam and condensate, including piping, equipment, traps and other fittings, be constructed of high-grade stainless steels.

4.4.2 Boiler Plants

Hot-Water Boiler Plants

High-efficiency (condensing or noncondensing) hot-water boilers are often provided in new health care facilities in lieu of providing space heating from a central steam plant. High-efficiency hot-water boilers should be provided in multiple parallel configurations and, as with steam boilers, redundant boiler capacity is often required by the owner. Take care to ensure that the selected boilers can burn both gas and oil where dual-fuel capability is desired. High-efficiency boilers can be either condensing or noncondensing. Condensing boilers achieve higher efficiencies by providing lower supply water temperatures; however, they require additional maintenance. Designing high-efficiency hot-water boiler systems with 130°F to 140°F [54.4°C to 60.0°C] supply water temperatures allows for dedicated heat recovery machines to provide space-heating hot water in addition to domestic hot water. Designers, however, generally do not count heating capacity from dedicated heat recovery machines to meet design heating-load requirements. Dedicated heat recovery machines operate to meet the smaller of the cooling or heating load; for the machine to operate at peak heating capacity, a minimum cooling load must be available. Hot-water supply temperatures of 130°F to 140°F [54.4°C to 60.0°C] have an impact on the size of heating coils in air-handling units and at terminal devices that must be accounted for in other aspects of the design. High-efficiency hot-water boiler systems require primary/secondary pumping arrangements for variable-flow systems and typically have lower energy costs and more maintenance requirements when compared to steam-to-hot-water converters.

Steam Plants

Due to the range of equipment requiring steam, many hospitals use a central steam plant to meet all sterilization, HVAC system humidification, kitchen process, and hot-water loads. Different components of the steam system require widely varying steam pressures, so the steam plant is typically sized to meet the highest required steam pressure, with pressure reducing stations provided at various points in the system to meet lower-pressure loads. Health care facilities may also use a steam plant sized to meet only the facility sterilization, HVAC system humidification, and kitchen process loads, with a separate hot-water heating plant. Steam plants are not as common in today's HVAC industry as in previous decades and building owners may want to minimize the amount of steam equipment operating in the facility. Generally, unless transport costs are extreme, it is more efficient to heat water with high-efficiency boilers than with steam-to-hot water converters.

Sterilization

Sterilization of medical instruments is important to maintaining patient health and preventing the spread of diseases in a hospital. Instrument sterilization can be provided by local electric self-generating sterilizers or, more commonly, by high- or medium-pressure steam plants, although many modern sterilizers do not use plant steam in direct contact with instruments. Steam sterilizers require high-quality steam, 97% quality or better, to prevent excess moisture from wetting packs or instruments. Sterilization requires that instruments be exposed to steam at a temperature of 250°F [121°C] or higher for a length of time, so steam pressures of 50 to 80 psi [345 to 552 kPa] are required. Sterilization is more effective with saturated steam than superheated steam, so it is important for the designer to minimize superheated steam. Excessive superheat may result if the sterilizer jacket is maintained at a higher temperature than the chamber or if there is excessive pressure reduction before the sterilizer connection. Steam condensate comes in direct contact with medical devices during the sterilizing process is considered contaminated and is not returned for reuse.

Humidification

Humidification is required in most patient care areas of a hospital, but can be provided throughout all hospital areas. Humidification steam should be high quality to minimize wetting of ductwork, filters, and other components that are susceptible to microbial growth. Steam pressures from central steam plants to humidifiers are normally in the 10 to 20 psi [69 to 138 kPa] range. Steam can also be provided from small, point-of-use electric, gas, or steam-to-steam generators at lower pressures (0 to 5 psi [0 to 35 kPa]). Small, point-of-use generators have the advantage of producing clean steam, but typically require high levels of maintenance for proper operation. Evaporative water systems should not be used to provide humidification in health care facilities because of the risks posed to patient care and the spreading of disease.

Humidification and Chemical Treatment

Although a majority of medical facilities use steam from central steam boilers that have been chemically treated for humidification, some owners prefer using "clean" or "pure" steam. If chemical treatment is used in steam humidification systems, federal regulations and industry guidelines restrict or prohibit the use of certain additives to which people may be directly exposed through the humidification system. There are specific concerns regarding the quantity of amines in humidification systems using chemically treated steam. The Food and Drug Administration (FDA) has determined permissible exposure limits (PELs) for amines on food, and PELs have been set by the Occupational Safety and Health Administration (OSHA). Additional studies have determined the threshold of concentration of amines where odor becomes noticeable and offensive; this information is listed in Table 4-1. Indoor air quality (IAQ) testing has been performed in buildings using humidification systems with FDA-approved amines for boiler treatment and determined that, in a properly treated boiler system, the concentration of amines in the air is significantly lower than the concentration levels for odor complaints (Rabinovich 2004). A good maintenance program that regularly monitors the level of

amines in the steam and condensate system should maintain reasonable levels of amine concentration in the facility.

ANSI/ASHRAE/ASHE Standard 170-2008, *Ventilation of Health Care Facilities* (ASHRAE 2008) allows the use of chemically treated steam within the limits of the FDA-approved amines. ANSI/ASHRAE Standard 62.1-2010, *Ventilation for Acceptable Indoor Air Quality* (ASHRAE 2010a) currently requires that water for humidification "originate directly from a potable water source or from a source with equal or better water quality." The Standard 62.1 committee, however, is considering updating the minimum water quality requirements to forbid the use of chemical additives in steam humidification systems. Engineers should discuss humidification options with owners and present benefits and drawbacks for each option. Cost-effective ways to provide clean steam include the use of small electric steam generators, gas-to-steam generators, or steam-to-steam generators.

Hot-Water Heating

In existing facilities with large central steam plants, space heating is often provided by steam-to-hot-water convertors. Shell-and-tube heat exchangers are frequently used to generate hot water for space heating because of the large approach temperatures between steam and hot water. Although plate-and-frame heat exchangers are occasionally used, they are generally not preferred because of their susceptibility to fouling and higher maintenance requirements. Multiple heat exchangers should be provided in a parallel configuration. If no redundancy is provided, each heat exchanger should be minimally sized to provide heat to all critical-care spaces and patient rooms, along with a safety factor to prevent freezing in other areas of the facility. In many instances, two heat exchangers are provided, each sized to meet 100% of the load; sometimes, each heat exchanger is sized to meet 75% of the load. Each heat exchanger should be provided with isolation valves to allow for maintenance of the equipment without disruption to the facility. If 100% redundant capacity is not provided with the steam-to-hot-water convertor, then redundant traps,

Table 4-1 *Permissible Exposure Limits (PELs) and Odor Thresholds for Amines*

Amine	PEL[a], ppm	PEL[b], ppm	Odor Threshold Limit[c], ppm
CHA (cyclohexylamine)	10	—	0.90
DEAE (diethylaminoethanol)	15	10	0.04
Morpholine	10	20	0.14
Octadecylamine	3	—	—

Notes:

a. Data from CFR (2012a). PELs for amines in steam approved by FDA for use in boilers where steam comes in direct contact with food, excluding use of such steam in contact with milk and milk products.

b. Data from CFR (2012b). PELs for amines in air from OSHA based on 8 h day.

c. Data from Rabinovich (2004).

each sized for 100% of the load, should be provided, along with isolation valves for each trap to allow for continuous operation of at least one heat exchanger when a trap fouls or fails.

4.4.3 Optimizing Steam Plant Efficiency

Stack Economizers

Steam boiler flues typically discharge flue gas at high enough temperatures that a stack economizer can be used to recover some of the heat from the flue gases. This may be done by mounting a heat exchanger in the boiler stack and circulating either boiler feedwater or condensate return water through the heat exchanger. Care should be taken to avoid condensation of flue gases in the boiler stack, and corrosion-resistant materials should be used in the heat exchanger.

Condensate Recovery

Recovering steam condensate saves water, reduces the cost of heating water to the boiling point, and (in chemically treated systems) reduces the amount of chemical treatment required. Typically, the only condensate not returned is from steam that has come in direct contact with medical instruments in a sterilizer.

Flash Steam Recovery

High-pressure condensate often must be returned to a flash tank to become pumped condensate for return back to the main boiler plant. When high-pressure return goes to a flash tank, the liquid portion quickly cools to approximately 210°F to 212°F [98.9°C to 100.0°C] and a quantity of low-pressure "flash" steam is created as a byproduct (which is typically vented to atmosphere). The low-pressure flash steam can be returned to a low-pressure steam supply system and used to serve a heat exchange device, such as a steam-to-hot-water convertor or steam-powered domestic hot-water heater. Refer to Chapter 11 of the 2012 *ASHRAE Handbook—HVAC Systems and Equipment* for additional information on flash steam recovery.

4.5 OTHER UTILITIES

4.5.1 Domestic Water Systems

Domestic hot-water plants must be sized to meet the peak demand, and the load can fluctuate frequently and greatly on an hour-by-hour basis. Storage of domestic hot water is necessary to provide large "capacitance" to the system to accommodate the varying demand rates of large health care facilities. Instantaneous steam-fired domestic water heaters are also common, but the system design must account for large load fluctuations. Steam valves may need to be sized for 10% and 90% capacity, rather than 50%/50% or 33%/66%.

Legionella pneumophila bacteria, the cause of Legionnaires' disease, is a concern for domestic hot-water systems; it is recommended that designers review the facility's existing (or assist the owner in creating a new) hazard analysis and critical control point (HACCP) plan. In addition to the existing ASHRAE Guideline 12-2000R, *Minimizing the Risk of Legionellosis Associated with Building Water Systems,* ASHRAE is currently developing ASHRAE Standard 188P, *Prevention of Legionellosis Associated with Building Water Systems,* which could also be used as a resource.

As with space-heating hot water, domestic hot water can be generated from steam or by using high-efficiency gas-fired equipment. The relative advantages and disadvantages of each system are discussed in the previous section and should be considered for domestic hot-water plants. Domestic hot-water systems using heat exchangers or tank heaters with steam typically require double-wall tubes to prevent contamination of potable water by the steam system.

4.5.2 Medical Gas Storage Rooms

Rooms containing medical gas manifolds or medical gas containers have special ventilation and heating requirements because of the fire risks associated with large quantities of gas. Storage rooms that contain less than 3000 ft^3 [85 m^3] (at standard pressure and temperature) of gas may be ventilated by natural ventilation; otherwise, a dedicated mechanical ventilation system is required to provide exhaust near the floor of the room. To prevent fires, heat must be provided by indirect means, like steam or hot water, and not by direct-fired gas units. Designers should review the *Health Care Facilities Code* from the National Fire Protection Association (NFPA), the *International Fire Code*®, and local codes for specific design requirements pertaining to medical gas storage and manifold rooms.

REFERENCES

ASHRAE. 2008. *Ventilation of health care facilities.* ANSI/ASHRAE/ASHE Standard 170-2008. Atlanta: ASHRAE.

ASHRAE. 2010a. *Ventilation for acceptable indoor air quality.* ANSI/ASHRAE Standard 62.1-2010. Atlanta: ASHRAE.

ASHRAE. 2010b. *Energy standard for buildings except low-rise residential buildings.* ANSI/ASHRAE/IES Standard 90.1-2010. Atlanta: ASHRAE.

CFR. 2012a. Boiler water additives. In Secondary Direct Food Additives Permitted in Food for Human Consumption, Subpart D—Specific Usage Additives. 21CFR173.310. *Code of Federal Regulations.* Washington, DC: Food and Drug Administration, U.S. Department of Health and Human Services.

CFR. 2012b. Table Z-1, Limits for air contaminants. In Occupational Safety and Health Standards, Subpart Z— Toxic and Hazardous Substances. 29CFR1900.1000. *Code of Federal Regulations.* Washington, DC: Occupational Safety and Health Administration, U.S. Department of Labor.

Koenigshofer, D.R. 2009. Backup power and cooling plans for critical facilities. Part II: Case study: Hospital EPS load breakdown. *Building Operating Management*, May.

Rabinovich, S. 2004. Hospital steam humidification systems and the chemicals they use. *HPAC Engineering*, May.

BIBLIOGRAPHY

ASHRAE. 2009. *ASHRAE Handbook—Fundamentals*. Atlanta: ASHRAE.

ASHRAE. 2011. *ASHRAE Handbook—HVAC applications.* Atlanta: ASHRAE.

ASHRAE. 2012. *ASHRAE Handbook—HVAC systems and equipment.* Atlanta: ASHRAE.

ASHRAE. 2010. *Safety standard for refrigeration systems.* ANSI/ASHRAE Standard 15-2010. Atlanta: ASHRAE.

ASHRAE. Pending. *Prevention of legionellosis associated with building water systems.* Standard 188P. Atlanta: ASHRAE.

ASHRAE. 2000. *Minimizing the risk of legionellosis associated with building water systems.* Guideline 12-2000R. Atlanta: ASHRAE.

ASHRAE. 2012. *Practical guide to seismic restraint,* 2nd ed. Atlanta: ASHRAE.

ICC. 2012. *International fire code®.* Washington, DC: International Code Council.

NFPA. 2012. NFPA 99: *Health care facilities code*. Quincy, MA: National Fire Protection Association.

SMACNA. 2008. *Seismic restraint manual: Guidelines for mechanical systems*, 3rd ed. Chantilly, VA: Sheet Metal and Air Conditioning Contractors' National Association.

CHAPTER 5

LIFE SAFETY

5.1 HEALTH CARE OCCUPANCY LIFE SAFETY

The fundamental approach to life safety for inpatient health care facilities is unique in that it is based on a "defend in place" concept, wherein the building life safety features and systems are relied upon to provide early warning, suppression, and containment of fire and smoke. Building evacuation is considered the option of last resort because the patient population is largely incapable of self-preservation actions, and some are dependent on critical life-support equipment,. Codes and standards define special requirements for the construction and performance of the building structure, architectural elements, and engineering systems to establish this critical level of life safety. The role of the HVAC designer is to recognize and implement those system requirements that preserve the integrity of fire and smoke separations; provide for smoke detection, containment, and exhaust; preserve egress pathways; and facilitate the strenuous requirements for periodic maintenance and testing of HVAC life safety equipment and system function. This chapter is intended to provide an overview of the salient life safety requirements for inpatient facilities designated as "new health care" by *NFPA 101: Life Safety Code* (NFPA 2012c), or as Institutional Group 2 (I-2) by the *International Building Code® (IBC®)* (ICC 2012). Some common life safety requirements of the NFPA and model building codes are excluded from application to these occupancy designations because of a mandate for total building sprinkler and alarm systems. These exclusions may not apply to the ambulatory care and existing health care occupancies under which some categories of health care facilities are classified.

5.2 ESTABLISHMENT OF CRITERIA

As with all other aspects of health care HVAC design, the designer must first establish the applicable codes, standards, and criteria for each project that are mandated by the authority having jurisdiction (AHJ).

Facilities that are mandated (by AHJs or by owners) to be accredited by The Joint Commission (TJC) must comply with *NFPA 101: Life Safety Code* and the other NFPA standards referenced within that document. Some of the more important of these for the HVAC designer include *NFPA 90A: Standard for the Installation of Air-Conditioning and Ventilating Systems* (NFPA 2012a), *NFPA 92: Standard for Smoke Control Systems* (NFPA 2012b), and *NFPA 72: National Fire Alarm Code* (NFPA 2013a). As of August 2012, TJC surveys buildings for compliance with the 2000 edition of NFPA 101, although they will accept compliance with later editions if the entire facility is designed to that edition. The material contained in this chapter is based for the most part upon the 2012 edition of NFPA 101. Individual AHJs or owners will normally require compliance with model building codes, such as the IBC, or jurisdiction-specific modifications of those codes, which may contain more strenuous requirements than NFPA 101. Careful consideration must be given to all applicable code requirements, and it is essential to secure agreement with the AHJ regarding which codes and which versions will be applied.

5.3 KEY ELEMENTS OF LIFE SAFETY

The key life safety features for health care facilities include a fire-resistive structure; total building sprinkler systems; fire alarm systems; fire-rated separations of floors, exits, vertical shafts and other openings; division of floors into a minimum of two smoke zones; and smoke control. Smoke zones function as areas of refuge for horizontal evacuation in an extreme fire emergency. Specific requirements apply to egress and exiting capacity and configuration. Egress corridors must be constructed to substantially resist the passage of smoke, and the transfer of air between corridors and adjacent spaces is limited. Buildings with atria may require an engineered smoke control system (ESCS) to mitigate smoke in the atrium, as an alternative to providing fire separation from adjacent spaces. Although not required by NFPA, some AHJs may call for total-building ESCS or for smokeproof stair enclosures involving mechanical ventilation and makeup air. Requirements for protection of duct and piping openings in fire- and smoke-rated barriers are defined by NFPA 90A, *NFPA 80: Standard for Fire Doors and Other Opening Protectives* (NFPA 2013b), and *NFPA 105: Standard for Smoke Door Assemblies and Other Opening Protectives* (NFPA 2013c). In buildings with cooking facilities, the requirements of *NFPA 96: Standard for Ventilation Control and Fire Protection of Commercial Cooking Operations* (NFPA 2011) apply to the configuration and construction of exhaust ductwork to protect the facility from the hazard of grease fires originating in the ductwork.

5.3.1 Fire Separations

Two-hour fire-resistive horizontal construction is required between each floor in a health care occupancy and for vertically separating health care occupancy areas within a building from other occupancies (unless the latter fully comply with all of the health care life safety standards). For facilities housing health care occupancies of less than four floors in height, one-hour fire-resistive ratings are required for all vertical opening enclosures (including utility shafts and stair

enclosures), whereas two-hour fire-resistive construction is required for buildings with more than four stories. Rooms containing potential fire hazards, such as storage, supply, mechanical rooms containing fired equipment, and trash collection rooms, are required to have one-hour fire-resistive envelopes. The smoke barriers required to establish smoke zones on each floor are also required to carry a minimum one-hour fire resistance. Horizontal exits, if provided, require two-hour fire-resistive construction.

5.3.2 Smoke Separations

Health care occupancies must be provided with smoke barriers to establish at least two smoke zones on each floor on which patients are housed or treated, and on adjacent floors as defined by code. The maximum permissible area of a smoke zone, with certain exceptions for smoke zones adjacent to atria, is 22,500 ft^2 [2090 m^2]. As previously noted, these smoke barriers are also required to have minimum one-hour fire-resistive construction. Although they must be constructed to resist the passage of smoke, egress corridors are not required to be smoke- or fire-rated in health care or other fully sprinklered buildings. The IBC, and possibly other codes, require stair towers to be smoke rated as well as fire rated.

5.3.3 Protection of Openings

NFPA 101 and NFPA 90A generally require that ducted penetrations of two-hour-rated fire barriers be protected by a listed fire damper with a fire rating of 90 minutes. Exceptions for certain exhaust ducts in shafts are described in NFPA 90A. Steel-ducted penetrations of one-hour-rated construction are not required by NFPA (but may be by other codes) to be provided with fire dampers, but must be fire stopped in accordance with NFPA 80 (which also governs fire stopping for piping penetrations). Fire dampers are mechanically actuated by a fusible link. Code requirements for the location and operation of smoke dampers depend on whether the associated air-handling system is designed to be operated as an engineered smoke control system (ESCS) or to otherwise operate to supply makeup air, establish pressurization, or prevent smoke recirculation during a fire emergency. When not designed as an ESCS or for special fire emergency operation, NFPA 90A requires that smoke dampers be provided to isolate air-handling units (AHUs) having a capacity greater than 15,000 cfm [7080 L/s]. These dampers must be located at both supply and return, and are shut down when the associated AHU is not in operation. When an AHU is located on the floor it serves (or on the roof above) and serves only that one floor, isolation smoke dampers are not required. For facilities with fully ducted HVAC systems, smoke dampers are not required in duct penetrations of smoke barriers. Smoke dampers are operated by an automatic alarm initiating device, such as a smoke detector, manual fire alarm pull station, or water-flow alarm, or may be manually operated from a firefighter's control station.

Fire and smoke dampers must both be installed in accordance with the conditions of the manufacturer's listing. Dampers may be listed exclusively for horizontal or for vertical installation. Note that dampers

5.3.4 Fire and Smoke Damper Requirements

have listed velocity ratings that must be matched to actual duct airflow velocities. In addition to the conditions of listing, fire dampers must be installed in compliance with NFPA 80, and smoke dampers in compliance with NFPA 105. When certain codes or standards, such as the IBC, require ducted openings in rated construction to be both fire- and smoke-rated, combination fire/smoke dampers are used. Fire damper fusible links are required to have a temperature rating of approximately 50°F [23.6°C] above the maximum normally encountered operating temperature, but not less than 160°F [71.1°C]. Exceptions to allow higher-temperature fusible links are provided for systems handling higher-temperature air or those that must continue to function during a fire emergency. Code-mandated periodic inspection, maintenance, and testing of fire and smoke dampers require that the operators be accessible. NFPA 90A requires that design drawings show the locations and mounting arrangements of all fire and smoke dampers.

5.3.5 Corridor Air Transfer

NFPA 101 and NFPA 90A recognize the need to allow air transfer between egress corridors and adjoining areas to establish pressure differentials or as required "for clinical purposes." To this end, NFPA 101 allows doors to have a maximum 1.0 in. [25 mm] undercut, and both standards allow vented louvers in doors to toilets, bathrooms, sink closets, and similar spaces not containing combustible materials. The use of above-ceiling plenums for air supply, return, or exhaust is allowed, provided that construction of the plenum and its contents meet code-defined requirements for flame and smoke spread. Designers should note, however, that ANSI/ASHRAE/ASHE Standard 170-2008 (ASHRAE 2008), which is referenced by NFPA 90A, Appendix A, does not allow spaces with required pressure relationships to be served by plenum returns.

5.3.6 Smoke Detection

NFPA 90A requires that smoke detectors be provided

- downstream of the air filters and ahead of any branch connection in air supply systems having a capacity greater than 2000 cfm [944 L/s]; and
- at each story prior to the connection to a common return and prior to any recirculation or fresh air inlet connection in air return systems having a capacity over 15,000 cfm [7079 L/s] and serving more than one story.

NFPA 90A requires that, on detection of smoke, the fan systems associated with the detector shut down, unless the return air system is required to function as part of an ESCS. Designers should note that when an air-handling system serves multiple stories, smoke detection at any single detector will result in loss of HVAC service to all smoke zones served by that system. Smoke detectors are required to be installed in accordance with NFPA 72, and be connected to and monitored for integrity by the building fire alarm system.

5.3.7 Smoke Control

In general, HVAC smoke control can be categorized as either a "passive" system or an "active" system. A passive system reacts to an automatic alarm initiating device (e.g., smoke detector, sprinkler system water-flow alarm, manual pull switch) by shutting down the associated air-handling equipment and closing smoke dampers in the zone of alarm. Active systems include ESCS, in which the HVAC system and/or dedicated fire-emergency fan equipment establishes pressure zones to isolate the zone of fire origin and contain or exhaust smoke. Active smoke control may also be applied to exhaust smoke from an atrium, or as one option in creating a smokeproof enclosed exit stair tower. It is important to understand that all smoke control devices, including the activation controls for smoke and combination fire and smoke dampers, must be UL-listed for the purpose.

5.3.8 Passive Smoke Control

With passive control, the HVAC system, by shutting down all service to the zone or floor under alarm, does not recirculate smoke or provide a source of fresh combustion air to the area. NFPA 90A requires that at least one manual shutdown switch be provided for each air-handling system, located at a firefighter control station. This allows the manual operation of smoke dampers. In some instances, owners or AHJs may require an additional emergency shutoff switch to be provided at a nurse's station. The great advantage of a passive system is its simplicity and dependability. Active atrium smoke exhaust or pressure-isolated smokeproof tower systems may be encountered in a building with an otherwise overall passive control approach.

5.3.9 Active Smoke Control (ESCS)

Active systems are designed to automatically contain the spread of smoke to a given zone by establishing a positive-pressure boundary around the zone under alarm. Smoke may be exhausted from this zone, or all air movement shut down. Some model codes require high-rise hospitals (highest occupied floor 75 ft [23 m] or more above the lowest level of fire department vehicle access) to be provided throughout with active smoke control. These systems can consist of dedicated fans, dampers, ductwork, and other equipment, or a combination of dedicated smoke evacuation and "normal HVAC" equipment (as in Figure 5-1), which exhaust smoke and establish pressure boundaries. All components of the combination system must be connected to the building's emergency power system, and the activation controls must be listed for smoke control operation. Smoke control functions must take priority and override other HVAC system control functions during a fire emergency.

Active systems must be provided with a firefighter's smoke control system to permit manual control or override of the building automation system. The potential advantage of the active approach is the more effective isolation of smoke and fire during a fire emergency. The disadvantage of an active system is the added complexity of controls, particularly in nondedicated systems, and the operation and maintenance costs associated with required periodic retesting. The design of active systems must be in accordance with NFPA 92.

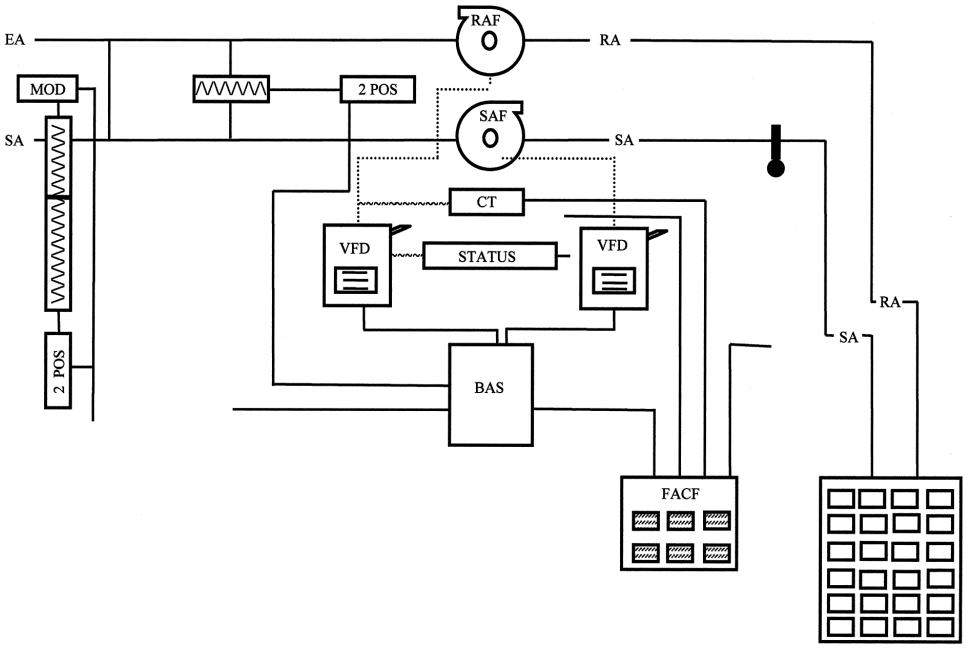


Figure 5-1 *Nondedicated AHU Smoke Evacuation Schematic*

5.3.10 Smoke Control for Atriums

NFPA 101 defines an atrium as "a large volume space creating a floor opening or series of floor openings connecting two or more floors that is covered at the top…" used for purposes other than a stair or escalator enclosure, utility shaft, or elevator hoist-way. NFPA requires that the atrium be separated from adjoining spaces by a 1 h fire-rated barrier, or by glazing protected by dedicated sprinklers, unless an engineering analysis can demonstrate that smoke generated within the atrium will be contained at the top of atrium as described by the code. The engineering analysis may be based on use of an ESCS and should be executed in compliance with NFPA 92. In most cases, building architects or owners will prefer an ESCS, to allow open access to the atrium. The modeling for these systems should take into account fire size and location, materials likely to be burning, the geometry of the plume, etc. (as defined by NFPA 92) and will determine the amount and location of exhaust and makeup air rates required to control the level of smoke accumulation. NFPA requires the system to be activated by sprinkler flow alarm or by manual operation from a firefighter's control station.

5.3.11 General Considerations

The number of devices that must operate to effectively control or remove smoke will impact the reliability of the system and increase construction and operating/maintenance costs. Smoke dampers are expensive and are key sources of air leakage. In addition, code requirements for periodic damper inspection and testing can result in HVAC service interruption and reentrainment of settled dust from the duct into the airstream. These considerations dictate close consideration of the approach to smoke control and the routing of ductwork to minimize the number of dampers. Model or local codes may require monitoring of the positions of smoke and combination fire/smoke

damper blades, particularly in active systems. This will require end switches on the dampers and monitoring by the building automation or fire alarm system. In most cases, if a device does not fail in a smoke/fire-safe condition upon wire break, the control wiring must be supervised to within 3 ft [0.9 m] of the controlled device. NFPA 92 establishes that dampers must reach their required position within 75 s of activation, which is a performance that not all dampers on the market can achieve.

5.3.12 Smokeproof Enclosures

Although not required by NFPA, some codes may require that multistory health care facilities be provided with exit stairwells that are located on the exterior of the building and designed to prevent the spread of smoke from the adjacent building into the stair enclosure. These smokeproof enclosures, sometimes termed "smokeproof towers," exclude smoke by (1) using a naturally ventilated vestibule open to the outside, (2) using mechanical ventilation incorporating a vestibule, or (3) by pressurizing the stair enclosure. The decision regarding which approach to take may be made by the respective AHJ, the owner, or the design architect. Given the complexity of the air-handling equipment and features involved, and the associated impact on future maintenance and periodic retesting, the HVAC engineer should be involved in the early concept planning for these approaches.

5.3.13 Mechanical Ventilation Incorporating a Vestibule

With this approach, NFPA 101 requires that an intervening vestibule be provided between the building and stair tower, ventilated at a rate of not less than 1 ach and exhausting 150% more air than is supplied, via a dedicated ductwork system. Air is to be supplied to the vestibule at a height not greater than 6 in. [152 mm] above the floor, and exhausted entirely within the architectural ceiling smoke trap extending not less than 20 in. [508 mm] above the top of the doors. The stair tower must be positively pressurized to not less than 0.10 in. of water [24.9 Pa] relative to the vestibule (with doors closed), using an air supply that will discharge not less than 2500 cfm [1180 L/s] through a dampered relief opening located at the top of the tower.

5.3.14 Pressurized Stair Enclosure

Pressurized stair enclosures do not require a vestibule between the stair tower and the adjacent building. Per NFPA 101, the stair tower is to be pressurized to maintain not less than 0.05 in. of water [12 Pa] positive pressurization relative to the adjacent building, and to maintain this differential "under likely conditions of stack effect and wind speed." NFPA restricts the location of the air-handling equipment and ductwork providing the stair pressurization, and defines requirements for fire separation and ventilation of the equipment enclosure.

5.3.15 Activation and Testing of Mechanically Ventilated and Pressurized Stair Systems

Stair ventilation and pressurization systems are activated by an area smoke detector located within 10 ft [3 m] of each entrance to the smokeproof enclosure, by a sprinkler water-flow alarm, or manually from a firefighter's control station. NFPA requires that the systems be tested to prove that they are operational before acceptance, and that the systems be retested on a semiannual basis thereafter.

5.3.16 General HVAC Design Considerations

The arrangement and configuration of the HVAC distribution system with respect to building life safety features will have significant affect on overall project construction cost, future maintenance costs, system performance, and service reliability and availability during a fire emergency. In addition, the location of ductwork and piping distribution systems can determine whether exiting arrangements in equipment rooms, floors, and normally unoccupied floors or spaces meet code requirements. The locations of fire and smoke zones should be established very early in conceptual design by the architect and/or fire protection designer, as these decisions will significantly impact the capacity and location of primary air-handling equipment and distribution pathways for piping and ductwork. Consider that, when an AHU serves more than one smoke zone, activation of a smoke detector or other alarm in any zone will result in loss of HVAC service to all zones served, a situation that the owner may find unacceptable. The HVAC designer should be engaged early to exert influence on those factors affecting the overall design.

5.3.17 AHU Capacity and Distribution Pathways

The HVAC designer should consider, as early as feasible in the conceptual planning phase, the capacity of AHUs and the pathways for ductwork and piping systems. The number of smoke zones (acceptable to the building owner or AHJ) to be served by a single AHU will affect the capacity of the unit. Careful consideration should also be given to the arrangement of ductwork systems in relation to facility fire and smoke barriers, to minimize the required number of dampers. Fire and smoke dampers are both expensive to purchase, install, and maintain, and are among the largest sources of air leakage in duct systems. Piping penetrations through rated barriers should also be minimized, to reduce the cost of fire-stopping assemblies and their future inspection and maintenance. Note that HVAC ductwork and piping are not allowed to traverse exit enclosures, except to serve equipment dedicated to conditioning the enclosure. Where ductwork or piping must traverse an exit pathway, they must be located in a rated ceiling with access doors, and with sprinklers located both above and below the ceiling. In planning vertical distribution, be aware that NFPA 90A excludes certain exhaust air systems in shafts conveying environmental air.

5.3.18 Protection of Exit Pathways

The 2012 edition of NFPA 101 for the first time introduced a direct reference to "normally unoccupied building service equipment support areas," which may not contain high-hazard contents or operations, fuel-fired equipment, or storage of combustible materials. In health care occupancies, such spaces must have a designated means of egress when their area exceeds 90,000 ft^2 [8361 m^2]. This egress pathway must have an unobstructed width of not less than 28 in. [711 mm], and a height of not less than 80 in. [2032 mm]. The pathway must remain clear of equipment, including ductwork, piping, conduit, etc. NFPA 101 also separately requires that, for mechanical rooms, boiler rooms, and furnace rooms that contain no fuel-fired equipment, a common path of travel not exceeding 100 ft [30.5 m] is required.

Because it is reasonable to classify an air-handling equipment room as either a "mechanical room" or a "normally unoccupied building service equipment support area," the exit-access requirements for such rooms less than 90,000 ft^2 [8361 m^2] in area are not entirely clear. Indeed, the *2012 NFPA 101®: Life Safety Code® Handbook* (NFPA 2012d) indicates that the effect of the new language is to exempt normally unoccupied building service equipment support areas less than 90,000 ft^2 [8361 m^2] from the requirements for minimum unobstructed egress path height and width; markedly, it does not exempt the common path-of-travel distance. Because it is necessary to provide access to all equipment requiring maintenance or inspection within an equipment room, it is good engineering practice to provide maintenance pathways, reasonably clear of obstructions, of dimensions not less than 28 in. [711 mm] wide by 80 in. [2032 mm] high, to do double duty as emergency egress.

5.3.19 Operation and Maintenance Considerations

NFPA standards, as well as best engineering practices, provide for physical access to HVAC ductwork and life safety equipment that must be periodically cleaned, inspected, maintained, or retested. NFPA 90A and NFPA 72 require duct access openings at each fire damper, smoke damper, combination damper, and smoke detector. Duct access doors must be of adequate size (minimum 18 by 18 in. [457 by 457 mm] when possible) to allow periodic retesting of the devices. Fire dampers are tested by physical removal of the fusible link. NFPA 90A and NFPA 72 also establish frequency of inspection and testing for detectors and dampers. Marked or labeled access panels are required in the architectural ceilings below the duct openings. Ensure that access to dampers is not blocked by other ductwork, cable trays, piping, or other equipment when planning for ductwork routing. More detailed treatment of equipment maintenance is provided in Chapter 10.

5.3.20 HVAC Controls Interface with Fire Protection System

The HVAC system controls and hardware must be coordinated with fire and smoke control elements to avoid system damage and to assure proper operation during fire emergencies. Even with passive smoke control systems, it must be assured that HVAC systems properly respond to shutdown signals from the building fire alarm and to manual control from the firefighter's control station (where required). Additionally, it is critical to consider the effect of fire or smoke damper activation on an air-handling system's operation, particularly when the dampers are near the AHU, to ensure that sudden over- or underpressurization does not damage the equipment. Consider the use of over-/under-pressure-relief dampers. As previously noted, when the HVAC system must operate in combination with an active smoke control system, the level of control complexity increases tremendously, especially so when the system is nondedicated. A valuable tool for displaying (and later testing) the system is a device initiation/reaction matrix, developed during design to show the reaction of specific equipment to a fire alarm signal. A system matrix might graphically show, for a given zone, which AHU supply and return fans, dedicated or shared makeup and exhaust fans, return and relief dampers, isolation and other smoke dampers, and automated door

closers in the zone and in adjacent zones must react to an alarm indication. The functioning of the systems must be thoroughly proven through a rigorous commissioning process before final acceptance.

REFERENCES

ASHRAE. 2008. *Ventilation of health care facilities.* ANSI/ASHRAE/ASHE Standard 170-2008. Atlanta: ASHRAE.

ICC. 2012. *International building code®(IBC®).* Washington, DC: International Code Council.

NFPA. 2013a. *NFPA 72®: National fire alarm and signaling code.* Quincy, MA: National Fire Protection Association.

NFPA. 2013b. *NFPA 80: Standard for fire doors and other opening protectives.* Quincy, MA: National Fire Protection Association.

NFPA. 2012a. *NFPA 90A: Standard for the installation of air-conditioning and ventilating systems.* Quincy, MA: National Fire Protection Association.

NFPA. 2012b. *NFPA 92: Standard for smoke control systems.* Quincy, MA: National Fire Protection Association.

NFPA. 2011. *NFPA 96: Standard for ventilation control and fire protection of commercial cooking operations*. Quincy, MA: National Fire Protection Association.

NFPA. 2012c. *NFPA 101®: Life safety code®.* Quincy, MA: National Fire Protection Association.

NFPA. 2012d. *2012 NFPA 101®: Life safety code® handbook*. Quincy, MA: National Fire Protection Association.

NFPA. 2013c. *NFPA 105: Standard for smoke door assemblies and other opening protectives*. Quincy, MA: National Fire Protection Association.

CHAPTER 6

CONTROLS AND INSTRUMENTATION

6.1 INTRODUCTION

This chapter describes characteristics and components of automatic control systems for HVAC systems serving health care facilities. General control theory and applications are discussed in detail in Chapter 7 of the 2009 *ASHRAE Handbook—Fundamentals* and Chapter 47 of the 2011 *ASHRAE Handbook—HVAC Applications*.

Controls are an essential part of any HVAC system. They provide a comfortable environment for patients, staff, and visitors; optimize energy cost and consumption; improve employee productivity; in some cases, may control smoke in the event of a fire; and control cooling for hospital equipment. Controls are essential for proper and efficient operation of HVAC distribution systems and also for proper and efficient operation of central plant equipment.

Automatic controls are used to maintain a setpoint for a controlled variable when disturbances cause a change in that variable. In HVAC systems, the most commonly controlled variables are pressure, temperature, humidity, and flow rate.

6.2 CHARACTERISTICS OF CONTROL SYSTEMS

6.2.1 A Discussion of Fail-Safe Modes

The consideration of fail-safe modes for HVAC systems and their controls is of particular importance in health care facilities with patients who are not ambulatory. A control valve that fails to "full heat" in an office building is not nearly as critical as one that fails in a patient room. Control actuators have three different failure options—fail closed, fail open, and fail in place. In each case, the designer must consider the appropriate fail-safe mode.

The other important consideration for fail-safe mode involves a direct digital control (DDC) system that relies on a communications

bus for sharing of data. Careful consideration must be given to the mode of operation when, for example, the outdoor air temperature reading is lost. Likewise, prudent system design dictates that the inputs and outputs for a given control loop (e.g., supply air temperature and chilled-water control valve output) reside in the same controller, so that it will continue to provide a basic level of control even on failure of panel-to-panel communications.

6.2.2 Pneumatic Control

Pneumatic control systems use compressed air to operate actuators, sensors, relays, and other control equipment. Pneumatic controls

- are naturally proportional;
- require clean dry air;
- are explosionproof;
- provide for simple, powerful, low-cost, and reliable actuators for valves and dampers;
- are commonly used for simple (VAV box, etc.) zone control;
- are the simplest modulating control means;
- are generally low cost; and
- are truly nonproprietary (vendor-independent).

6.2.3 Electric Control Systems

Electric control systems include valve and damper actuators, temperature/pressure/humidity controllers, relays, and sensors. They are powered by low voltage or line voltage, depending on the circuit requirements. Controllers and actuators can be wired to perform as either two-position (such as ON/OFF or limit) or proportional devices. Electric controls

- are most commonly used for simple ON/OFF control;
- often use an integral sensor ;
- provide a simple sequence of control;
- can function within broad environmental limits; and
- are largely nonproprietary.

6.2.4 Electronic Control Systems

In an electronic control system, an analog sensor signal is amplified and then compared to a setpoint or override to actuate a controlled device. Electronic controls

- provide precise control;
- offer solid-state repeatability and reliability;
- allow remote sensor locations;
- allow simple remote setpoint adjustment; and
- offer completely packaged actuators and controllers.

6.2.5 Direct Digital Control (DDC) Systems

In a microprocessor-based system, controllers can be used as stand-alone devices or they can be incorporated into a building management system (BMS) using a computer to provide additional monitoring and control functions. Microprocessor-based controls

- provide precise control;
- enable energy management control;
- allow self tuning;
- incorporate proportional-plus-integral (and when needed, derivative) control loops;
- can easily perform complex sequences of control;
- support global control (e.g., can share outdoor air temperature or air-side economizer status);
- allow remote setpoint adjustment and display;
- can use pneumatic actuators;
- provide extensive and easy-to-use trending and alarming functions; and
- are usually proprietary (to some extent).

6.2.6 Computerized Building Management System

The objective of a building management system (BMS) is to centralize and simplify the monitoring, operation, and management of HVAC systems. BMS functions in health care facilities typically include

- monitoring environmental conditions, systems, and plants;
- centralized alarm reporting;
- reducing energy use and cost through centralized control of energy-consuming systems;
- data trending;
- providing historical records; and
- supporting maintenance management programs.

Using a centralized system with network communications and user-defined limits for comfort conditions, it is possible to optimize comfort and energy consumption simultaneously.

Modern DDC networks often use a facility's Ethernet local area network (LAN) for communication. Although this is usually a simple matter, caution must be exercised to ensure that there are no bandwidth or security issues associated with this approach. For example, very-high-bandwidth transmissions (such as medical images) can cause traffic delays. The control system must be capable of handling such interruptions. The single most important security issue is to ensure the protection of patient data.

6.2.7 Open-Protocol Control Systems

Open-protocol control systems that use communications protocols such as LonWorks® and BACnet® (ASHRAE 2010b) have become more prevalent in recent years. These systems reduce the need for vendor-specific hardware, because basic data can be shared between controllers from different manufacturers. This can effectively reduce the owner's dependence upon a single control vendor. In addition, money can be saved at the time of installation if packaged systems, such as boilers and chillers, are specified with open-protocol controllers, because the control contractor will not need to provide hardware sensors for the equipment.

Although vendor independence is a big advantage for these types of systems, one must be careful not to overdo the mixing and matching of controllers. For example, a given manufacturer's air terminal controller will be provided not only with the means to share basic data with other open protocol systems, but it will also include software that is proprietary to the controller and will allow more detailed and thorough startup, programming, and checkout of the controller. Thus, using one brand of controller, especially when large numbers of unitary systems are involved, has its advantages.

6.3 ROOM PRESSURIZATION CONTROLS

6.3.1 Pressurization Control Methods

Two room pressurization control methods are commonly found in health care applications: airflow differential ("cfm offset") and room differential pressure control. It is important to keep in mind that the best method is the one that will be most reliable and require the least maintenance and calibration. With both methods of control, the difference between supply and return/exhaust air volume is made up through door undercuts and other gaps in the room structure.

Because of the complexity of both of these methods, and their tendency to lose calibration over time, it is recommended that a visual or other type of indicating system be included to provide local system status indication.

Finally, note that the current trend in rooms that include pressure controls is to dedicate them to either positive or negative function rather than make them switchable.

6.3.2 Airflow Differential Control

The pressurization required for a specific room in a health care facility is usually accomplished (under most codes) by providing differentials in the airflow rates of supply, return, and exhaust air. A room is considered positively pressurized if it has an excess of supply air volumetric flow rate into the room compared to the sum of return and exhaust air volumetric flow rates out of the room. Negatively pressurized rooms have less supply air than the sum of return and exhaust air. In general, the differential is on the order of 50 to 100 cfm [24 to 47 L/s] for patient rooms, and normally 5% to 10% of supply flow for larger rooms. It is very important that the differential be high enough that it can be accurately measured with typical test and balance equipment, and is within the normal control and sensing range of typical DDC system sensors.

The method of flow control can vary with system design. One of the more common methods is to maintain a controlled constant supply volume via an air terminal with an airflow-measuring device, and then manually setting room return/exhaust (in conjunction with central return/exhaust fan volume control). Another method actively controls return/exhaust airflow from each room. This method is more expensive and less reliable, because the airstream being measured is dirty; therefore, the airflow-measuring devices in the exhaust/return airstreams are prone to fouling. In general, measurement of return/exhaust airstream flows for control purposes should be avoided unless the maintenance staff can ensure that they will be able to keep the devices in proper operating condition at all times. In most facilities, this will not be possible or practical.

The advantages of airflow differential control include immunity to room door operations (and other external influences) and simplicity of control.

6.3.3 Room Differential Pressure Control

The second common method of room pressurization control is room differential pressure. With this method, the differential pressure between a room and (for example) adjacent corridor is measured with a precision differential-pressure transducer and the supply and/or exhaust/return airflow is adjusted to maintain a fixed setpoint.

The room differential pressure control has a more complicated control algorithm. In addition, it is subject to fluctuations from door openings and closings, exterior wind gusts, and, perhaps most importantly, changes in the room envelope, such as the wearing down of door gaskets or cracks/openings in the room structure.

6.3.4 Outdoor Air Economizer Controls

An air-side economizer has three main functions under normal operating conditions: free cooling, outdoor air ventilation, and building pressurization. For information on the design of economizer systems, see ASHRAE Guideline 16, *Selecting Outdoor, Return, and Relief Dampers for Air-Side Economizer Systems* (ASHRAE 2010a). The most common HVAC system air-side economizer includes a supply and return fan. The two most common methods of controlling the airflow are airflow matching and static-pressure control.

With airflow matching control, the supply and return airflow volumes are measured, and a fixed offset is maintained by controlling the return air fan speed. This system's setpoint is usually equal to the sum of related building exhaust volumes (e.g., toilet exhaust) plus an offset to ensure positive building pressurization. This method works well as long as the supply and return airflow-measuring devices are accurate and low maintenance. The designer must be careful and allow sufficient ductwork to comply with the installation requirements of the airflow station. In addition, fouling of the return airflow sensor must be addressed, because that airstream is usually unfiltered and laden with dirt, dust, or lint.

With static-pressure control, the mixed-air plenum is controlled to a fixed negative static pressure during minimum position (noneconomizer) operation. This negative pressure is usually controlled by modulating the return air dampers. The outdoor air dampers remain in a fixed minimum position. During system calibration and start-up, the amount of outdoor air is measured by the test and balance contractor, and the static-pressure setpoint is set to the value that provides design minimum outdoor airflow. The return fan discharge pressure is controlled to a slightly positive pressure. This ensures that air flows out of the relief dampers and into the mixed-air plenum.

The static-pressure control method has the advantages of lower maintenance and less susceptibility to dirt and poor ductwork arrangements.

6.4 OPERATING ROOM CONTROLS

6.4.1 Temperature and Humidity Control

Operating rooms may require wide setpoint ranges for temperature and humidity. Most codes require local room temperature setpoint adjustment throughout the entire range under all conditions. In some operating rooms, the medical staff may prefer a room temperature as low as 60°F [15.6°C]. Maintaining the code-mandated maximum relative humidity is often a challenge under such low room temperatures.

6.4.2 Variable-Air-Volume and Room Static Pressure Controls in Operating Rooms and Critical Areas

Some codes require that operating rooms have constant-volume air systems. Certain codes allow reduction of airflow when the operating room or critical area is unoccupied, as long as a means is provided to automatically increase airflow as soon as the room becomes occupied. Most codes require, however, that room pressurization be maintained continuously. Therefore, controls should be included to ensure correct pressure relationships on air volume reset. The simplest way to do this is to have a static pressure sensor in the room to modulate the supply air volume to maintain a minimum pressurization in the room, with return air volume set by a manual damper.

6.4.3 Smoke Control in Anesthetizing Locations

Some codes require a sequence of control in anesthetizing locations that will purge the room of smoke and introduce 100% outdoor air in the supply duct. The intent of this requirement is to buy time for removing or relocating patients who are under sedation. The sequence typically includes indexing outdoor and relief air dampers 100% open, and return air dampers 100% closed. The air-handling system normally includes supply and return (or relief) fans to accomplish this. Usually, the supply fan will continue to run until smoke is sensed in either the outdoor air or supply airstream.

In systems with this sort of sequence of control, it is imperative that the various safeties are prioritized in the correct fashion so that the fan cannot be inadvertently turned off by staff or by the fire alarm system. Additionally, the HVAC system must include preheat coils and cooling coils (as appropriate) that are designed to handle 100% outdoor air at winter and summer design conditions, respectively.

6.4.4 Laboratory Controls

Many hospitals and clinics have associated clinical, pathological, research, and pharmaceutical laboratories. Codes in some jurisdictions require constant-volume controls in hospital laboratories. If a variable-air-volume system is used, it should maintain pressure relationships between the laboratory and adjacent spaces. Care must be taken to not overcomplicate the controls in a laboratory. Many fume hoods available today, for example, have a bypass feature that makes them substantially constant volume. Such a hood reduces the need for a lot of special volume controls in the laboratory air-conditioning system.

6.4.5 General Control Sequences Used in Hospitals and Clinics

The following control sequences can be used as a design guide for typically encountered health care operational situations.

Supply Fan Control by Duct Static Pressure/Supply Fan Motor Speed (Variable-Frequency Drive [VFD]) Control

The supply fan motor speed can be modulated to provide supply air system static-pressure control. During the start-up mode, the supply fan should slowly ramp up to speed to maintain the setpoint of the static-pressure controller.

Humidification

The humidifier should be modulated to maintain space or leaving room air humidity. As the room air humidity increases, the humidifier should modulate closed. The reverse should occur as the exhaust or room air humidity decreases. A high-limit, duct-mounted humidity controller should limit the signal to the humidifier if the supply air humidity exceeds 85% (hardware adjustable). On loss of airflow, the system should be driven to the closed position.

Fan and Damper: Fire Alarm System Control

The control and fail-safe modes for HVAC systems with respect to fire alarm system control should be carefully considered. The sequence of control is often dictated by building codes; the means for execution of the sequence, however, is left (in part) to the designer. Generally, the more control that can be left to the fire alarm system, the simpler and more reliable the system will be. In addition, the more the system is hard-wired (i.e., the less that software is used) the more reliable it will be.

Duct Static-Pressure Safeties

When motorized smoke, isolation, or control dampers are used in a supply air system, the return air or exhaust air ductwork design must ensure that a closure in the supply system does not blow apart the supply ducts or collapse the return air ducts. Ductwork can be damaged if a variable-frequency drive, inlet vanes, or their controls are set improperly. The following steps can prevent this situation (any delay in smoke damper closing, however, should be approved by the authority having jurisdiction):

- Time delay after fan(s) shut down: on a command to shut down a fan, hard-wired time-delay relays should prevent dampers from closing for several seconds after the fan(s) shut off; this should prevent a buildup of pressure until the fan spins down and prevent the fan high-/low-static limit from tripping.

- On shutdown, ensure that a differential pressure (DP) sensor across the fan indicates that a differential pressure of less than a preset value has been achieved before closing any damper.
- A mechanically actuated relief damper may be placed in the ductwork to relieve excessive pressure.
- On a signal to start the air-handling unit, the supply and exhaust isolation dampers (as well as the outdoor air damper and smoke dampers) should open before or when the fans start. Isolation damper end switches can prove that dampers are open and allow the fan(s) to start through hard-wired interlocks.
- An analog discharge air high-static safety located before the supply air isolation/smoke damper should limit the speed of the supply fan .
- An analog return air or exhaust air low-duct-static-pressure sensor located before each return and exhaust fan should reduce the speed of (or stop) the other fans in the system and provide input to the DDC system on sensing a static pressure below the normal operating setpoint.

Hydronic System Controls

In a properly designed hospital HVAC system, the heating and cooling hydronic systems incorporate fail-safe features such as redundancy and load prioritization. An extra heat transfer package, for example, can quickly pay for itself if one frozen chilled-water coil (and resulting flood) is avoided. The controls for such systems should include logic to address the situation when, because of failures, central system capacity is less than demand. Examples of protective measures include shutting off or reducing flow to noncritical areas, such as administration and waiting, to maintain control within more critical areas. Similar to generator load-shedding prioritization, a list of HVAC units and their priorities should be established and reviewed with the hospital administration.

Ultraviolet Device Controls

Any HVAC system that includes ultraviolet (UV) equipment for air treatment should include UV filters on any viewports along with door switches to disable the UV device when an access door is opened. In some cases, it will be necessary to install switches in adjacent AHU sections, because UV radiation can pass through coils and filters in certain configurations.

Miscellaneous Control Monitoring Points

The following list of points should be considered for monitoring by the building automation system, even though they are not part of the building HVAC. In some cases, monitoring of these points and/or systems is required by code. Through monitoring of these points, the facility operator can be alerted to problems early on, thereby minimizing service outages:

- Medical air system alarm and line pressure
- Medical vacuum system alarm and line pressure

- Medical gas system alarm and line pressure (e.g., oxygen, carbon dioxide, nitrous oxide, nitrogen, etc.)
- Domestic water booster pump alarms and line pressure
- Domestic hot-water supply and return temperature
- Fire pump status
- Emergency generator status
- Main power circuit breaker status

Energy Efficiency Control Programming

The requirements of a health care setting can make it very difficult to save energy. However, there are some areas where energy efficiency can be included in the control routine. These include

- setpoint dead bands to avoid simultaneous heating and cooling;
- supply air temperature reset for variable-air-volume systems; and
- supply air static-pressure reset for variable-air-volume systems.

These control routines must include high or low limits to avoid problems, such as high space humidity, which can result from excessive supply air temperature reset.

"Green" HVAC System Controls

In some health care market areas there is a trend toward "green" HVAC systems. When such systems are used, the control system should include sufficient safeties to avoid operational problems. For example, chilled-beam systems should include both a low-chilled-water-temperature limit and a space dew-point monitor and limit. Failure to provide these safeties could result in condensation on the beam surfaces. These systems also require frequent calibration of humidity sensors to ensure safe operation. Heat recovery wheels should be monitored for differential static pressure, to alert staff of a seal failure.

REFERENCES

ASHRAE. 2009. Chapter 7, Fundamentals of control. *ASHRAE Handbook—Fundamentals.* Atlanta: ASHRAE.

ASHRAE. 2011. Chapter 47, Design and application of controls. *ASHRAE Handbook—HVAC applications.* Atlanta: ASHRAE.

ASHRAE. 2010a. *Selecting outdoor, return, and relief dampers for air-side economizer systems.* ASHRAE Guideline 16-2010. Atlanta: ASHRAE

ASHRAE. 2010b. *BACnet®: A data communications protocol for building automation and control networks.* ANSI/ASHRAE Standard 135-2010. Atlanta: ASHRAE.

LonWorks®. San Jose, CA: LonMark International. Available at http://www.lonmark.org.

CHAPTER 7

EXISTING FACILITIES

7.1 OVERVIEW

This chapter addresses the assessment of existing HVAC systems and provides general design considerations for existing facilities. In addition to the normal HVAC design procedures, design for health care facility renovations or additions must

- involve an understanding of the uniqueness of health care design and the owner's specific construction requirements;
- include an assessment of the condition, capacity, and code compliance of the existing HVAC system(s);
- determine preconstruction air and water flows (chilled and heating hot water) to areas outside the project area that are served by the same air-handling unit (AHU); and
- develop construction documents that include infection control provisions related to the HVAC systems.

7.2 FACILITY ASSESSMENT (FA)

Construction cost overruns often reflect inadequate infrastructure assessment during the budgeting process. Before budgeting for a renovation project, the condition, capacity, and code compliance of the existing mechanical and electrical systems must be determined. HVAC requirements vary greatly from space to space in a health care setting, so it cannot be assumed that an existing HVAC system is adequate because there will be no change in floor area.

A common scenario: a firm is hired to design the mechanical, electrical, and plumbing (MEP) systems for a small renovation at a local hospital. The hospital has budgeted $X for the project. The project is small and the floor area is the same, so it is assumed that the HVAC system will only involve minor ductwork revisions. Not long

into the project, load calculations are performed, which determine that the HVAC system needs 10% more airflow than the present AHU is providing. The fan laws dictate that the AHU needs 33% more fan motor power to accommodate the 10% airflow increase. The best case scenario is that the AHU and motor are oversized and the only change will involve pulleys and belts. The worst case is a need for an entire new AHU. This worst case was not included in the budget and sets off a series of painful processes that involve trimming scope, value engineering, scope and fee renegotiation, and ultimately the owner's representative needing to justify additional funds to the COO/CFO. All of this could have been avoided with a proper facility assessment before the project was budgeted.

A comprehensive facility assessment (FA) identifies the condition, capacity, and code compliance of a facility's infrastructure, including architectural, structural, and MEP systems. It presents a global view of the infrastructure systems that can assist annual operations planning and budgeting as well as master planning and budgeting for future expansion or renovations. The MEP portion of a comprehensive FA should

- assess the condition and capacity of all mechanical, electrical, and plumbing infrastructure systems, including incoming utilities, cooling plant and distribution, heating plant and distribution, emergency and normal power distribution, air distribution systems, controls, paging, communications (phone, intranet, BAS), medical gases, pneumatic tube system, fire alarm, fire protection, domestic hot and cold water, fuel oil, and gas;
- determine the existing peak loads on the various systems and identify spare capacity;
- analyze backup (N+1) capacity of the equipment and systems;
- identify deficient equipment and systems and rank them in order of recommended repair/replacement for annual budgeting purposes;
- provide a one- or two-paragraph concept description of the top 5 to 10 repair/replacement projects, including scope and budget estimate; and
- summarize the spare capacity of the various infrastructure systems to assist in scoping future expansion projects.

A facility assessment may also include

- locating all mechanical and electrical equipment on floor plans;
- identifying areas served by each AHU; and
- updating existing riser diagrams.

7.2.1 Conducting an HVAC Facility Assessment

For the purposes of this manual, the facility assessment discussion is limited to HVAC systems (cooling, heating, ventilation, controls, and air distribution). Age, condition, health risk, capacity, energy

consumption, maintenance, code compliance, and known future renovations and expansions are issues to be addressed in the FA.

The following five "Cs" should be addressed by an FA:

- Capacity: ability to maintain design conditions
- Condition: an overall rating of the physical condition
- Criticality: criticality of area or systems served
- Clearance: adequate clearance for proper maintenance
- Code compliance: items not meeting current code

An FA includes taking an inventory of system equipment and listing the nameplate data, age, capacity, condition, and year the equipment will reach the end of its service life (for further detail, see Chapter 39, Operation and Maintenance Management, in the 2011 *ASHRAE Handbook—HVAC Applications* [ASHRAE 2011b]). Equipment does not necessarily have to be replaced at the end of its service life. "End of service life" serves as an indicator for equipment to be watched and budgeted for replacement. Assigning numerical ratings to each of the five Cs (e.g., 1 = good, 4 = poor) and summing the ratings will yield a replacement prioritization list.

7.2.2 Equipment Inspections

The internal working parts of AHUs and cooling towers can be inspected while in operation. But those of chillers, pumps, boilers, condensate tanks, and heat exchangers cannot. The best way to assess the condition of these items without opening them is to consider maintenance and repair records, interviews with maintenance personnel, age, evidence of leaks, noise, excess vibration, oil analysis, ability to maintain set points, and production efficiency. Chillers and boilers should, under good practice, be opened once a year for inspection and cleaning. Ask the maintenance crew to alert you when the chillers and boilers are going to be opened so that you can inspect the tubes, shell, lining, firebox, and general condition of internal surfaces.

Air handlers and cooling towers can be observed while running, if this action is first cleared with the facility maintenance personnel. Opening AHU doors may set off alarms and affect the pressurization in rooms served by the AHU. Before opening an AHU door, check that it opens in the right direction. Doors on the negative-pressure side of the fan(s) should open out. Doors on the positive-pressure side of the fan(s) should open into the AHU. If the opening direction is incorrect, the door may slam in and damage the AHU or slam out and injure the inspector. In some cases, the air pressure may be too great to open a door, and the unit will need to be shut down before entering. One can get very wet inspecting a cooling tower while it is running; an umbrella may help.

7.2.3 Assessing Boilers

Many states require annual boiler inspections and recertification. Inspection dates are arranged ahead of time with the inspector. A scheduled inspection is a good time to inspect the condition of the tubes, shell, firebox, and lining. If the boilers have economizers, open them and check for soot or other deposits on the heat exchange surfaces. Check combustion efficiency with a portable combustion-gas analyzer. Determine peak load from firing-rate records, gas meter readings, or fuel oil consumption readings during peak consumption periods (generally in winter for cold climates, but maybe in a different season in warmer climates because of reheat systems).

7.2.4 Assessing Chillers

Under full-load conditions, determine chiller capacity and efficiency by measuring the flow rate through the evaporator, the chilled- water supply and return temperatures, and the operating voltage and amperage. At the same time, if pressure gages are available, observe pressure drop through the evaporator and condenser (on water-cooled machines) and compare to manufacturer's data. Excessive pressure drop is an indicator of scale or corrosion build-up on the tubes. Determine chiller efficiency (kW/ton [kW/kW]). If efficiency is less than that indicated by manufacturer's data, this may be attributable to scaled tubes or shell, impeller wear, expansion valve wear, or low refrigerant level. All of these possibilities need to be checked by a trained technician. Water flow measurements can be made with a rented Doppler-based strap-on measuring instrument. Chiller capacity can be calculated from measured data as follows:

For I-P units,

$$\text{tons of chilled-water cooling} = (\text{gpm} \times \text{chilled-water } \Delta t \times 500)/12{,}000$$

where

$500 = 8.33 \text{ lb/gal}_{water} \times 60 \text{ min/h} \times 1 \text{ Btu/lb}_{water}\cdot°\text{F}$
$12{,}000 = \text{Btu/ton cooling}$

For SI units,

$$\text{kW of cooling} = \text{L/s} \times \text{chilled water } \Delta t \times 4.18 \text{ kJ/kg}\cdot\text{K} \times 1.0 \text{ kg/L}$$

7.2.5 Assessing Cooling Towers

Visual inspection of cooling tower louvers, fill, sumps, casing, and fan(s) is fairly straightforward. Most cooling towers have side access doors or inspection panels to allow visual examination of interior parts. Cooling tower problem areas include the lower basin (sometimes called the cold basin) and the metal structure around the basin. Galvanized steel basins and structural members rust much more rapidly than a stainless steel basin and structure. Fill degrades over time; it becomes brittle and breaks up. Apply a little pressure to the fill to see how brittle it is.

7.2.6 Assessing Air-Handling Units

Air-handling units require more day-to-day maintenance and have a greater risk of hospital-acquired infections than any other piece of HVAC equipment. Space temperature, humidity, ventilation, and air cleanliness may suffer if an AHU is not properly maintained. Figure 7-1 shows an example of the effects of poor maintenance. The weakest point of an AHU is the area immediately downstream of the cooling coil. Condensation from the cooling coil will rust exposed ferrous components; therefore, designers should specify an aluminum or stainless steel floor, pan, cooling coil supports, and drain pan. Water standing in the drain pan rusts the pan and invites biological growth that can create airborne contaminants and liabilities for the owner. AHUs must be assessed during the summer to determine the effectiveness of the condensate drainage system and during the winter to determine proper operation of steam coils, humidifiers, and economizers.

Fan capacity: Measure airflow by traversing the supply duct or using an anemometer at a filter bank or coil, where the air velocity is relatively constant and uniform. Identify fan manufacturer and model data, fan motor horsepower [wattage], and full-load amps; measure change in pressure ΔP across the fan, the diameter of the fan pulley, and the motor running amps. Compare this information to manufacturer's fan curves to determine spare capacity. If the manufacturer and model information are not available, an estimation of capacity can be made by measuring the diameter of the fan scroll and matching this to another manufacturer's curve for a similar size fan and motor. Remember that airflow is proportional to the cube of the horsepower [motor wattage], so a 10% increase in airflow requires a 33% increase in fan power (see the fan laws in Table 7-1). Increasing motor power may require a larger

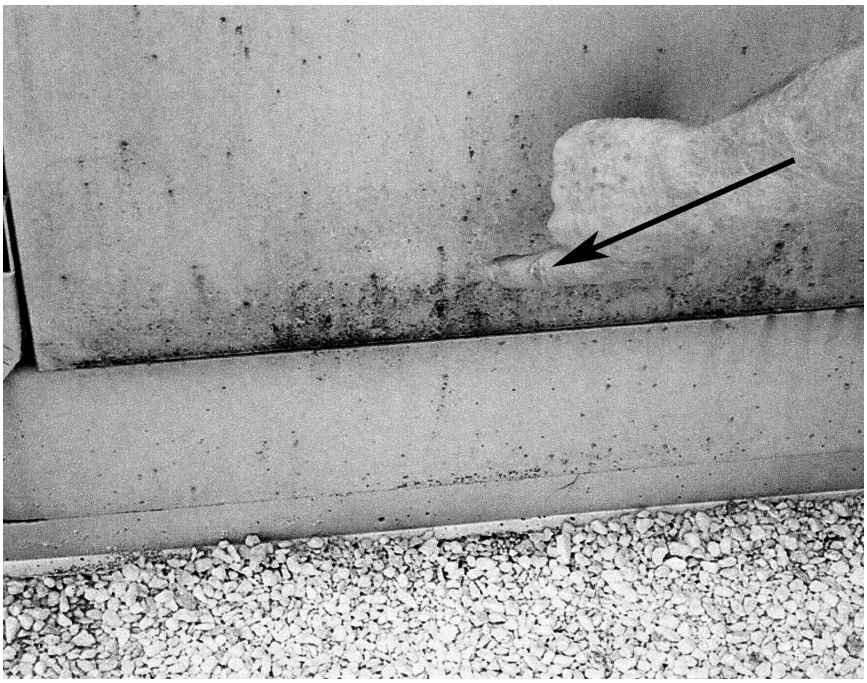


Figure 7-1 *Poorly Constructed AHU: Air Leak Caused Condensation and Mold*

TABLE 7-1 *Fan Laws*

1	New Airflow/Old Airflow	=	New Speed/Old Speed
2	New SP/Old SP	=	(New Speed/Old Speed)^2
3	New HP/Old HP	=	(New Speed/Old Speed)^3

motor starter, disconnect, and conductors. Fan pulley sizes will be limited by the belt guard and possibly by other structural components around the motor.

Cooling capacity: If as-built documents are not available, determine cooling coil capacity by counting coil rows and fin spacing, measuring the size of coil tubes, determining chilled-water supply temperature, and consulting typical manufacturer's data. If the facility has a building automation system (BAS) that monitors cooling-valve position, check the historical data. If the chilled-water control valve is running 100% open for any length of time, the coil is struggling to meet the load. Check if the supply air temperature setpoint is reasonable. If maintenance personnel get a call that a space is too warm, they will often adjust the supply air temperature setpoint to a lower value. This may cause the chilled-water valve to go wide open and rob chilled water from other AHUs. If the chilled-water ΔT is higher than designed, the water flow is too low. Conversely, if the ΔT is lower than designed, water flow may be too high, chilled-water supply temperature may be too high, or coil heat transfer is hampered by dirty/bent fins or plugged tubes. Verify that the control valve is properly sized.

Filtration: Check existing filter condition and seals. Pay particular attention to the access door side of the filters to make sure that the filler strips seal tight against the door. If the filter track protrudes beyond the filters, there must be a blank-off to fill this space, or air will leak around the filter. There may be telltale dirt stains on the AHU casing if air is bypassing the filters. Dirt bypassing the prefilters will deposit on the cooling coil, reducing the coil's capacity to transfer heat. Dirt bypassing the final filters will be entrained in the supply air to the space. Check manufacturer's data for pressure drop at specific air velocities and compare to field observations. If the pressure drop is less than the manufacturer's value, the filters have a leak. Properly installed filters will have a minimum of 0.20 to 0.50 in. of water [50 to 124 Pa] pressure drop, depending upon the MERV rating (see Table 7-2). Check manufacturer's published data for pressure drop at the specific AHU air velocity.

Condensate drain: Place hand over end of condensate drain pipe to see if air is blowing out or being sucked in. Either case is an indication of an improperly sized trap. Air blowing out may be acceptable if the AHU is in a hot mechanical room. If the AHU is located outdoors, air blowing out of the drain pipe is wasted energy. Air drawn into the AHU is unconditioned, unfiltered air that is introduced into the airstream

TABLE 7-2 *Typical Initial Pressure Drops for Air Filters (at 500 fpm [2.5 m/s])*

Filter MERV Rating	Application	Initial ΔP, in. of water [Pa]
7-8	Prefilters	0.20 to 0.30 [50 to 75]
13 to 14	Final filters	0.40 to 0.50 [100 to 124]
16 (95% for 0.3 μm particles)	HEPA filters	0.50 to 0.60 [124 to 149]
16 (99% for 0.3 μm particles)	HEPA filters	1.00 [249]

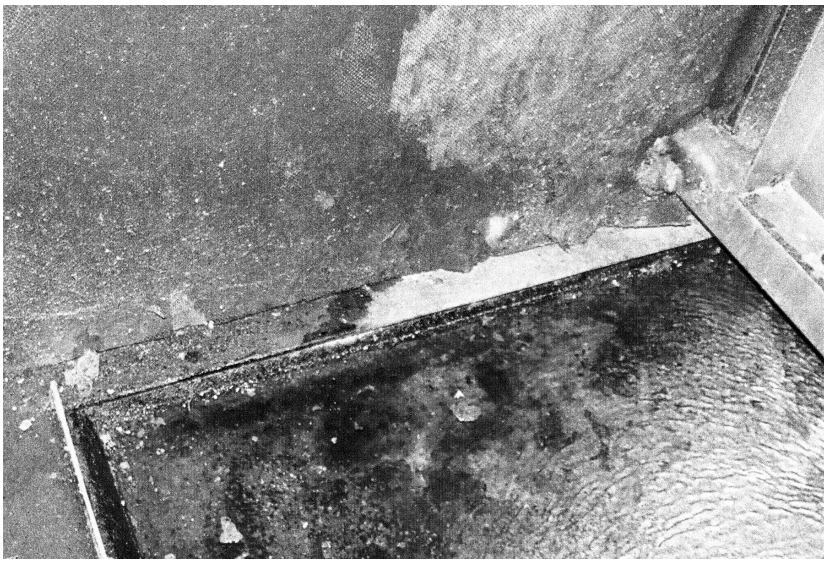


Figure 7-2 *Standing Water in Condensate Pan Caused by Improper Drain Design*

downstream of the cooling coil. Poor condensate drainage is the downfall of many air handlers. A poorly sloped drain pan, drain on side of pan rather than bottom, and improperly sized drain traps can all cause water to stand in the drain pan (as seen in Figure 7-2, where the internal lining is peeling off). Standing water increases the risk of rust inside the AHU and provides a breeding ground for undesirable biological growth. If water is standing in the drain pan, determine if the drain pan can be retrofitted with a proper (Figure 3-9) pan and trap. If not, it may be possible to raise the AHU and rebuild the pan and trap; otherwise, the AHU should be replaced. A draw-through AHU (assuming 2 in. of water [498 Pa] negative pressure at the cooling coil) needs to be mounted 8 to 10 in. [203 to 254 mm] above the floor or roof to install a proper condensate trap and drain line. A blow-through AHU (assuming 5 in. of water [1244 Pa] positive pressure at the cooling coil) needs to be mounted 12 to 14 in. [305 to 356 mm] above the floor or roof for a proper condensate trap. Figure 7-3 (note the water standing in the bore) and Figure 7-4 illustrate the results of failing to plan for proper condensate drainage.

Figure 7-3 *Core Bore of Concrete Floor to Install Condensate Trap*

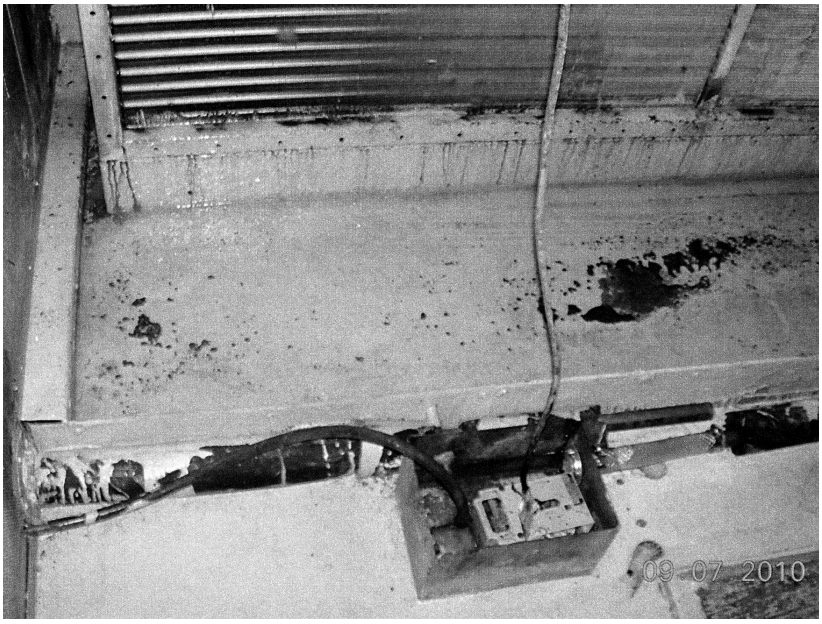


Figure 7-4 *Portable Sump Pump in Condensate Drain Pan*

Preheat coils and humidifiers: Preheat coils are only needed when the outdoor air is below freezing and the AHU has 100% outdoor air capability; thus, the dampers could fail open. Humidifiers are required in colder climates where the outdoor air dew point drops below 30°F [−1.1°C] and in special building areas (such as burn and neonatal units) where high humidity is required. Both systems are not needed several months a year and should be shut off tightly to avoid energy waste. Although it is often assumed that steam control valves shut off tightly, as control valves age they are less likely to do so. When inspecting AHUs during the off-season, touch the inlet pipe to the coil or humidifier to ensurethat it is cold. It is highly recommended that manual block valves be shut off during the off-season.

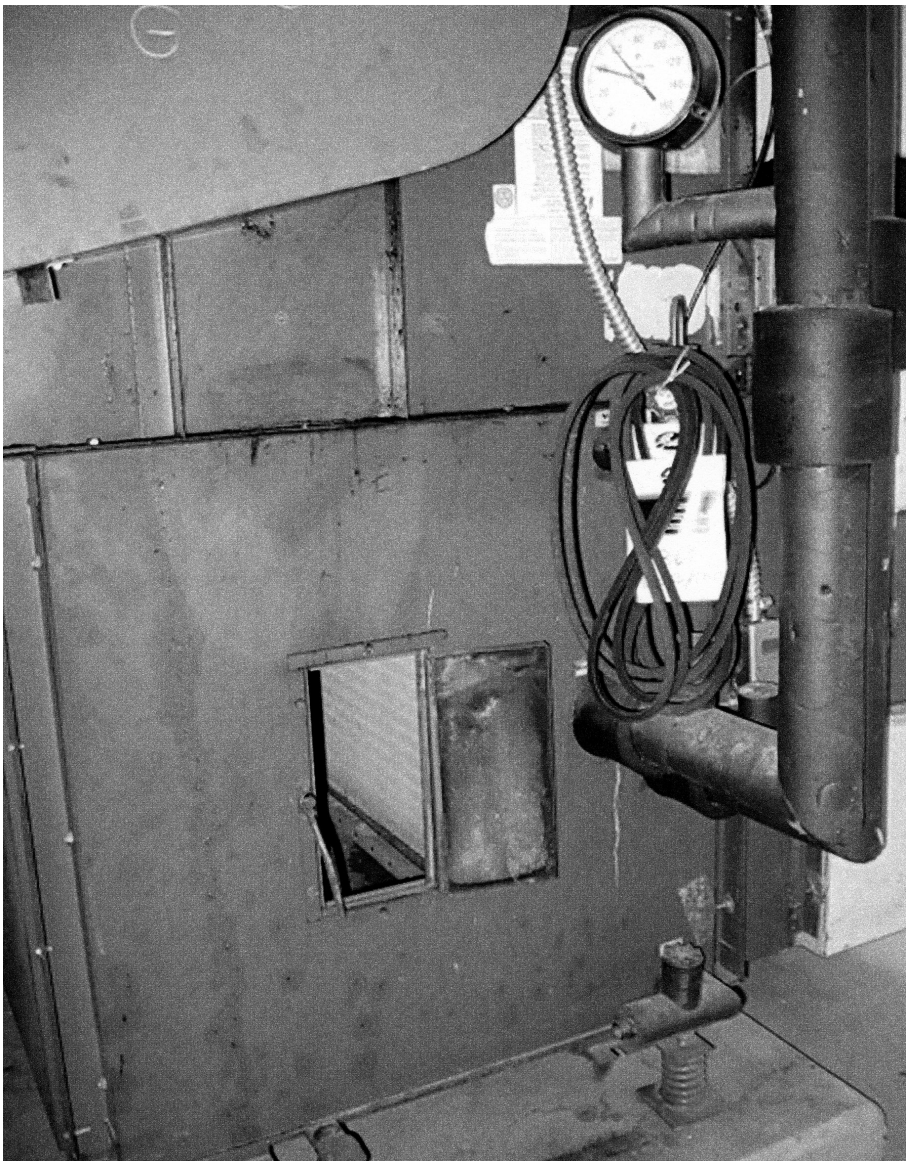


Figure 7-5 *Example of Poor Maintenance Access*

Clearance/access: Clearance directly impacts air quality, cost of maintenance, and life of the unit. Proper clearance invites repetitive inspections and thorough maintenance, significantly reduces maintenance time and cost, and extends the life expectancy of an AHU. A well-maintained unit will last several years longer than one that is not maintained properly. Small, commercial-grade AHUs with 12 in. [305 mm] access doors and 12 to 18 in. [305 to 457 mm] clearance are difficult, if not impossible, to maintain. Figure 7-5 shows an example of poor maintenance access. Some of these units have no clearance at the coils or condensate drain pan; thus, the units must be dismantled for inspection, cleaning, and maintenance. For example, if not drained properly, condensate will sit in a drain pan and invite biological growth that can present a health risk and potential liability for the hospital. Having no clear access to the downstream side of a cooling coil invites

this unwanted biological growth. Coils, drain pans, dampers, and temperature sensors must be cleaned and adjusted annually. Prefilters must be changed every 3 to 6 months, depending on outdoor air conditions. Final filters must be changed every 6 to 24 months. Fan belts must be checked and adjusted every 3 to 6 months. Humidifiers, pressure sensors, and airflow sensors must be checked annually.

Optimally sized AHUs: Small AHUs should be combined and replaced with custom–made, walk-in AHUs with a minimum of 30 in. [762 mm] clearance between all components. The minimum recommended inside dimension is 7 ft high by 7 ft wide [2.1 by 2.1 m]. This will provide a net 6 × 6 ft [1.8 × 1.8 m] coil (16,000 cfm at 450 fpm face velocity [7550 L/s at 2.3 m/s]) and a filter rack using common 24 × 24 in. [610 × 610 mm] filters. This is also large enough to allow maintenance personnel to stand while cleaning coils and drain pans, changing filters, greasing bearings, checking control sensors, checking economizer dampers, etc. Small units can take 2 to 5 times longer to maintain than a larger walk-in unit. One 16,000 cfm [7550 L/s] walk-in AHU replacing two 8000 cfm [3775 L/s] units could significantly cut maintenance time.

Adequate clearance provides the following benefits:

- *Lower maintenance cost.* Experience indicates that many commercial-grade AHUs demand 3 to 5 times as much time to maintain filters, coils, drain pans, and the area downstream of cooling coil because of difficult or impossible access and clearance. In some cases, inaccessible cooling coils and drain pans go for years without being maintained; this introduces fertile conditions for hospital acquired infections (HAIs). A custom AHU with proper access and clearance will significantly reduce the cost of maintenance.
- *Less planned shutdown time.* In 24/7-critical areas (ED, ORs, imaging, pre- and post-op, ICUs, isolation rooms, etc.) shutdown time must be minimized. Maintenance time can be minimized with adequate access and clearance.
- *Fewer unexpected failures.* Obviously, equipment that is not maintained will fail. Failure of an AHU in a critical area, without backup systems and an in-place emergency plan, could be catastrophic. AHUs that are maintained on a regular schedule have a lower risk of unexpected failure.
- *Longer equipment life.* Equipment that is maintained properly will last much longer than equipment that is not.

Assessment rankings: Once an assessment of the five Cs is complete, a ranking process identifies individual projects and sorts them in order of worst condition to best condition. As noted previously, consider combining smaller AHUs. Then prepare a project write-up describing which units (if any) are being combined; where the temporary or

permanent unit will be installed; where points of connection to existing utilities can be made; capacity of the building structure and utility infrastructure to support the project; and including a budget cost estimate. The cost estimate should include A/E design fees and contingency. This write-up will provide the information the hospital engineering group needs for its annual budget requests.

7.3 DESIGN CONSIDERATIONS FOR RENOVATION PROJECTS

This section discusses design considerations that are unique, or deserve special attention, when designing renovation projects in health care facilities. It expands on the chapter on health care facilities in the *ASHRAE Handbook—HVAC Applications*.

7.3.1 Special Environment

Special considerations are involved when designing health care HVAC systems in order to address the delicate condition of patients and the 24/7 presence of staff and patient families. Patient safety is the first and foremost requirement for any construction activity in a hospital.

7.3.2 Design Standards

Because of the size and diversity of projects, many design codes and standards apply to health care facilities. Chapter 1 discusses the basics of these various standards, and their interrelationships. HVAC requirements/recommendations fall into two general categories: (1) environmental control (e.g., addresssing temperature, relative humidity, pressure differential, exhaust, filtration, air changes, fresh air, recirculated air, etc.) and (2) life safety (e.g., addresssing fire, smoke, etc.). The environmental requirements are primarily based on ASHRAE standards that have been incorporated into the FGI *Guidelines* (FGI 2010). The life safety requirements are based on NFPA (National Fire Protection Association) standards.

A list of widely accepted standards follows. These represent the latest best-practice techniques and recommendations; however, they are only guidelines until adopted by (most) states and local authorities having jurisdiction (AHJs), who adopt these standards by reference or base their codes on them. Note that there may be a few years lag between the time these standards are published and the time they are accepted by AHJs; therefore, be aware that there may be differences between local codes and current standards. Consult *NFPA 101®* (Chapters 43 and 44) for the application of other NFPA standards. Pay close attention to the footnotes in Chapter 8, Table 3, Design Parameters, in the 2011 *ASHRAE Handbook—HVAC Applications*. See the following publications for additional information:

- Facilities Guidelines Institute: *Guidelines for Design and Construction of Health Care Facilities*
- *ASHRAE Handbook—HVAC Applications*, Chapter 8, Health-Care Facilities
- ASHRAE Standard 52.2-2007*, Method of Testing General Ventilation Air Cleaning Devices for Removal Efficiency by Particle Size* (a standard for filter ratings)

- ANSI/ASHRAE Standard 62.1-2010*, Ventilation for Acceptable Indoor Air Quality*
- ANSI/ASHRAE/ASHE Standard 170-2008*, Ventilation of Healthcare Facilities*
- *NFPA 90A: Standard for Installation of Air-Conditioning and Ventilation Systems*
- *NFPA 92A: Standard for Smoke-Control Systems Utilizing Barriers and Pressure Differences*
- *NFPA 99: Health Care Facilities Code*
- *NFPA 101®: Life Safety Code®*

7.3.3 Asbestos Survey

Check for asbestos in older areas, particularly in paint, flooring, gypsum board, mastic, transite duct, and pipe insulation. Ask if the hospital has performed an asbestos survey.

7.3.4 Facility Standard Operating Procedures

Include in the project specifications the owner's requirements for obtaining work permits, employee badging, parking, use of facilities, utility shutdown procedures, ILSM (interim life safety measures), and ICRA (infection control risk assessment) meetings, etc. These items should be addressed by the architect as contractor conditions; however, they also apply to the architect and engineer while doing field work. See Chapter 11 for further discussion.

7.3.5 Above-Ceiling Permit

Many hospitals have adopted an "above-ceiling permit" policy that allows only a few ceiling tiles to be removed at a time. The engineer must obtain this permit before making above-ceiling inspections (see Chapter 11).

7.3.6 Fire and Smoke Barriers

The architect should compile a life safety plan early in the design process that identifies fire- and smoke-rated walls in the project area. Show these walls on the MEP drawings with different symbols. All ducts passing through fire-rated walls require fire/smoke dampers. Because area usage can change over the years, identify which AHU serves a given area, and determine its fire alarm sequence. If the area is served by more than one AHU, check that the fire alarm sequences and emergency shutoff buttons are compatible. See Chapter 5 for further discussion of life safety systems.

7.3.7 Above-Ceiling Clearances

Do not trust existing design drawings for the locations of equipment or structure. Seldom are projects constructed exactly as shown on design drawings. Field-verify the height of ceilings, structural members, and any other building components that will be reused, including ductwork or piping that will remain or to which connections will be made. Ceiling space over corridors can be very congested. In patient care areas, it is not unusual to have ductwork, terminal boxes, diffusers, chilled-water pipes, steam, sewer lines, domestic hot and cold water, oxygen, vacuum, medical air, conduits, communication cables, cable trays, speakers, and light fixtures vying for space above the corridors. Years ago, 24 to 30 in. [610 to 762 mm] clearance was

thought adequate; now 36 to 48 in. [915 to 1220 mm] is the minimum required clearance. Imaging and surgery areas require no less than 48 in. [1.2 m] for utility booms and imaging structure (see Chapter 8). Many hospitals have been through multiple additions and renovations. Interfaces between old and new work may involve very limited clearances under beams. Ceiling clearance in one area may not be the same as that in another. Ask veteran hospital staff if there have been building additions in the past. Ultimately, above-ceiling inspections must be made in several places. Don't assume that the structure is the same throughout the space.

7.3.8 Reusing an Existing AHU

If reusing an AHU is being considered, the unit's condition, capacity, and type of components must be determined. Identify the components in the existing AHU and the components needed for the renovation project. If the area previously served by a unit was not a patient care or surgery area, the AHU may not have proper temperature and humidity control components, filtration, outdoor air provisions, or fan pressure classification. See section 7.2.6, Assessing Air-Handling Units, for more details.

7.3.9 Surrounding Areas

If an AHU serves more than the area under construction, provisions must be made to keep the nonconstruction areas in operation and prevent migration of airborne contaminants from the construction area to the surrounding area. Supply air from the AHU may be used in the construction area if the construction area maintains negative pressure to surrounding areas. The construction area must be under negative pressure with respect to the surrounding areas at all times during construction. Air may be returned to the AHU from the construction area if no fumes are returned and the air is filtered before entering the return ductwork (typically by placing filters over all return air openings). These measures are addressed in the ICRA (see Chapter 11).

Determining the areas served by an AHU is not an easy task. Whether the information comes from a facility assessment, the HVAC supervisor, or old design drawings, it must be verified by inspecting ductwork above the ceiling or by shutting down the AHU long enough to check air outlets. It may be possible to shut the AHU down for short periods in noncritical areas; check with the facility HVAC supervisor.

7.3.10 Establish Preconstruction Airflow to Areas Outside the Project Area

If areas outside the construction area are served by an AHU involved in renovation activities, establish the preconstruction conditions to avoid postconstruction liability for conditions that existed before the construction began. Before starting design request that the owner hire a test and balance (TAB) contractor to measure the total supply and return airflow and static pressure to areas outside of the renovation area. A full TAB effort is not required, only traverses at the mains to establish the total flow. Make this measurement at the start of construction before any work is performed and again at the completion of construction.

7.3.11 Replacing an Existing AHU

Upgrading or replacing an AHU serving an area that is to remain in service requires the installation of a parallel AHU. The new unit may be temporary or permanent, but must be installed and running before the old unit can be repaired or removed. This involves finding space to install a second AHU while the first is still running. Space must also be found for new supply and return air mains, new electrical power, chilled water, steam, hot water, drains, and outdoor air intake.

7.3.12 Existing Air Distribution System

Determine the existing air distribution system type and its suitability for the new project. Older HVAC systems generally reflect the state-of-the-art at the time the facility was built. These could include dual-duct systems, constant-air-volume (CAV) reheat systems, variable-air-volume (VAV) reheat systems, two- or four-pipe fan-coil systems, and sometimes a mixture of these. Dual-duct systems are rarely used today because of high cost and a lack of ceiling space. VAV systems have limited health care application because of space-to-space pressure differential requirements. Fan-coil units are no longer allowed in patient care areas. Therefore, hospital HVAC systems today are almost exclusively single-duct, CAV, hot-water terminal reheat systems. There may be situations where only a part of an HVAC system was renovated and there is a mixture of old and new systems (e.g., partial conversion of a dual-duct system to a single-duct system). Don't assume that an existing air distribution system is being used as originally designed.

7.3.13 Switchable Pressure Isolation Rooms

Some older isolation rooms were designed to switch between positive and negative pressure. These systems did not work well and are now prohibited by the FGI *Guidelines* (FGI 2010). Replace these systems wherever found, and do not reuse them.

7.3.14 Isolation Room Exhaust Fans

To avoid exposing maintenance personnel or others working on a roof to exhaust air from isolation rooms, exhaust fans with high-velocity vertical discharge (2500 to 3000 fpm [12.7 to 15.2 m/s] or more) should be installed, with the top of the discharge at least 10 ft [3 m] above the roof.

7.3.15 Location of Isolation Rooms

Encourage architects to locate isolation rooms away from stair-wells, elevators, or any other floor-to-floor shafts. Pressure fluctuations in the shafts can affect the pressure differential of the isolation room and cause airborne infectious isolation (AII) rooms to go positive or protective isolation rooms to go negative. Although the architect is responsible for floor plans and location of rooms, if given a chance the engineer should advise.

7.3.16 Internally Lined Ducts and AHUs

All internally lined ductwork should be replaced (to avoid the situation shown in Figure 7-6). All ductwork and coils downstream of internally lined ducts serving a new construction area should be cleaned. Do not clean ductwork serving areas outside of the construction areas.

7.3.17 Consolidation of Small Air Handlers

If project is served by a small AHU (less than 16,000 cfm [7550 L/s]), consider replacing similarly sized AHUs in the vicinity with a larger, more-accessible AHU (see section 7.2.6 regarding assessing AHUs).

7.3.18 Fan-Coil Units

Fan-coil units are discouraged because they are difficult to maintain, provide poor filtration, and contribute to a high risk of infection. ASHRAE Standard 170 does not recommend fan-coils in surgery, recovery, trauma, and other areas. This advice is mirrored in the FGI *Guidelines* (FGI 2010) and Chapter 8 of the *ASHRAE Handbook—HVAC Applications* (ASHRAE 2011a). Many state and local AHJs have adopted the FGI/ASHRAE requirements as code.

7.3.19 Isolation Valves

Locate the shutoff valves nearest to the construction area. Isolation valves may not be found on all branches. If this is the case, it may be necessary to shut down other areas of the hospital. This needs to be considered during the design phase and provisions made for the nonconstruction areas that will be affected. If outlying areas have to be shut down, the owner may want to take this opportunity to install shutoff valves in the other areas. Have a contingency plan in case the shutoff valves do not close tightly.

7.3.20 Labeling

Many hours are spent tracing pipes and ducts through a facility when systems are not labeled. This time-consuming search repeats itself each time the engineer designs a new project, a contractor constructs a new project, or maintenance personnel have to find a valve or repair a system. A heating-hot-water line can be mistaken for a chilled-water line quite easily if not readily accessible to touch. Specify that all pipes and ducts be labeled every 15 ft [4.6 m], within 5 ft [1.5 m]

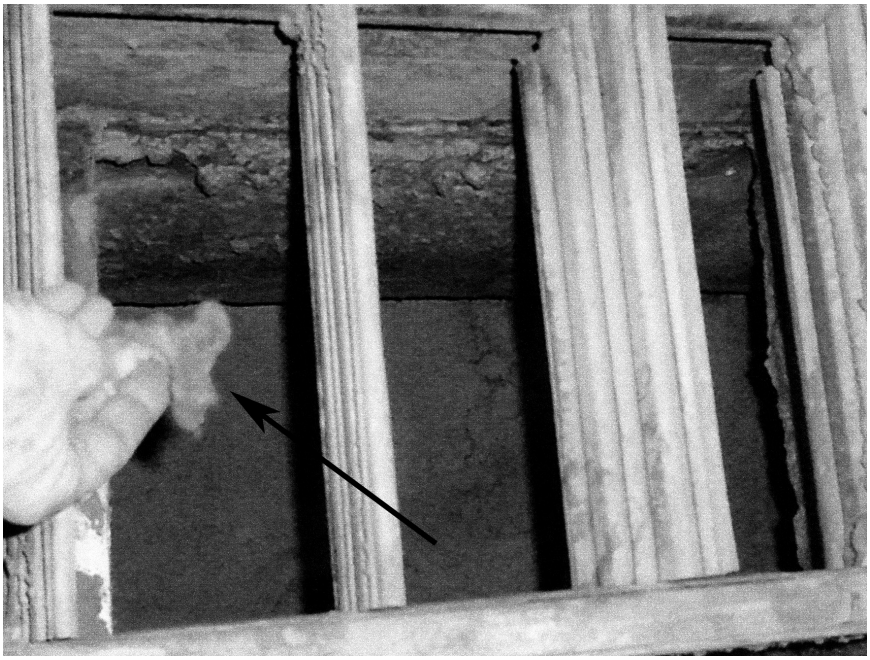


Figure 7-6 *Ductwork Lining Peeling off into Airstream*

of all elbows and tees, and on both sides of a wall penetration within 3 ft [0.9 m] of the penetration. Use different colors for different services. Lettering should be a minimum of 1 in. [25 mm] high and commensurately larger as the pipe or duct dimensions will permit. Check to see if the owner has standard colors or labels.

7.3.21 Remove Unused Components

Remove all unused equipment, ductwork, and piping. Do not allow it to be abandoned in place.

7.3.22 Updating Peripheral Systems

If an HVAC system serves areas outside of the construction project, check with the AHJ regarding requirements for upgrading those areas to the latest codes or standards.

7.3.23 Phasing Plan

Many projects will require that the work be phased. For bidding purposes, it will help the contractors understand which work items are included in each phase if information is provided to show/explain work phases. This information and/or drawings should be part of the architectural sheets.

7.3.24 Commissioning

Determine the owner's desires for commissioning. An owner may want the renovation area commissioned as well as all other areas served by the same AHU. See Chapter 12 for further discussion of commissioning and retrocommissioning.

7.3.25 Working Hours

Specify, on drawings or in specifications, the times during which the contractor is allowed to work in the project area and in areas outside the project area where miscellaneous work to support the project must be undertaken. See section 7.3.29, Disruptions to Areas Outside the Project Area, for further discussion.

7.3.26 Proper Electrical Branch

Determine the criticality of the area served by the HVAC system, and ensure that it is connected to the proper electrical power branch. Generally, AHUs are connected to the equipment branch.

7.3.27 Infection Control Risk Assessment (ICRA)

Work with the hospital infection control department to establish an ICRA (infection control risk assessment) plan. See Chapter 11 for further information.

7.3.28 Interim Life Safety Measures (ILSM)

Work with the hospital safety committee to establish interim life safety measures (ILSM). See Chapter 11 for further information.

7.3.29 Disruptions to Areas Outside the Project Area

Connecting to existing systems may require that (1) work be done outside the project area or (2) utilities serving areas outside the project area be shut down. Depending on the criticality of the area, this may require substantial temporary measures. Shutdowns and work in areas outside the project area must be coordinated with the project manager during the design phase and be communicated to the contractor in the design documents. Make it clear that only facilities operations personnel are allowed to shut down any utility.

Keep in mind that certain utilities (e.g., medical vacuum) are more critical than others, and these may require more extensive mitigation measures. The following is a general guide to hours-of-use for various hospital departments:

- *No shutdowns.* Many critical areas in a hospital cannot be shut down without moving the activity elsewhere or shutting down only a small portion at a time. These areas include patient rooms, isolation rooms, intensive care units, emergency department, emergency operating and imaging rooms, pre-op and post-op units, labor and delivery, nursery, portions of the lab, at least one pharmacy and sterile supply (larger hospitals have multiple pharmacies and sterile supplies).
- *Evening shutdowns.* Part-time functions that operate seven days per week include the kitchen (usually closed or with a skeleton crew in late evenings/early mornings), dining areas, and medical records.
- *Evening and weekend shutdowns.* Part-time functions that typically operate five days per week include day surgery, cancer treatment, rehabilitation/therapy, imaging rooms not needed by the emergency department, endoscopy, and administrative offices.

7.4 CONTRACTOR QUALIFICATIONS

Construction in a health care facility differs from most other construction environments. Proximity to patient care areas requires special construction procedures. Consider hiring a contractor with health care experience and Certified Healthcare Constructor (CHC) certification from the American Society for Healthcare Engineering (ASHE). During construction, make sure that the contractor

- maintains cleanliness measures established in the ICRA (see Chapter 11);
- reduces construction noise (e.g., using jackhammers or impact guns may not be allowed);
- schedules work so as to least disrupt patients;
- coordinates shutdowns with the hospital project manager and includes a schedule in bid documents; and
- maintains proper clearance in the ceiling for maintenance, particularly on the controls side of terminal boxes (needing 24 in. [610 mm] clear).

REFERENCES

ASHRAE. 2011a. Chapter 8, Health-care facilities. *ASHRAE Handbook—HVAC Applications.* Atlanta: ASHRAE.

ASHRAE. 2011b. Chapter 39, Operation and maintenance management. *ASHRAE Handbook—HVAC Applications.* Atlanta: ASHRAE.

FGI. 2010. *Guidelines for design and construction of health care facilities.* Dallas, TX: Facility Guidelines Institute.

BIBLIOGRAPHY

ASHRAE. 2011. *ASHRAE Handbook—HVAC Applications.* Atlanta: ASHRAE.

ASHRAE. 2007. *Method of testing general ventilation air-cleaning devices for removal efficiency by particle size.* ANSI/ASHRAE Standard 52.2-2007. Atlanta: ASHRAE.

ASHRAE. 2010. *Ventilation for acceptable indoor air quality*. ANSI/ASHRAE Standard 62.1-2010. Atlanta: ASHRAE.

ASHRAE. 2008. *Ventilation of health care facilities*. ANSI/ASHRAE/ASHE Standard 170-2008. Atlanta: ASHRAE.

ICC. 2012. *International building code®(IBC®).* Washington, DC: International Code Council.

NFPA. 2012. *NFPA 90A: Standard for the installation of air-conditioning and ventilating systems.* Quincy, MA: National Fire Protection Association

NFPA. 2009. *NFPA 92A: Standard for smoke control systems utilizing barriers and pressure differences.* Quincy, MA: National Fire Protection Association.

NFPA. 2012. *NFPA 99: Health care facilities code*. Quincy, MA: National Fire Protection Association.

NFPA. 2012. *NFPA 101®: Life safety code®.* Quincy, MA: National Fire Protection Association.

CHAPTER 8

ROOM DESIGN

8.1 INTRODUCTION TO ROOM DESIGN

Many rooms in hospitals require special design considerations because of heightened infection concerns, high internal loads, special equipment, unique processes, and unique patients. Air change and pressurization requirements for all such rooms are listed in Table 3-3; these values reflect ANSI/ASHRAE/ASHE Standard 170-2008 (ASHRAE 2008) with addenda through July 2012. This chapter presents best practice suggestions along with details about how to achieve these requirements..

Many spaces in hospitals require maintenance of a differential pressure relative to adjacent spaces. For example, ORs, protective isolation, and sterile supply require positive pressure, whereas airborne infectious isolation, toilet, soiled, bronchoscopy, and decontamination rooms require negative pressure.

8.2 ROOM PRESSURIZATION

Measuring a differential air pressure between a room and the corridor may provide evidence that all air movement is in one direction. There are a number of factors, however, that may well allow air to escape from a room or air to enter a room in spite of a negative or positive room-to-corridor pressure relationship. One such factor is opening and closing of the room door.

The truly significant factor in determining the amount of air migration from a room to a corridor is the airflow volume differential (Hayden et al. 1998). In all cases, some air volume migration occurs through an open door when the air pressure difference is essentially zero.

An anteroom is recommended as a means of reducing airborne contaminant concentration by containment and dilution of the migrating

air and to protect the adjacent corridor from excess airflow into or out of the isolation room. In one study, for a range of room air exhaust flows from 50 to 220 cfm [24 to 104 L/s], the migration between a room and its anteroom was found to be 35 to 65 cfm [17 to 31 L/s] (Hayden et al. 1998). For example, through dilution, a 500 ft^3 [14 m^3] anteroom with a migration of 50 cfm [24 L/s] would (in an hour) experience a 90% reduction in the transmission of contaminated air to and from the patient room.

Provide a tight envelope to maintain desired pressurization. Walls must extend from floor to structure and openings (such as electrical and medical gas outlets) must be sealed. Maintain a specific differential airflow rate between supply and return/exhaust. Airflow from one space to another occurs through cracks or gaps in walls, ceilings, floors, and around doors. The sum of the areas of all these pathways is called the leakage area. The infiltration or exfiltration flow from a room is a function of the leakage area and the pressure differential across all surfaces of the room. Isolation is maintained only when the airflow is unidirectional on each surface. Air pressure differential is a measurable quantity and should be maintained at 0.01 in. of water [2.5 Pa] relative to adjacent spaces.

As discussed in Chapter 6, differential measure may be achieved by controlling supply and exhaust via a pressure monitor; or it can be accomplished with a fixed offset between supply and exhaust airflow. A minimum differential airflow rate for a very tight room is 200 cfm [94 L/s]. The engineer must encourage the architect to seal the room to allow a 0.01 in. of water [2.5 Pa] pressure difference with a fixed air volume difference. *ASHRAE Handbook—Fundamentals* (ASHRAE 2009) provides a method to estimate the allowable leakage area as follows:

$$A_L = C_5 Q_r \, (\rho/2 \, \Delta p_r)^{1/2} / C_D \Delta p_r$$

A_L = air leakage area, $in.^2$ [cm^2]
C_5 = units conversion, 0.186 [10 000]
Q_r = air leakage volume, cfm [m^3/s]
ρ = air density, 0.0724 lbm/ft^3 [1.158 kg/m^3] at normal room temperature
C_D = discharge coefficient, often set to either 1.0 or 0.6
Δp_r = reference pressure difference, in. of water [Pa]

The coefficient C_D depends upon the gaps through which the air flows. An estimate of this parameter, 0.186, has been made and empirically tested. The designer should estimate the leakage area A_L using the method from the *ASHRAE Handbook—Fundamentals* chapter on infiltration.

A room's static-pressurization value is wholly dependent upon the differential airflow and the room's leakage rate. Figure 8-1 shows, for

a room with 1.0 ft² [0.09 m²] of leakage area, that a differential pressure Δp_r of just under 0.01 in. of water [2.5 Pa] occurs when the difference between the room's supply air and the total room exhaust is 250 cfm [118 L/s]. This relationship exists regardless of the room's ventilation rate (air changes per hour). Therefore, to maintain a specific room pressurization value, supply and exhaust airflow must be controlled and maintained at the appropriate value.

Most modest-sized patient rooms will have a total room leakage area of at least 0.5 to 1.0 ft² [0.05 to 0.09 m²], even with relatively tight construction. To attain a tighter room, extensive sealing and meticulous attention to wall, ceiling, and floor penetrations (where conduit, piping, ductwork, and other items pass through) are required. Leaky rooms require a larger airflow offset, thereby wasting energy. An offset of 100 to 200 cfm [47 to 94 L/s] is desirable.

8.2.1 Negative Air Pressure

If the leakage area for a negative-air-pressure room cannot be reduced to that needed for an airflow differential of 100 cfm [47 L/s], recalculate with the known air leakage area and solve for Q_r. In most cases, Q_r will need to be larger; and can even equal the total cooling supply air volume. To reduce the value of Q_r, the ventilation designer should influence the envelope tightness as a means of decreasing the leakage area. Per Figure 8-1, leakage areas of 60 in.² [38,700 mm²] require a Q_r of 100 cfm [47 L/s] at 0.01 in. of water [2.5 Pa]. Maintaining

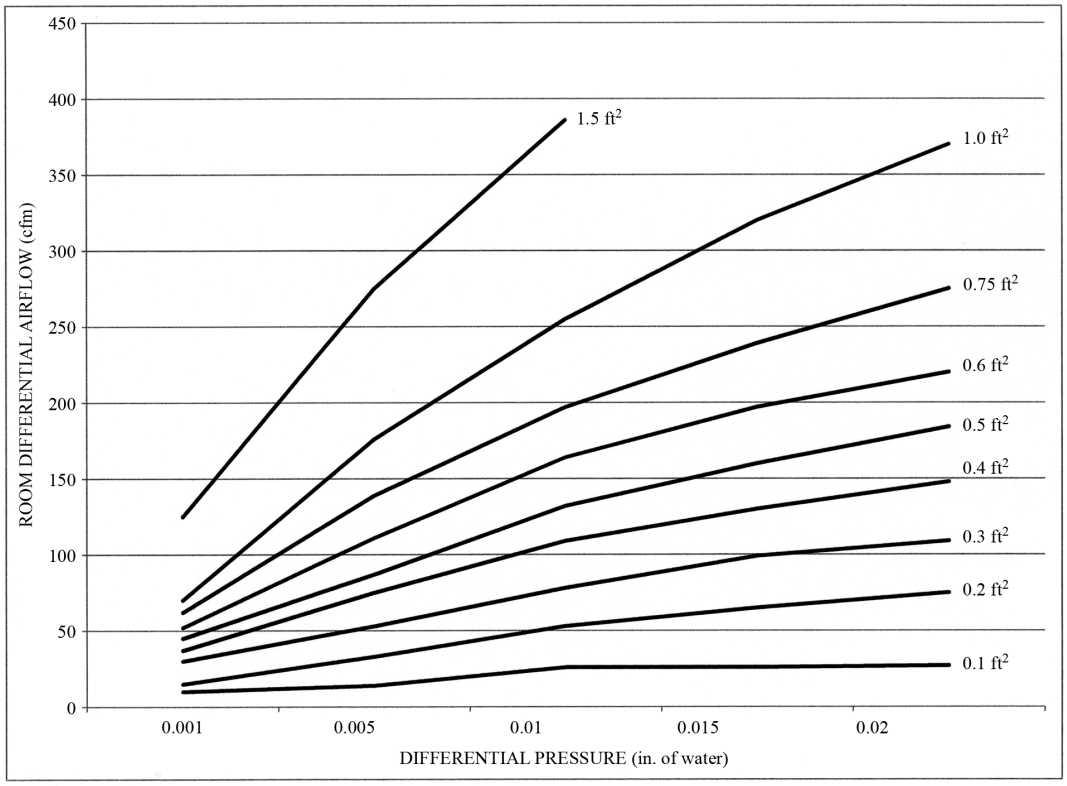


Figure 8-1 *Room Differential Airflow versus Differential Pressure for Various Room Leakage Areas*

a negative air pressure difference between a room and the corridor may not be enough to provide isolation. Because there are up to six possible shared bounding surfaces for any room, and because there may be adverse pressure relationships across any of these surfaces, each surface must be considered. Pressures in adjoining rooms may be lower than in the room under consideration and air may flow out. To prevent such flows, the Q_r may need to be increased beyond that required to maintain appropriate flow to the corridor only. The value of Q_r must be set to ensure that the negative-air-pressure room will pull air from all of the surrounding spaces.

8.2.2 Positive Air Pressure

Maintaining positive air pressure, preferably with anterooms and continuous alarms, requires continuous monitoring of pressurization. To reduce airflow to or from corridors, anterooms are highly recommended.

8.3 OPERATING ROOMS

The purposes of the HVAC system in an operating room (OR) are to minimize infection, maintain staff comfort, and maintain patient comfort. As indicated in Table 8-1, the recommended air change per hour (ACH) value has been 15 to 25 for 40 years. The current recommendation in the FGI *Guidelines* (AGI 2010) and ANSI/ASHRAE/ASHE Standard 170-2008 (per Table 3-3) is 20 ach supply air including 4 ach of outdoor air (20% outdoor air). Note that 100% outdoor air systems have not been recommended since the early 1980s; although until very recently the U.S. Veteran's Administration has required 100% outdoor air systems. Operating rooms must be designed for a positive pressure differential of 0.01 in. of water [2.5 Pa]. As discussed above, this will require a 200–400 cfm [94–189 L/s] offset. Although ANSI/ASHRAE/ASHE Standard 170-2008 does not require continuous monitoring, various authorities having jurisdiction (AHJs) frequently request or require monitoring of temperature, relative humidity (RH), and dew point in ORs.

The surgical suite contains operating rooms as well as substerile rooms, clean supply, sterile corridor, preoperative preparation, and postoperative recovery care (postanesthesia care unit [PACU]). Common usage of the term "OR" is often intended to include both the surgical room and these support areas. In some hospitals, other spaces, such as locker rooms, doctor's lounges, control desks, anesthesia workrooms, and even surgical waiting areas, may be included in the general term. The OR special environment, however, embraces only the restricted area of the surgical suite. Surgeries may be classified as shown in Table 8-2.

As indicated in Table 8-3, most standard operating rooms require MERV 14 filtration. In the past, some standards recommended MERV 17 in orthopedic and organ transplant surgery operating rooms. Although this is no longer the case in ANSI/ASHRAE/ASHE Standard 170-2008, many deem it good practice. Assuming that the final filter assembly is tight, only one final filter is necessary. Placing two final filters in series, such as one in the AHU and one outside the OR, is

unnecessary and wastes fan energy while increasing maintenance. Having a second final filter may also require maintenance personnel to enter the operating rooms. Therefore, a terminal filter is not recommended when there is a good final filter in the AHU.

Figure 8-2 shows a schematic operating room. As indicated, a typical internal cooling load is 2 to 3 tons [7.0 to 10.6 kW]. With an air change rate of 20 and supply air at 47°F to 50°F [8.3°C to 10.0°C], the system can provide 6 to 7 tons [21.1 to 24.6 kW] of cooling, roughly twice the actual load. Thus, in almost all operating rooms, the required ACH drives the size of the HVAC system, not the internal load.

During the design phase, it is essential to determine the desires of the doctors and staff for temperature and humidity and to match those desires with the capabilities of the system. For example, a system that provides chilled water no lower than 45°F [7.2°C] will not be able to provide supply air with a dew point below about 49°F [9.4°C]. As shown in the psychrometric chart in Figure 8-3, the lowest dry-bulb

Table 8-1 *Recent History of HVAC Standards for ORs*

Year	Source	Temperature,°F [°C]	RH, %	ACH, ach	OA, ach
1971	ASHRAE (1971)	68 to 76 [20 to 25]	50	25	5
1974	U.S. HEW	68 to 76 [20 to 25]	50 to 60	25a	25
1974	U.S. HEW	68 to 76 [20 to 25]	50 to 60	25b	5
1978	U.S. HEW	68 to 76 [20 to 25]	50 to 60	15a	15
1978	U.S. HEW	68 to 76 [20 to 25]	50 to 60	25b	5
1983	AIA	70 to 75 [21 to 24]	45 to 60	20	4
1987	AIA	70 to 75 [21 to 24]	50 to 60	15	3
1987	ASHRAE (1987)	68 to 76 [20 to 25]	50 to 60	15/25	15/5
1992	AIA	70 to 75 [21 to 24]	50 to 60	15	3
1999	ASHRAE (1999)	62 to 80 [20 to 27]	45 to 55	25	5
2001	AIA	68 to 73 [20 to 23]	30 to 60	15	3
2002	NFPA (2002)	68 to 73 [20 to 23]	50	25	5
2003	ASHRAE (2003a)	62 to 80 [20 to 27]	45 to 55	25	5
2003	ASHRAE (2003b)	68 to 75 [20 to 24]	30 to 60	25	5
2005	NFPA (2005)	68 to 73 [20 to 23]	35	25	5
2006	AIA	68 to 73 [20 to 23]	30 to 60	15	3
2008	ASHRAE (2008)	68 to 75 [20 to 24]	20 to 60c	20	4
2010	FGI (2010)	68 to 75 [20 to 24]	20 to 60c	20	4

Sources: Adapted from references cited in table, along with documents of the American Institute of Architects (AIA) and the U.S. Department of Health, Education, and Welfare (U.S. HEW).

Notes:
a. Requirement if 100% OA was preferred.
b. Requirement if recirculation was preferred.
c. Some AHJs require a minimum relative humidity (RH) of 30%.

Table 8-2 *Classification of Surgeries*

Class	Characteristics
Class A surgery	Provides minor surgical procedures performed under topical, local, or regional anesthesia without preoperative sedation; excluded are intravenous, spinal, and epidural procedures, which are Class B or C surgeries
Class B surgery	Provides minor or major surgical procedures performed in conjunction with oral, parenteral, or intravenous sedation or performed with the patient under analgesic or dissociative drugs
Class C surgery	Provides major surgical procedures that require general or regional block anesthesia and/or support of vital bodily functions

Source: ACS (2000).

Table 8-3 *Minimum Filter Efficiencies*

Space Designation (According to Function)	Filter Bank No. 1, MERV[a]	Filter Bank No. 2, MERV[a]
Classes B and C surgery; inpatient and ambulatory diagnostic and therapeutic radiology; inpatient delivery and recovery spaces	7	14
Inpatient care, treatment and diagnosis, and those spaces providing direct service or clean supplies and clean processing (except as noted below); AII (rooms)	7	14
Protective environment rooms (PE)	7	17 (HEPA)[c]
Laboratories; Class A surgery and associated semirestricted spaces	13[b]	N/R[d]
Administrative; bulk storage, soiled holding spaces; food preparation spaces; and laundries	7	N/R
All other outpatient spaces	7	N/R
Skilled nurses facilities	7	N/R

Source: ASHRAE (2008).

Notes:
a. Minimum efficiency reporting value (MERV) is based on method of testing described in ANSI/ASHRAE Standard 52.2-2007.
b. Additional prefilters may be used to reduce maintenance for filters with efficiencies higher than MERV 7.
c. Filter Bank #2 may be MERV 14 if MERV 17 tertiary terminal filter is provided for these spaces.
d. N/R = not required.

temperature that can be achieved at 49°F [9.4°C] dew point at 60% rh is 66°F [18.9°C]. Although FGI and ASHRAE recommend a temperature range of 68°F to 74°F [20.0°C to 23.3°C] at 20% to 60% rh, many surgeons request temperature/humidity settings outside of these ranges. Inability to maintain low OR temperature is probably the number one complaint by surgeons to facility engineers.

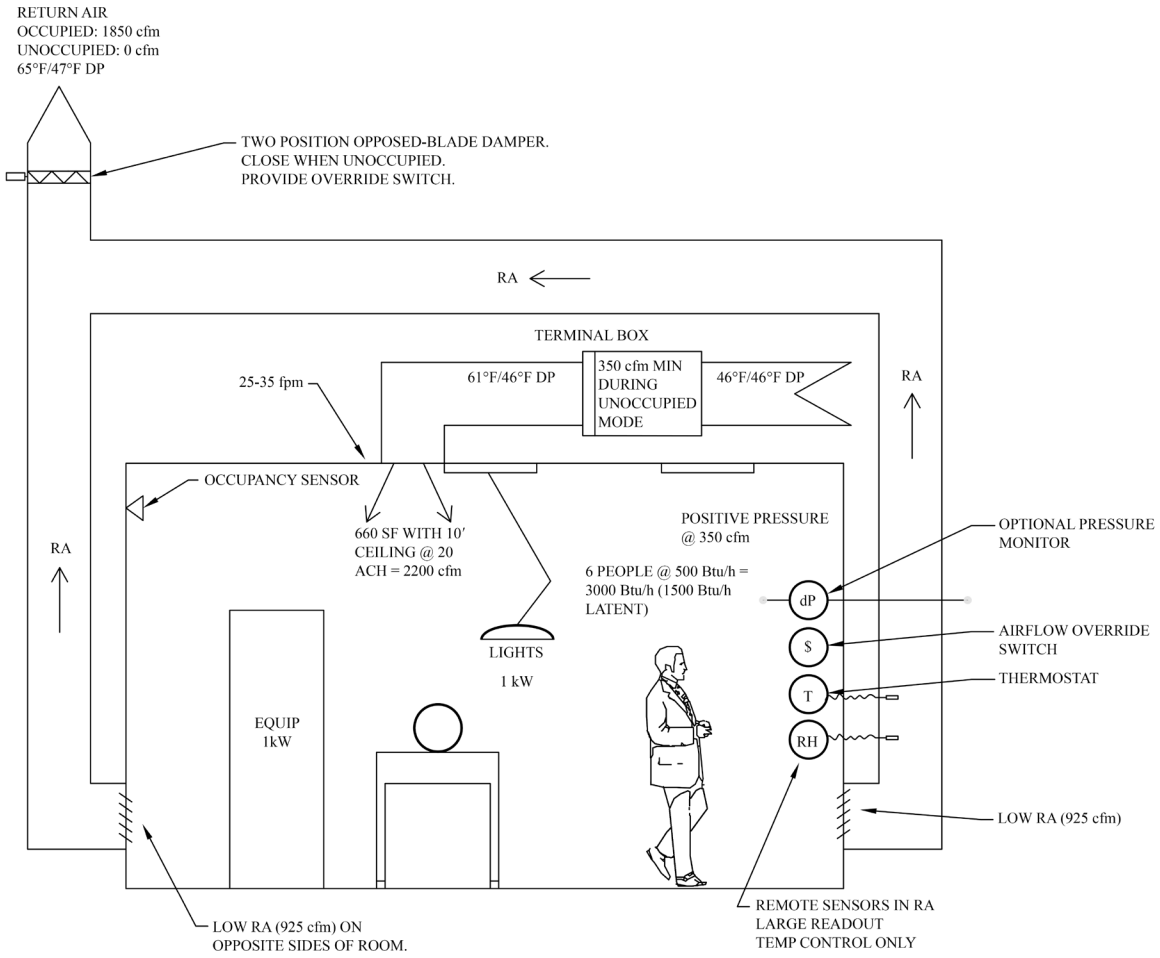


Figure 8-2 *Typical OR Layout*

Table 8-4 shows characteristics typically desired in different types of operating rooms. As indicated, orthopedic and cardiac operating room surgeons frequently request very low temperatures, often as low as 60°F [15.6°C].

Figure 8-3 shows a "sweet spot" when supply air is at about 45°F [7.2°C] dew point. At this condition, virtually all of the commonly requested combinations of temperature and humidity can be maintained. Note that the ANSI/ASHRAE/ASHE Standard 170-2008 humidity range is 20% to 60% rh with temperatures from 68°F to 75°F [20.0°C to 23.9°C]. A key point to remember is that surgeons should be allowed to set only the dry-bulb temperature and not the relative humidity. Allowing surgeons to pick a particular point on the psychrometric chart would be exceptionally difficult and expensive to maintain.

Referring again to Figure 8-3, if chilled water of about 40°F [4.4°C] is available, and if the coils are sized appropriately for the load, then 46°F dry bulb/44°F dew point [7.8°C/6.7°C] can be obtained with chilled water only. In summer, in most regions, these conditions

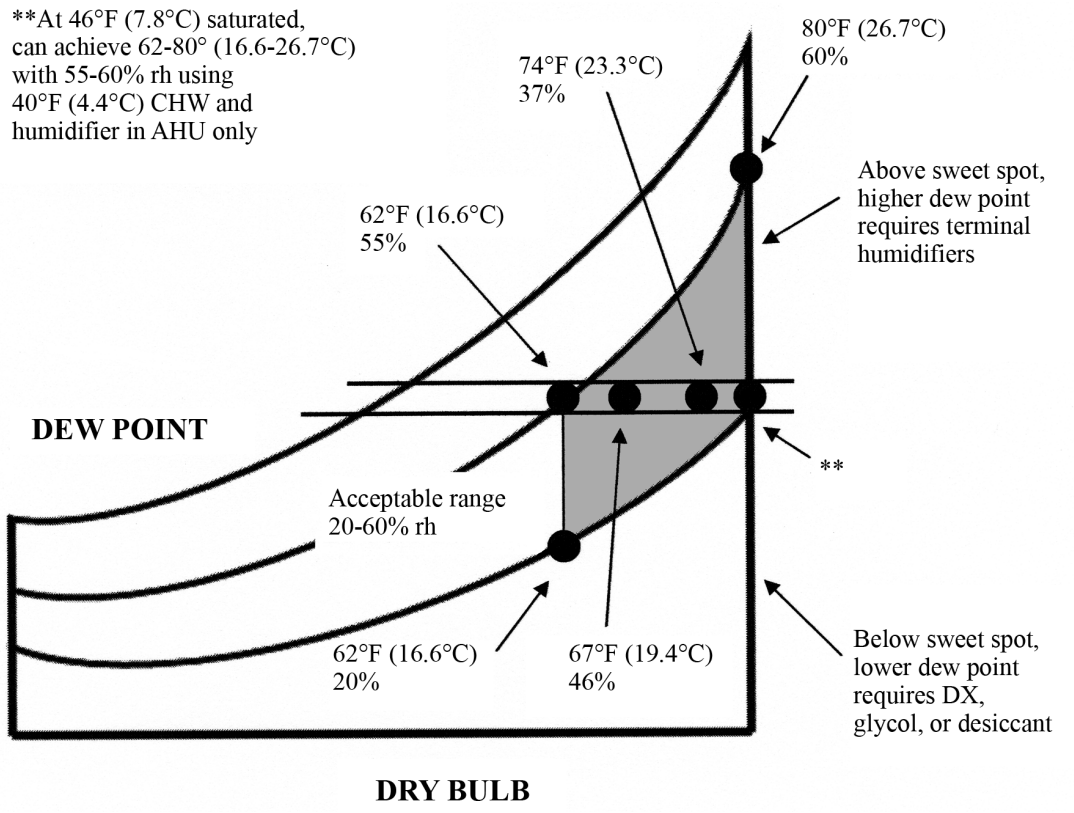


Figure 8-3 *OR Conditions with Supply Air at 46°F [7.8°C]*

will be achieved using a saturated cooling coil. In dry climates, reheat energy would be saved by controlling the supply air dew point to ≤45°F [7.2°C] and allowing the supply air temperature to increase to, for example, 55°F [12.8°C]. In winter, air humidified to 45°F [7.2°C] dew point at the AHU will meet the normal design requirements. With few exceptions, supply air at 45°F [7.2°C] dew point will meet the requirements of all operating rooms without the need for terminal humidification. This is shown in Figure 8-3. Conditions below 62°F [16.7°C] and 55% rh will require less than 45°F [7.2°C] dew point, and thus will be very difficult to achieve with chilled water only. This situation will require supplemental desiccant or DX/glycol cooling systems. Conversely, operating rooms (burn and pediatric units) at over 80°F [26.7°C] and 60% rh will require terminal humidification. To the extent possible, it is desirable to avoid terminal humidifiers, because they present significant problems with leakage, maintenance, above-ceiling space requirements, and energy consumption. Clearly, maintenance of a single humidifier inside an AHU is considerably less demanding than for terminal humidifiers located throughout an operating suite. Given the importance of humidity in hospitals, accurate and reliable humidity sensors are essential. However, humidity sensors are notoriously inaccurate, and with control sequences based on humidity (dew point), errors will add greatly to energy and performance problems.

Table 8-4 *Typical Operating Room (OR) Requirements*

OR Room Type	Requirements
Heart	Low temperature, fast reheat, large room
Orthopedic	Low temperature, large room, extra filtration
Cystoscopic	Medium temperature
General	Medium temperature
Pediatric	High temperature
Neurological	Low temperature, large room
Trauma	High temperature
Burn	High temperature

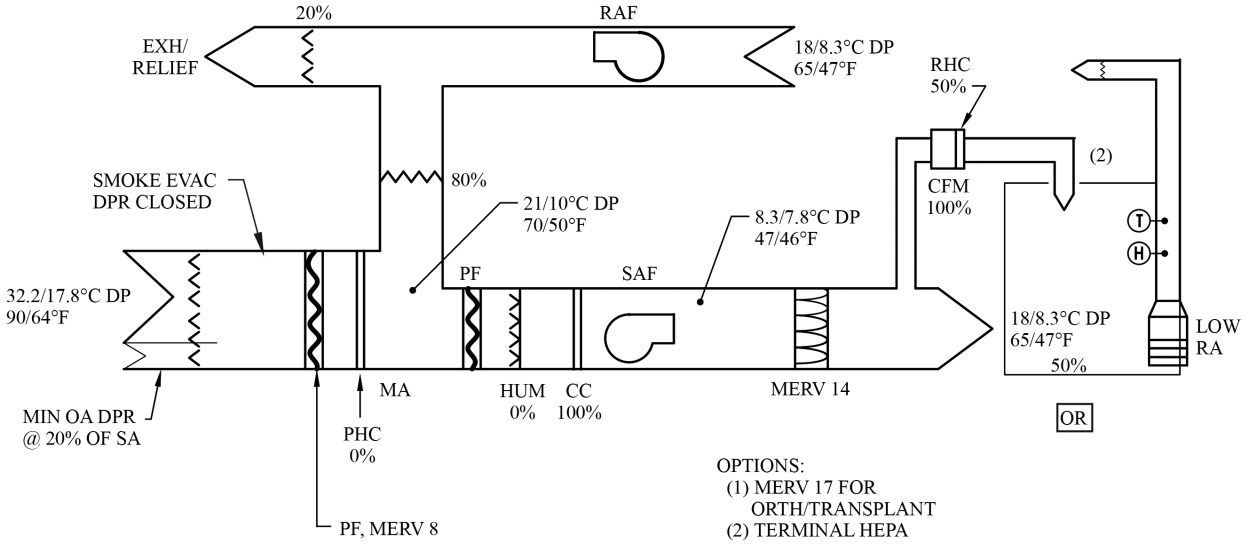


Figure 8-4 *Example OR Air-Handling Unit in Summer*

Figure 8-4 shows a typical OR air-handling unit. Note that a draw-through configuration is preferred, to get "free" reheat from the fan motor and reduce the chances of having wet final filters. Locate the humidifier upstream of the chilled-water coil to take advantage of the higher temperature at this location, which facilitates steam absorption. There is another reason to locate the humidifier in front of the chilled water coil; should it malfunction, excess condensation will be removed by the chilled-water coil acting as a demister even if the chilled water flow is off. This is preferable to a humidifier failure causing condensation to strike the expensive final filters. Many hospitals choose to install redundant air-handling systems (or redundant supply fans in a given AHU). Typically, these fans are sized to supply about 67% airflow with the other fan off. A dividing panel with removable door can

be installed inside the AHU to allow work to be done on one supply fan while the other continues to operate.

There are, of course, many other configurations of air handling units, such as dual path, blow-through series cooling coils, and desiccant dehumidification wheels. For more information on these configurations, see Murphy (2006).

Because the objective is generally to obtain a low supply dew point, the designer should do everything practicable to maximize performance with the available chilled water. Heat transfer can be maximized by applying the basic theories of thermodynamics, reducing supply temperature and dew point at saturation. One approach is to increase the heat transfer area by increasing the number of coil rows and/or fins. Generally, 10 fins per inch [per 25 mm] has been found desirable from the standpoint of maintenance and cleaning. Heat transfer can be increased by maintaining a relatively high chilled-water flow velocity of around 6 fps [1.8 m/s] as shown in Figure 8-5. Likewise, Figure 8-6 shows the influence of lower air velocity on supply temperatures. As indicated, lowering the air velocity through a coil from 550 to 450 fpm [2.3 m/s] will lower the supply temperature by 1.5°F [0.7°C]. Current energy codes may suggest airflow velocities as low as 250 fpm [1.3 m/s]. See Chapters 3 and 12 for further information.

It is often difficult to find a good location for a wall-mounted thermostat in an operating room, because the room is filled with equipment, much of which generates heat. It is preferable, therefore, to provide a remote sensor in the return air. The humidity sensor should also be located in the return air. As noted previously, the user will not be given humidity control, but experience has shown that most operating staff are interested in knowing the relative humidity. Therefore, it is preferable to provide a good sensor with a readout connected to the building automation system.

8.3.1 Occupancy Control

As shown in Figure 8-7, over 40% of the cooling load for an OR in summer is a result of reheat. Further, as discussed in Chapter 12, about 20% of the total energy use of a hospital is for fans. Thus, reducing OR airflow during unoccupied periods can save a great deal of energy use for fans, cooling, and reheat. Several factors complicate unoccupied setback in the OR suite, including the following:

- Maintenance of positive pressurization using supply and return air control device (most older systems will not have return control)
- Maintenance of adequate ventilation to exhaust fumes from off-hour cleaning
- Control strategies for override (light switch, occupancy sensor, time clock, etc.)
- Rapid transition from unoccupied- to occupied-air-changes while maintaining desired temperature and humidity

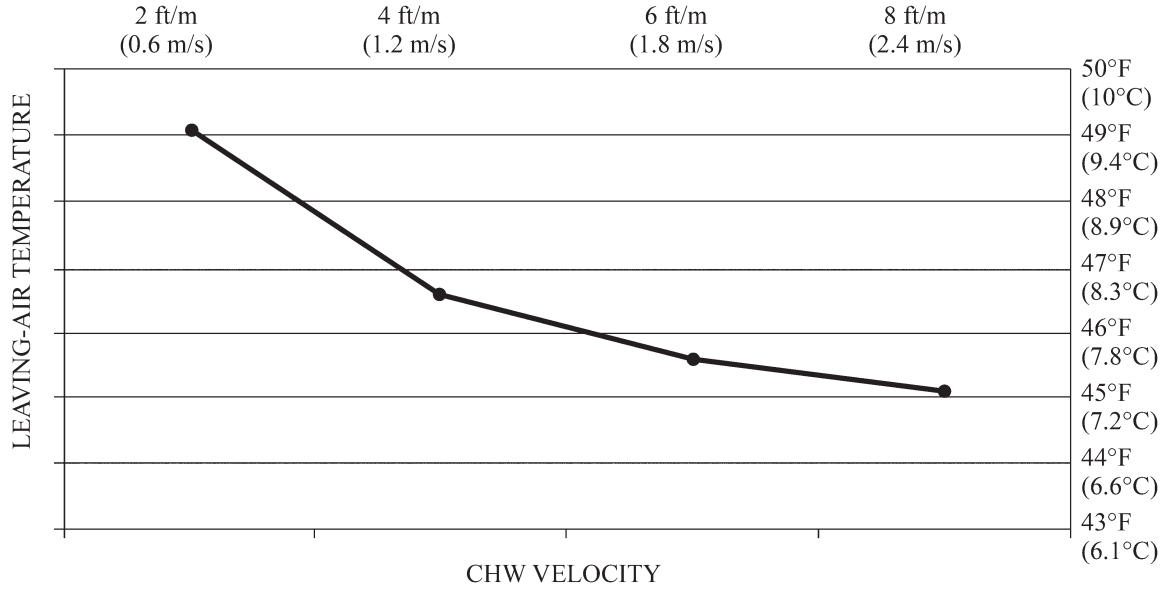


Figure 8-5 *Effect of Chilled-Water Flow on Leaving Air Temperature*

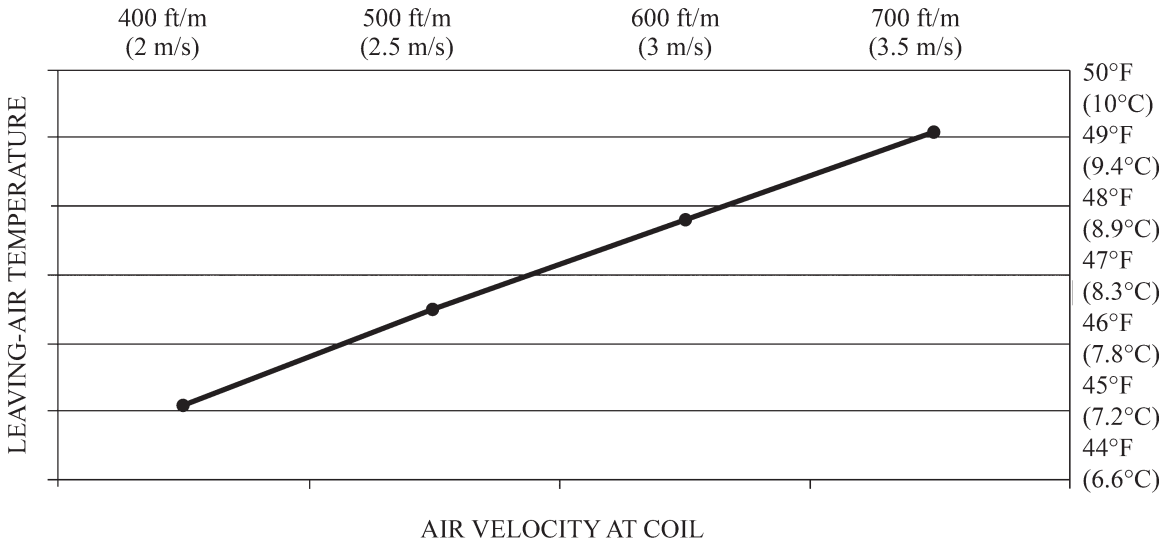


Figure 8-6 *Effect of Air Velocity on Leaving Air Temperature*

As discussed earlier in this chapter, there are two basic mechanisms for maintaining pressurization: (1) fixed offset between supply and return/exhaust airflows, and (2) maintenance of a measured pressure differential (usually at least 30% of design flow). Both strategies require measurement and control of both the supply and return airstreams. The hardware and control strategies to maintain pressurization (detailed in Chapter 6) pertain not only to ORs but also to isolation rooms, bronchoscopy, and all areas requiring pressurization. A positive and reliable mechanism for override is required, regardless of the control strategy. Methods for accomplishing override are by (1) the overhead light switch, using low voltage relays, (2) a separate switch, and (3) occupancy sensors (movement detection). Again, the key is reliability

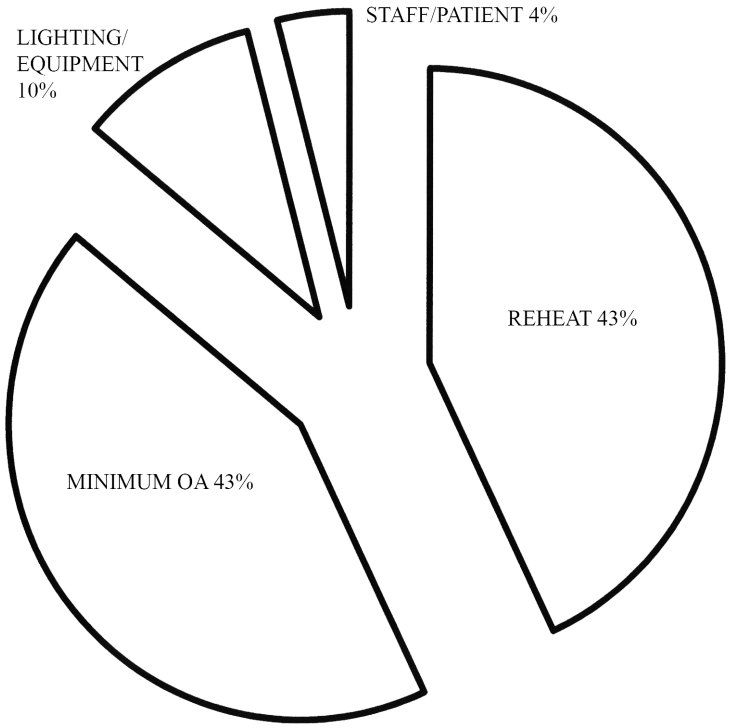


Figure 8-7 *Sources of Operating Room Cooling Loads*

and maintenance of pressurization. Many hospitals have decided that the problems and risks of setback exceed the benefits.

8.3.2 Air Distribution

A simple way to save energy in ORs is to maintain constant air volume, but reduce room setpoint during unoccupied periods. This will reduce reheat and often satisfy a surgeon's desire for a cold room. This strategy should be discussed with the clinical staff.

Current recommendations for air distribution design are based heavily on the work on Memarzadeh and Manning (2002), which included an analysis of air change rates as well as air velocity. The air velocity recommendations are based on the theory of a small thermal plume radiating up from an open surgical site. This plume, while not necessarily aseptic, will, in theory, contain only the microbes that are already present on or in the patient. If the thermal plume is undisturbed, particles from the air supply and/or from the staff will be diverted and not directly impact the surgical site. Thus, Memarzadeh and Manning recommended a maximum face velocity of 25 to 30 fpm [0.13 to 0.15 m/s] so that the supply air will not disrupt the plume. This air velocity is specified in ANSI/ASHRAE/ASHE Standard 170-2008. Ongoing ASHRAE research project RP-1397, which is investigating hospital operating room air distribution to verify CFD predictions of conditions that sustain the thermal plume, indicates that wound temperatures in orthopedic surgery are relatively low (80°F [26.7°C]). These researchers, therefore, question if a thermal plume could be created at such a low temperature. This research thus far indicates

that supply air temperature is the major determinant of laminar flow. If confirmed by subsequent research, it could result in changes to the regulations regarding supply air temperature, velocity, and diffuser configuration.

The majority of OR air supply systems are based on laminar flow diffuser arrays (Group E). At least 70% of the diffuser array above the table (out to 12 in. [305 mm] beyond the table) must be dedicated to supply air and not blocked by light fixtures, booms, sprinklers, etc. Many hospitals are now installing "hybrid" ORs. These are operating rooms with built-in imaging equipment, usually CT or fluoroscope machines. Occasionally, MRIs are installed in ORs. Hybrid ORs can be a large as 1000 ft^2 [93 m^2], requiring high required airflows to maintain 20 ach (3333 cfm with a 10 ft ceiling [1573 L/s at 3 m]). Otherwise, all of the temperature, humidity, air change, and design recommendations above apply equally well to a hybrid OR. Assuming that the imaging computer systems are located in a separate equipment room, the presence of an imaging machine in the OR will not greatly increase the cooling load; therefore, the required air changes will still far exceed the internal load. See the section on Imaging Rooms for more information.

8.3.3 Laminar Array Systems

Laminar flow diffusers, defined by Straub and Chen (1957) and Straub et al. (1956) as Group E, are nonaspirating diffusers with air flowing downward from the ceiling and minimum entrainment of room air. Diffuser design points must be 25 to 35 cfm/ft^2 [127 to 178 L/s per m^2]. All laminar diffusers must be room-side accessible for cleaning and/or filter replacement.

For Class B and C operating rooms (ORs), the laminar diffusers are set into arrays intended to create a uniform laminar airflow profile covering a critical zone (or area equivalent to the footprint of the surgical table plus 12 in. [305 mm] on each side) to continuously sweep contaminants down and away from the patient and surgical staff for removal through low baseboard return grilles. No more than 30% of the critical zone can be taken up by ceiling obstructions, such a task lights, surgical light booms, medical-gas columns, gypsum board, and the like. Class A OR designs similarly require laminar diffusers. However, an array is not defined, and other ventilation requirements are less stringent.

FGI (2010) recommends that all ceilings in restricted areas (such as operating rooms) must be of monolithic construction to form a barrier between interstitial space and the OR. FGI stipulates that cracks, fissures, and crevices are not permitted and that all finishes must be cleanable, scrubbable, and withstand cleaning compounds typically used in operating rooms. All ceiling penetrations should be gasketed or sealed. FGI clarifies the requirements when a central diffuser array is used, specifying that the diffuser array is not part of the monolithic ceiling and is fully acceptable, providing that any grid

system forms a single assembly in the ceiling with all openings gasketed. Thus, gasketed ceiling systems designed for ORs are acceptable.

An air curtain system (Figure 8-8) is another method for ventilating an operating room. It consists of a laminar array above the operating table with a four-sided linear slot diffuser outside the perimeter of the surgical area. Between 67% and 75% of the total supply air is provided by the air curtain, with the balance supplied through the laminars. The laminar diffusers are sized for 25 to 35 cfm/ft^2 [127 to 178 L/s per m^2] of diffuser face area and the air curtain is sized to provide 25 to 45 cfm/linear foot [38.8 to 69.8 L/s per m] of slot. At a minimum, the inside dimension of the linear air curtain is approximately 3 ft [0.9 m] beyond each side of the surgical table; allowing sufficient room around the table for the surgical staff and its equipment without the staff being inside the jet of the air curtain. This system may be best suited for very large ORs where large volumes of air are required to achieve 20 ach.

8.4 IMAGING ROOMS

The use of imaging systems is both growing and changing rapidly because of advances in technology and increasing applications. As with most computer-based equipment, imaging systems have a life of about five years. Therefore, it is crucial to design for the flexibility to frequently replace imaging equipment. Another challenge for the designer is that medical staff work hard to find new uses for existing imaging systems. For example, a room designed for diagnostics may become a treatment room, thus increasing the air change requirements from 6 ach to 12 or 15 ach. The room may even become a hybrid OR,

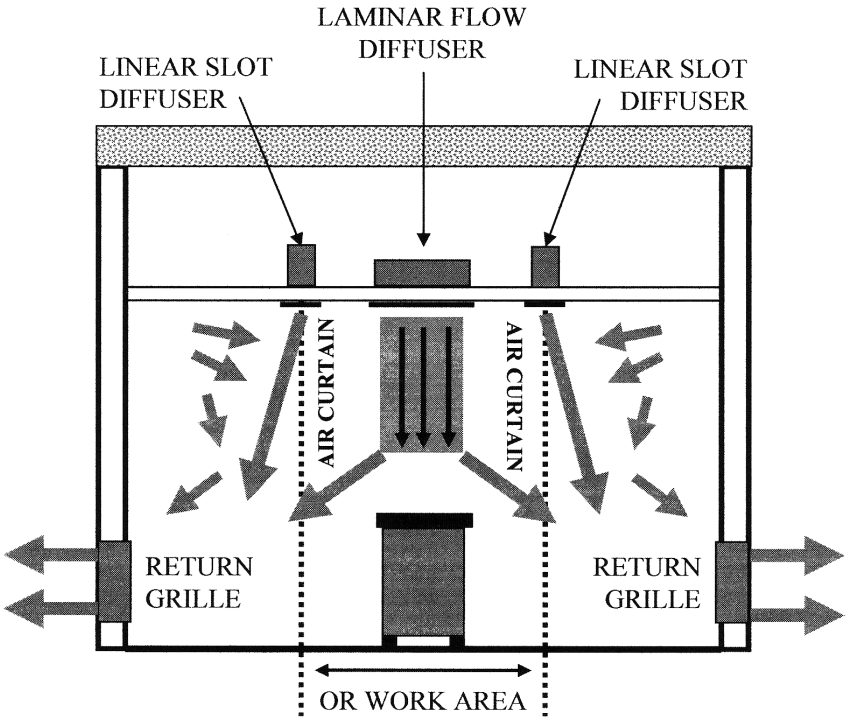


Figure 8-8 *Air Curtain Concept*

thus requiring 20 ach. Providing for future flexibility generally requires oversizing equipment for immediate use, which usually results in increased first cost. The judicious HVAC engineer will bring this to the attention of the owner early in the process and obtain the owner's guidance, preferably in writing.

Imaging systems generally consist of an assemblage of electronic devices that perform diagnostic imaging and/or patient treatment. They can generally be grouped as four types of devices: X-ray, ultrasound, magnetic, and radioactive. As shown in Figure 8-9, many of the systems, including fluoroscopy and CT, are based on X-ray

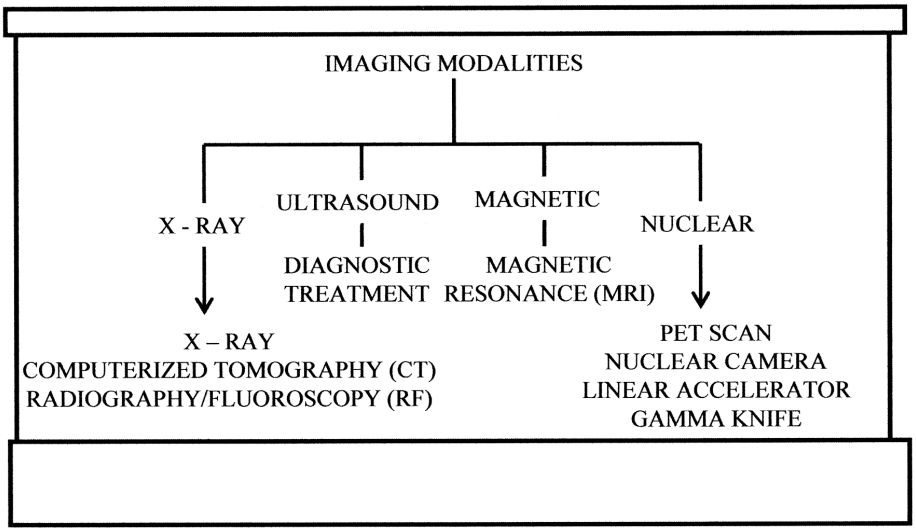


Figure 8-9 *Basic Imaging Modalities*
Source: Koenigshofer (2009).

Table 8-5 *Typical Applications of Imaging Modalities*

Imaging Type	Applications
Computerized tomography (CT)	Orthopedic, emergency, neurology
Fluoroscopy	Vascular, cardiac catherization, cystoscopy, electrophoresis (EP)
Gamma knife	Oncology
Linear accelerator	Oncology
Magnetic resonance imaging (MRI)	Orthopedic, neurology, vascular
Nuclear camera	Cardiology
Positron emission tomography (PET)	Neurology
Ultrasound	Prenatal, oncology
X-ray	Mammography, orthopedic, emergency, pulmonary

Source: Koenigshofer (2009).

technology. With this technology, X-rays generated in an X-ray tube pass through the patient and are then collected for imaging. Fluoroscopy is essentially a real-time X-ray, analogous to a video as compared to a photograph. CT falls in the middle of these technologies by taking multiple X-rays (slices) in an extremely short period of time. All of these technologies use an X-ray generator and image intensifier as detailed in Figure 8-10.

Table 8-5 shows various imaging modalities and their typical applications. As indicated, there is a great deal of overlap in the application of the differing technologies.

Figure 8-10 shows the components of typical imaging systems and the locations of energy input and heat output. As indicated, many systems have remote cooling units to remove heat from the imaging equipment. These remote coolers may be air-cooled exterior units, remote water coolers located inside the building, and/or remote chiller plants. Depending upon the manufacturer, the various devices shown may involve separate or combined components. Figure 8-11 shows one version of a chilled-water cooling system using house chilled water and interconnected process chillers.

A typical CT system installation consists of three rooms. The following three functions/rooms are typical for virtually all imaging systems that involve multiple components:

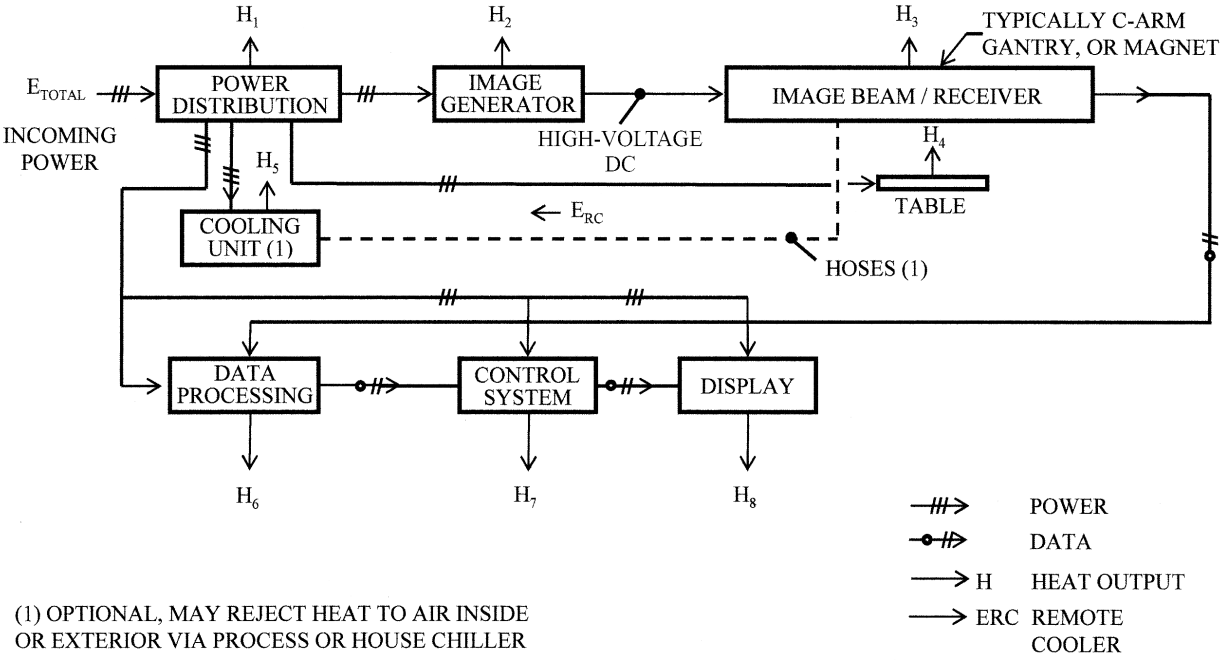


Figure 8-10 *Imaging System Energy Flows*
Source: Koenigshofer (2009).

- *Control Room:* monitors and computers for staff operation of the system
- *Procedure Room:* imaging equipment for patient diagnostics and treatment
- *Equipment Room:* housing data and electrical equipment

Typically, the main panel, computer, power distribution, UPS, and power generator are located in the equipment room. The actual imaging device is located in the Procedure Room along with some monitors, motorized patient table, exam lights, and injector. The data output items (e.g., computers, monitors, and printers) are located in the Control Room. Manufacturers use different terminology for the overall system and for the individual components. Occasionally, the data systems are located in the Procedure Room; this location uses valuable space, can create a significant cooling load, and should be avoided. Because the loads for each of the three rooms are so different, each room should be provided with a separate thermostatic zone (reheat box).

Table 8-6 gives heat gain values (energy consumption) as reported by the manufacturer for a typical CT system. As indicated, there are twelve devices that consume energy and produce heat.

Control Rooms are generally small, crowded, and busy, containing computers, monitors, and printers that produce heat while the staff is usually wearing heavy clothing and head and face protection. Therefore, this area must usually be maintained at 68°F to 70°F [20.0°C to 21.1°C] and airflow of over 20 ach is common.

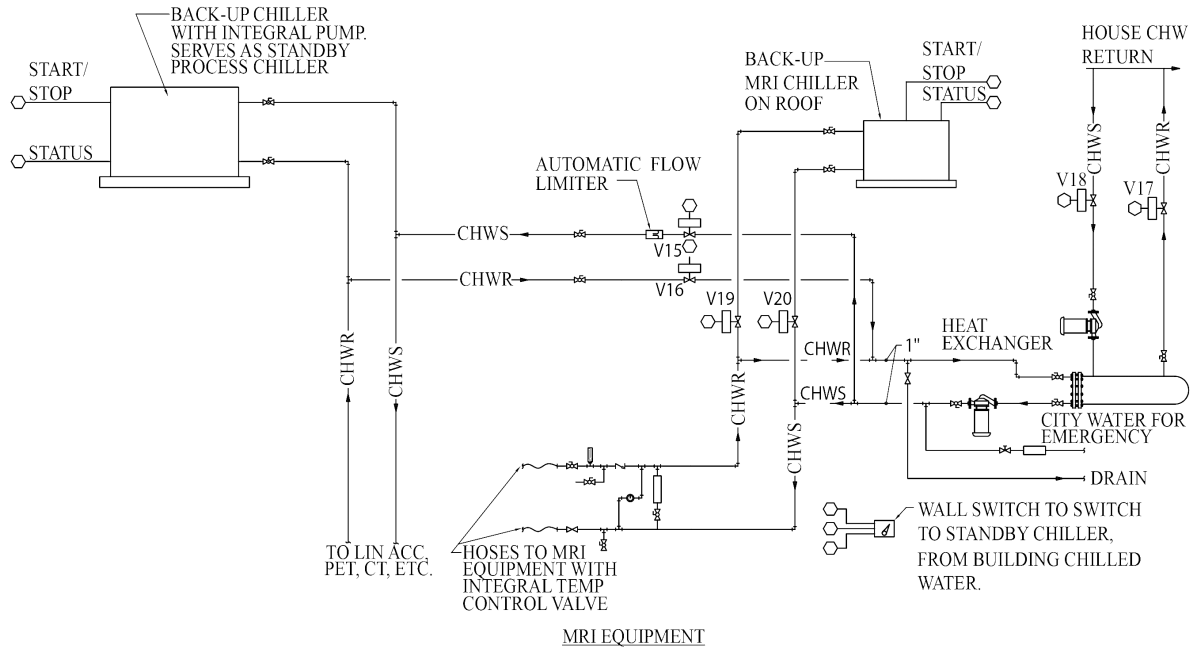


Figure 8-11 *Imaging System Cooling-Water Piping Schematic*
Source: Koenigshofer (2009).

Table 8-6 *Typical CT Equipment Heat Gain Data*

Item No.	Description	Weight, lb [kg]	Heat to Air, Btu/h [W]	Dimensions, in. [mm]			Remarks
				W	D	H	
1	Keyboard and control box	–	–	–	–	–	On customer's counter
2	18 in. [457 mm] flat-screen control monitor	22 [10]	238 [70]	18.3 [465]	4.8 [122]	17 [432]	On console/counter
3	Switch box	3 [1.4]	–	12 [305]	12 [305]	3 [76]	Wall mounted
4	Image construction system	–	1700 [498]	–	–	–	On customer's counter
5	Image evaluation keyboard (option)	–	–	–	–	–	On customer's counter
6	18 in. [457 mm] evaluation monitor (option)	22 [10]	238 [70]	18.3 [465]	4.8 [122]	17 [432]	On customer's counter
7	Image evaluation system (option)	220 [100]	1708 [500]	–	–	–	On floor/in container
8	Ethernet switch (option)	3 [1.4]	–	9.1 [231]	1.8 [46]	8.9 [226]	Wall mounted
9	UPS for IES (option)	28 [12.8]	171 [50]	8.1 [206]	18.9 [480]	8.9 [226]	
10	Container for ICS/ IES (option)	128 [58]	–	26 [660]	34 [864]	27.5 [699]	
11	Multimodality workplace computer	55 [25]	–	18.8 [478]	10 [254]	23.6 [599]	On customer's counter
12	Multimodality workplace keyboard/ monitor	–	–	–	–	–	On customer's counter
13	Gantry	4410 [2000]	4708 [1380	57 [1449]	36 [914]	78 [1981]	Represents load on external chiller
14	Patient table	1103 [500]	512 [150]	26.5 [637]	85 [2159]	22 [559]	
15	Power distribution Cabinet	1213 [550]	4085 [1197]	35.5 [902]	29.5 [749]	71.5 [1816]	
16	Heat exchanger cabinet (water/water)	441 [200]	1706 [500]	35.5 [902]	29.5 [749]	71.3 [1811]	Represents load on external chiller
17	Image reconstruction system	285 [129]	4777 [1400]	12.6 [320]	27.8 [706]	80.6 [2047]	
18	Monitor	131 [59.4]	238 [70]	–	–	–	Ceiling mounted
19	Surge suppressor	51 [23]	205 [60]	24 [610]	8.9 [226]	24 [610]	Wall mounted

Table 8-7 *Comparison of Reported Heat Gain for Cardiac Cath Systems*

Manufacturer	Procedure Btu/h [kW]	Equipment Btu/h [kW]	Control Btu/h [kW]	Total Btu/h [kW]
GE	4323 [1.26]	31,386 [9.14]	4592 [1.34]	40,301 [11.74]
Siemens (biplane)	3585 [1.04]	35,838 [10.44]	6385 [1.86]	45,808 [13.34]
Philips	5024 [1.46]	16,929 [4.93]	2994 [0.97]	24,947 [7.27]
Toshiba (biplane)	1092 [0.32]	34,769 [10.13]	1445 [0.42]	37,306 [10.87]

Source: Koenigshofer (2009).

Table 8-8 *Field-Test Results for Heat Gain to Water for Imaging Systems*

Device	Manufacturer	Model	Idle	High
			Btu/h [kW]	Btu/h [kW]
MRI	Siemens	Vision	30,285 [8.82]	31,882 [9.29]

Source: Koenigshofer (2009).
Note: 9:00 a.m. to 4:00 p.m.

In the Procedure Room, the required supply airflow is dictated by either the cooling load or the airflow recommended by ANSI/ASHRAE/ASHE Standard 170-2008, whichever is greater. In most cases, the required room air change is greater than the required air for cooling a Procedure Room, where the required airflow is 12 to 15 ach. However, if all electrical equipment is located in the Procedure Room, airflow may be load driven. Sometimes, the control equipment is located in an area of the Procedure Room separated by only a partition; thus, the load from the control equipment is in the Procedure Room.

If there is a separate Equipment Room, the airflow required for that space is determined by the sensible heat gain from the devices in the room. These rooms often look like data centers, with raised floors and computer room air-conditioning systems. The computers for several imaging systems may be in one room. Air changes may be 50 to 100 ach.

Table 8-7 compares the reported heat loads for actual Catherization Lab systems (fluoroscopy) that have been designed by the authors. System features and performance may not be comparable. Each system consists of 13–20 energy-consuming components. The sum of the indicated loads ranges from 25,000 to 46,000 Btuh [7.3 to 13.4 kW]. There is no indication in the literature if these are the maximum or average loads. Typically, however, manufacturers state that these are maximum, undiversified loads.

As indicated in Table 8-8, under idle and high-use modes, heat gains to the water cooling system for this MRI are nearly identical. This is substantiated by the graph of electrical demand shown in Figure 8-12.

The base (sleep) mode's demand is about 15% below the 1 h time-weighted average (TWA). As discussed earlier, MRIs often have a stand-alone process chiller. Good design practice will also tie the MRI into the house chilled-water system.

Table 8-9 summarizes the results of testing to determine heat gain from imaging systems (Koenigshofer 2009). As indicated, in some of the modalities, there is very little difference between the idle energy use and the 60 min maximum time-weighted average (TWA). Note that field-measured results can vary considerably from values reported by a manufacturer in their installation drawings. It is expected that Phase II of this research project will result in a much more extensive database for heat gains to air and water for imaging systems.

The most common imaging modalities in operating rooms at this time are fluoroscope and CT. As discussed previously, the 20 ach for ORs must be applied, which will likely exceed the internal cooling load, even with imaging equipment. However, internal loads should be double checked in cases where there is a relatively high supply air temperature (52°F to 56°F [11.1°C to 13.3°C]). Often, a hybrid OR will contain a number of devices (including large flat-screen monitors) that generate considerable cooling loads. The control area may be inside or outside of the OR.

Imaging equipment and articulating booms require significant structure above the ceiling, which makes routing ductwork very difficult. The HVAC designer should insist on obtaining manufacturer's installation drawings as early as possible.

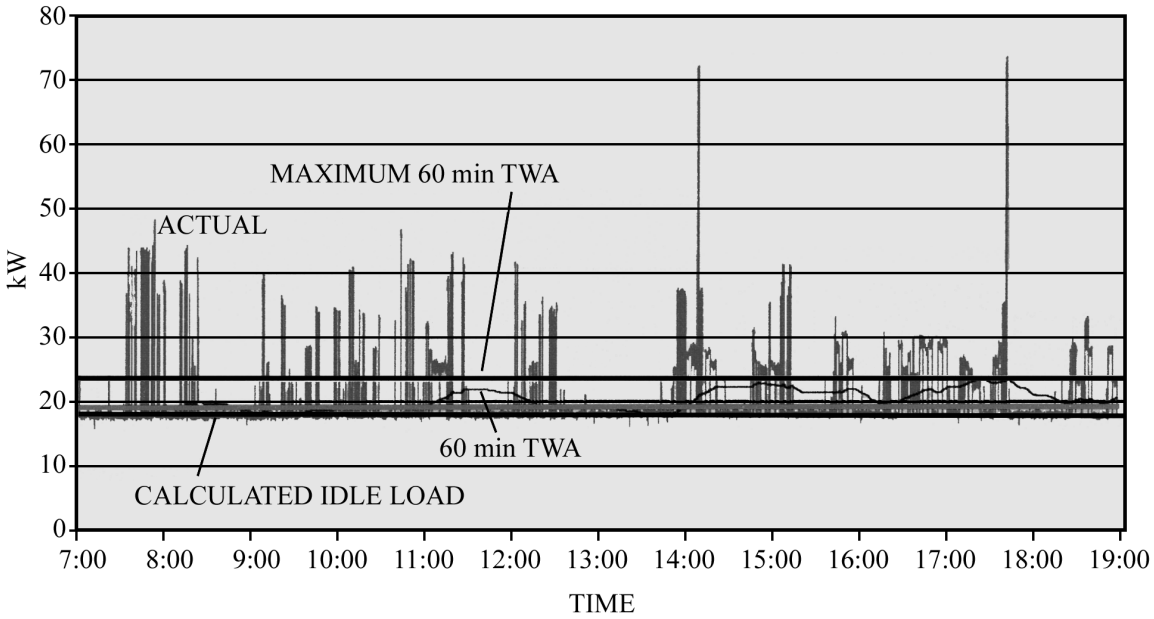


Figure 8-12 *Electrical Power Use by MRI*
Source: Koenigshofer (2009).

8.4.1 MRI Systems

Several features of MRI systems create unique challenges for the HVAC designer: an intense magnetic field, cooling, and emergency procedures for power outages. Because of the intense magnetic field produced by an MRI, all materials in the room must be nonferrous. Air distribution components are usually aluminum or a very-high-grade stainless steel. Wave guides must be installed to mitigate transmission of electromagnetic waves in and out of the MRI room. Rotating equipment (e.g., motors, fans, etc.) within the 1 gauss [100 microtesla] field can cause loss of image quality. The 1 gauss magnetic field usually extends outside the Procedure Room. Thus, the MRI may affect, or be affected by, metal objects outside the room. The manufacturer will supply this type of information. The walls of the MRI room will be lined with a nonmagnetic material such as copper, which will affect all penetrations. The ceiling/roof will frequently be a "knock out" arrangement to allow installation and replacement of the MRI from above. There may not be shielding in the ceiling/roof.

MRIs are supercooled magnets. The cooling is accomplished using liquid helium. The overall system is usually cooled with chilled

Table 8-9 *Field-Test Results of Heat Gain to Air for Imaging Systems*

System	Manufacturer	Max. 60 min TWA, Btu/h [kW]	Calculated Idle Btu/h [kW]	Manufacturer-Recommended Btu/h [kW]
MRI Vision*	Siemens	83,331 [24.27]	75,873 [22.10]	Not available
MRI Sonata*	Siemens	80,475 [23.44]	65,323 [19.03]	Not available
X-ray	Philips	4,258 [1.24]	3,692 [1.08]	4,604 [1.34]
Fluoroscopy	Philips	41,384 [12.06]	31,322 [9.12]	24,946 [7.27]
Fluoroscopy	Siemens	17,100 [4.98]	15,105 [4.40]	20,123 [5.86]
CT	Philips	24,085 [7.02]	22,437 [6.54]	65,450 [19.07]
PET/CT*	Siemens	43,008 [12.53]	33,438 [9.74]	N/A
Nuclear camera	Siemens	3,790 [1.10]	3,620 [1.06]	N/A
Linear accelerator*	Siemens	111,238 [32.40]	67,807 [19.75]	31,249 [9.10]
Ultrasound	Acuson/Siemens	2,927 [0.85]	1,692 [0.49]	Not available
Cyberknife (robotic surgery)	Accuray	45,720 [13.32]	35,440 [10.32]	Not available

Source: Koenigshofer (2009).
* Load to room air; unit is water-cooled with house chilled water or exterior condenser.

water, either from a dedicated air-cooled chiller or from the house chilled water system. These systems should be set up so that cooling can be provided by both cooling sources; and occasionally using domestic water as a third cooling source. Note that a heat exchanger should be used along with a temperature control valve that may be integral to the MRI machine. The MRI must receive clean chilled water at a temperature above the room dew point (usually 50°F to 55°F [10.0°C to 12.8°C]); thus, using return chilled water works well.

In the event of loss of coolant, the helium will expand rapidly; even explosively. A quench vent is required to allow the helium to be safely exhausted. The quench vent must be (1) stainless steel, (2) as straight as possible, (3) sized per manufacturer guidelines, (4) insulated to prevent condensation on the exterior of the vent pipe, and (5) vented to a safe outside location.

Exhaust systems are frequently provided to remove the helium and/or chemical fire suppressants. Oxygen sensors are often installed, in case a leak of helium displaces room oxygen. Sensor activation will result in the HVAC system going into "purge" mode. These controls, dampers, indicator lights, etc., must be carefully coordinated between the building automation system (BAS) and the fire alarm system.

8.4.2 PET Scan

Positron emission tomography (PET) is a diagnostic imaging technique based on injecting a patient with radioactive material and then capturing the radiation emitted. This is strictly a diagnostic process, requiring airflow of 6 ach. PET scanners are frequently water cooled and may use process and/or house chilled water. As always, care must be taken to avoid condensation in the unit. Therefore, the supply temperature of the water should be no higher than 55°F to 60°F [12.8°C to 15.6°C]. Frequently, a hot lab, an area where radioactive materials are prepared for injection, is associated with the PET scanner. Depending upon the procedures, this preparation may require a dedicated hood and exhaust system for the radioactive materials. Verify with the users the intensity of the radioactive materials and the duration during which materials may be open to the atmosphere. Then check with the authority having jurisdiction (AHJ) for interpretation and requirements regarding radioactive exhaust. These requirements may include charcoal filtration.

8.4.3 Cardiac and Interventional Lab

In "cath" and interventional labs, stents, balloons, and valves are placed in the body, usually using a small incision in the femoral artery. The device placed inside the artery is then guided using fluoroscopy. Because there is continuous X-ray exposure for considerable time, good shielding is a necessity. This is a procedure area (per Table 3-3) and requires 15 ach. The fluoroscopy machine may be air or water cooled. If the machine is air cooled, and if the computer equipment is also located in the Procedure Room, then it is possible that the air change rate may be driven by the internal load; this should be doubled checked. System users may require piped anesthesia, which will drive the various requirements of the NFPA for anesthesia areas. This includes

low returns, smoke purge, and possibly other requirements per the AHJ. A hybrid OR and an intense cardiac cath room are very similar. From an operational flexibility perspective, it is best to design a cath or interventional lab as an OR. This includes low returns as well as a monolithic/gasket ceiling, medical gases, etc.

8.4.4 Electrophoresis (EP) Lab

An electrophoresis (EP) lab is used to insert and adjust heart pacemakers. It is a procedure area requiring the same airflow (15 ach) as a cath lab. As with all fluoroscopy-based procedures, this room requires X-ray shielding from adjacent areas as well as from the Procedure Room to the Control Room.

8.4.5 Linear Accelerator

Linear accelerators are used for treating oncology patients. A beam of radioactivity is shot at a tumor to kill the cancer cells. Because there is no invasive procedure, 6 ach will suffice. There is usually an adjacent CT room where the patient is prepped and a target is drawn on the patient to focus the linear accelerator beam. Because of the radiation, accelerator rooms are built with extremely thick walls (18 to 24 in. [457 to 610 mm]), usually constructed of concrete but possibly also using lead. Therefore, careful planning is required for all penetrations into a linear accelerator room. Be aware that roofs over linear accelerators may not be shielded, making them dangerous to work on, and difficult for vertical expansion. The machine is usually water cooled, and it can use a house or dedicated-process chiller.

8.4.6 Nuclear Medicine

Nuclear medicine patients ingest radioactive material (barium) and are then put through a series of tests to monitor circulation. This is strictly a diagnostic area, requiring 6 ach, but it may be load driven because patients frequently engage in active exercise, and there may be treadmills and envelope loads from windows.

8.4.7 Computerized Tomography (CT)

CT is an X-ray-based procedure used for diagnostics. Opaque fluids are injected into the patient during the procedure. This is not considered an invasive procedure. The CT machine takes a series of X-ray slices (64, 128, etc.) that are then reassembled by a computer. CTs may be air or water cooled. A Control Room is necessary to shield the users from X-ray exposure. As discussed previously and shown in Figure 8-5, CT, like most multicomponent imaging systems, is generally installed in three separate rooms, each of which should have its own thermostat.

8.5 LABORATORIES

Additional information regarding laboratory design may be found in the *ASHRAE Laboratory Design Guide* (McIntosh et al. 2001) and in Chapter 14 of the *ASHRAE Handbook—HVAC Applications* (ASHRAE 2011b).

8.5.1 General Clinical Laboratory Considerations

Clinical laboratory spaces are typically divided into different laboratory areas or departments where specific functions and tests are performed. These areas may be adjacent to each other (without

dividing walls or partitions). Occupants may benefit from a temperature zone map that shows the areas controlled by each thermostat. To maintain differential pressures, exhaust air terminals can be set with a fixed offset from the supply air terminals, or other strategies may be used. For further information, see the sections on room pressurization in this chapter and Chapter 6. Some spaces, such as Biological Safety Laboratories, may require active monitoring of differential pressure.

Laboratory space design temperature setpoints often range from 70°F to 75°F [21.1 °C to 23.9 °C]. Areas where personnel may wear personal protective equipment may require a lower temperature. Air change requirements are typically 6 ach total and 2 ach outdoor air, with the exception of glass-washing rooms, which require at least 10 ach total, and biosafety level 3 areas, which may require 10 to 15 ach). Cooling loads and/or exhaust quantity may dominate and require higher air change rates than the minimum required by code. ANSI/ASHRAE/ASHE Standard 170-2008, Table 7-1 (see Table 3-3 in this manual), also lists design temperatures and air change values for clinical laboratory spaces.

Filtration for clinical laboratories consists of MERV 13 filters, according to ANSI/ASHRAE/ASHE Standard 170-2008 (see Table 8-4 in this manual). Higher filtration levels may be desirable for a specific application, but this is not common. The use of prefilters is a good idea (in order to increase the life of the MERV 13 filter), but is not mandatory.

Airflow distribution should be designed to minimize drafts and to maintain a stable room temperature, taking into account the large physical size of some analytical equipment and the uneven distribution of heat-producing equipment. A stable temperature may be required for some pieces of analytical equipment. A maximum range of ±2°F [±0.9°C] in an hour is common, but specific manufacturer's requirements should be consulted. In rooms with chemical hoods or biological safety cabinets (BSCs), the supply air should be provided through a laminar-type diffuser (Group E) located away from the hood/cabinet so that the air velocity is less than 30 fpm [0.15 m/s] in front of the hood/cabinet.

Effluent gases from analytical equipment such as gas chromatographs typically must be vented to the outside. Snorkels are frequently used.

Many laboratory areas have refrigerators that reject heat. Consider locating an exhaust grille over them to keep the heat from going into the space. Some refrigerators may have liquid nitrogen backup instead of emergency power backup. Most have temperature alarms.

Solvent/flammable cabinets are typically not vented unless there are large volumes of chemicals or if chemicals with a very strong odor (such as mercaptans) are being stored. Check with local codes and the

local fire marshal. Flammable cabinets located under chemical hoods may be vented into the chemical hood, typically with a kit from the chemical hood manufacturer, without impacting the overall exhaust airflow. Acid cabinets should not be vented into chemical hoods.

Laboratory areas may have a high concentration of pneumatic tubes used to transport samples. Pneumatic tubes typically have a large turning radius and should be coordinated with the ductwork and piping.

Exhaust from multiple chemical hoods or BSCs may be connected together (note that this is not always allowed) with appropriate cautions, but typically cannot be combined with general laboratory exhaust. The hood exhaust fan should be located at the end of the duct run and appropriate corrosion- and spark-resistant construction specified as necessary. Provide a balancing damper for each chemical hood or BSC. Confirm the sash height to establish the exhaust airflow, and consider energy-efficient sash configurations. Discuss, with the owner, sizing the HVAC system for a diversity of sash positions rather than for all open-at-100%. In addition to balancing dampers, provide isolation dampers at BSCs, if required for decontamination. Provide isolation dampers on the supply air to rooms with BSCs if the entire room is to be decontaminated. Include a decontamination sequence of operation for controlling the dampers.

8.5.2 Air Balancing for Differential Pressure

Balancing of laboratory spaces involves a few special considerations. Tolerances on airflows should be specified. Exhaust airflow tolerances are frequently specified to be –0% to +5% so that the air change rate established by the exhaust airflow is not compromised. Supply tolerances are typically –5% to +5%, with the caveat that room pressure differentials must be maintained.

In addition to specifying airflow balancing tolerances, the exact pressure differential to be maintained should be specified in the design documents and measured during balancing. Typical differential pressures for clinical labs are in the range of 0.01 to 0.05 in. of water [2.5 to 12.4 Pa]. The total airflow on the supply and exhaust side may be reduced, often to only 3 or 4 ach during unoccupied periods, to reduce energy consumption as long as pressure differentials are maintained. Setting up such reduced airflow requires extra balancing effort and coordination with the control system, and should be noted in the design documents. Lab users and maintenance personnel should be consulted.

As discussed at the beginning of this chapter, the initial balancing points for a negatively pressurized laboratory are typically based on the lowest volume of exhaust airflow required, with the supply airflow then adjusted accordingly to meet the cooling load, makeup air needs, and the pressure differential required. The exhaust airflow should be increased only if the supply airflow is at the minimum setpoint to meet the cooling and makeup airflow requirements and the space still not

adequately negatively pressurized. The system should be designed with flexibility in mind, both on the exhaust and supply airflow side, to facilitate balancing. This often means designing a range of 100 to 200 cfm [47 to 94 L/s] variation into the supply and exhaust airflows in each room. Tightly sealing the room and all ceiling and wall penetrations (electrical outlets, diffusers, light fixtures, thermostats, etc.) will minimize the required difference between supply and exhaust airflow. In may also be beneficial to have the architect specify doors with an adjustable gap on the bottom. Determine from the owner which doors are expected to stay closed and which are expected to be propped open, and design accordingly. Coordinate with the owner regarding who will provide the certification of chemical hoods or BSCs after balancing is complete.

8.5.3 Energy Conservation Considerations

To conserve energy, where it is safe to do so, consider the use of Class II Type A1 BSCs that recirculate air back into the space. Use a Class II Type B2 BSC if volatile chemicals are being used. Locate chemical hoods or BSCs away from doors or high traffic areas. Appendix I in the *National Institutes of Health (NIH) Design Requirements Manual for Biomedical Laboratories and Animal Research Facilities (DRM)* (NIH 2008) contains additional guidelines for the placement of BSCs, including the case where more than one BSC is located within the same room.

HVAC systems for laboratories may take advantage of hybrid systems, with one system aimed at providing ventilation and makeup air and the other system aimed at satisfying the internal cooling loads. Decoupling these design needs into separate systems can reduce the overall exhaust air volume and resulting energy consumption in laboratories with high internal sensible heat gains. Systems such as variable refrigerant flow, fan-coils, chilled beams, or newer fan-terminal units with cooling coils on the plenum inlets, may be considered to address the cooling loads. Diversity of laboratory equipment operation should be figured into the load calculations. Energy-recovery systems such as run-around loops may be utilized. Take care with energy recovery wheels and other devices that will have some air leakage from exhaust to supply air.

Consider reducing airflow or incorporating setback temperatures during unoccupied periods to conserve energy. Lighting can be dimmed as an indicator that a space is in reduced-airflow mode. Use caution if analytical equipment requires a stable temperature at all times. Confirm with the owner whether chemical hoods or biological safety cabinets need to operate continuously at full airflow or if their airflow can be reduced (i.e., sash closed). Sequences of operation should include provisions for supply or exhaust fan (and other system) failures.

8.5.4 Histology/ Histopathology

These procedures process and examine tissue samples (biopsies) from the body under a microscope. This may include gross specimen examination, automatic tissue processing, and slide preparation.

Provide exhaust for slide trays, grossing station, and chemical hoods. Chemicals such as formaldehyde, alcohol, benzene, toluene, and xylene are commonly used. Consider welded stainless-steel ductwork. This space will contain a microscope that may produce high heat gains. The grossing table will usually require a special exhaust connection. Countertops may also need to be provided with exhaust in the wall over the backsplash.

8.5.5 Urology

This area processes urine samples and conducts tests to detect chemicals or signs of diseases. To control odors, provide exhaust in the wall over sinks used for specimen disposal.

8.5.6 Other Labs

Most labs will contain hoods that may be recirculating, full exhaust, or a combination. The following comments are specific to the lab types noted:

- *Cytology:* involves microscopic examination of cell smears from the body for signs of disease or infection.
- *Genetics:* processes samples for DNA analysis.
- *Cytogenetics:* processes cells and blood to determine the quantity and condition of chromosomes (karyotype) for medical diagnosis. This lab contains a chemical hood or a biological safety cabinet to control dangerous chemical fumes (such as ethyl alcohol and xylene).
- *Hematology, coagulation, and blood bank/immunohematology:* processes whole blood samples, including blood counts and blood films.
- *Coagulation:* processes citrated blood (treated to prevent coagulation) to determine clotting times and coagulation factors.
- *Blood bank:* performs testing for blood types; tests for compatibility for transfusions; and prepares blood, plasma, or platelets for transfusion and storage. This area will contain blood refrigerators that produce heat.
- *Microbiology:* processes various specimens to determine the presence of pathogens, and tests to determine the impact of various treatments on the pathogens. Microbiology is sometimes used to broadly include specific sciences such as bacteriology, virology, serology, and mycology.
- *Bacteriology:* processes various specimens to specifically determine the presence and type of bacteria.
- *Virology:* processes various specimens to determine the presence and type of viruses.
- *Serology/immunology:* studies antigens and antibody reactions to determine illness and organ transplant compatibility. This lab may include agarose gel electrophoresis, immunoelectrophoresis, and immune-fixation. Samples may include serum, urine, and cerebrospinal fluid.

- *Parasitology:* processes various specimens to determine the presence and type of parasites.
- *Toxicology:* processes blood and urine to determine the presence of drugs.
- *Mycology/fungus:* processes various specimens to determine the presence and type of fungi. This lab may contain a biological safety cabinet that produces heat (and may be ducted). The lab may contain a hood for working with radioactive isotopes. The designer must determine the lab's biosafety level (typically level 2, occasionally level 3); determine whether the owner requires room differential pressure monitoring; and determine the need for an anteroom.
- *Chemistry/biochemistry:* this area processes blood specimens, typically serum or plasma, to determine the presence of various chemicals and blood properties. The lab may also perform therapeutic drug testing; endocrine testing; and diagnostic testing for abnormal metabolism of amino acids, organic acids, carnitine, and their derivatives. This type of lab may contain a chemical hood or a special perchloric acid hood.
- *Flow cytometry:* processes blood, tissue, and other specimens to determine the presence of specific molecules on the surface or interior of cells. Detects abnormal cells. This area typically needs specialized exhaust, because it can spread microbial contamination very easily.
- *Glass washing, sterilizing, and endoscope processing:* provide an exhaust canopy at the autoclave. Ethylene oxide (EtO) sterilizers require special ventilation and exhaust. Provide exhaust at the counter and at the floor where endoscopes are cleaned and hung to dry. The scopes are often cleaned in a hood with disinfectant.
- *Nuclear medicine:* the handling of radionuclides for various diagnostic and treatment procedures may require shielding or a radioisotope hood.
- *Soiled utility:* exhaust this area the same as a toilet. Transfer air from a nearby clean utility room if possible.
- *Media transfer:* involves preparation of media for laboratory tests. Some larger facilities purchase commercially prepared media while others (typically smaller ones) manufacture their own. May include high-temperature glassware washers/autoclaves for sterilization, chemical hoods, water filtration systems, and refrigerators and/or freezers.

8.6 PHARMACIES

8.6.1 General

Clinical Pharmacies include places where pharmaceutical drugs are prepared or compounded and dispensed for administration to the inpatient population. Some facilities also have a separate pharmacy for dispensing pharmaceutical drugs to employees or to outpatients. The drugs may be in the form of pills, IV solutions, inhaled mists, etc.

USP 797 (USP 2012) is a guideline from the United States Pharmacopoeial Convention for sterile compounding of mixtures in the pharmacy. Compliance with the guideline may or not be required by the local authority having jurisdiction (AHJ), state pharmacy certification board, or by facility preference. Sterile compounding is divided into three categories: low, medium, and high risk. The healthcare designer is most concerned if the pharmacy wishes to perform high-risk sterile compounding, where mixtures are made up in batches and not administered right away. In such instances, greater care must be taken to preserve the purity of the mixture. USP 797 compliance for high-risk compounding includes requirements for clean spaces where the compounding occurs, maintenance of pressure differentials, room air supply and exhaust criteria, and special storage of hazardous drugs. Sterile compounding of hazardous drugs, such as chemotherapy drugs, requires special consideration. Understand that there is a difference between *high-risk* and *hazardous* compounding and the associated environmental controls. Some pharmacy compounding areas involve the use of live viruses as part of clinical cancer research.

8.6.2 Temperature, Humidity, Filtration, and Air Change Rates

Pharmacy space design temperature setpoints often range from 70°F to 72°F [21°C to 22°C], although specific drugs may require a tighter temperature range. Care should be taken with system zoning to provide this temperature continuously. In facilities where the area is served by a building air-handling unit that is deenergized at night, other provisions, such as terminal heating and cooling, may need to be provided. Areas such as compounding rooms where personnel may be wearing more personal protective equipment may require a cooler temperature, such as 68°F [20°C].

Humidity control may be desired based on the types of drugs stored in the pharmacy but is not specifically required by ANSI/ASHRAE/ASHE Standard 170-2008, Table 7-1.

Typical pharmacies require MERV 14 final filtration with a MERV 7 prefilter, according to ANSI/ASHRAE/ASHE Standard 170-2008, Table 6-1; however, sterile compounding areas will require HEPA filtration.

Air change requirements are typically 4 ach total and 2 ach outdoor air with the exception of compounding spaces complying with USP 797, which may require 20 to 40 ach or greater. Early during design, confirm with the AHJ or the authority certifying the USP 797 lab whether they are going to require the minimum air change values listed in USP 797 or if they will certify the lab based on the ISO cleanroom level achieved during testing. In other words, if ISO 7 is achievable with only 20 ach, will they accept that or will they insist on 30 ach no matter what?

Energy-saving strategies for spaces that require high air change rates may include using terminal HEPA diffusers that recirculate most

of the air; laminar flow hoods; or recirculating biological safety cabinets (BSCs) instead of ducted cabinets; and minimizing the room size.

8.6.3 Air Distribution

Typical pharmacy spaces can be served with overhead supply diffusers and return grilles. Sterile compounding spaces, buffer areas, and anterooms that require higher levels of filtration for USP 797 compliance can include laminar HEPA diffuser grilles. These are typically, but not always, fan powered. Some spaces require low wall return for compliance. Supply diffuser layout should result in no more than 50 fpm [0.25 m/s] air velocity in front of laminar flow hoods or BSCs.

8.6.4 Pressurization

Refer to the laboratories section of this chapter for design considerations related to room sealing, air balancing, and room pressure monitoring for sterile compounding spaces.

Pharmacies are required to be positively pressurized to nonpharmacy spaces, according to ANSI/ASHRAE/ASHE Standard 170-2008, Table 7-1. Within the overall pharmacy boundary, other room pressure differentials may be required. For example, an office that opens into a pharmacy is typically neutral or pressurized relative to the pharmacy. Rooms where hazardous drugs are stored should be negative to the pharmacy or to an anteroom.

If anterooms or buffer areas are incorporated for USP 797 compliance, then a variety of pressure differential combinations could occur. A sterile compounding room is typically positive to an anteroom or buffer area, with the anteroom or buffer area positive to the pharmacy. A hazardous drug compounding room should be negative to the anteroom, with the anteroom positive to the pharmacy. Both the hazardous drug compounding room and the anteroom need to be ISO 7 clean spaces, if USP 797 compliance is desired. This allows the hazardous compounding room to be both a clean space for sterile compounding and a negatively pressurized space relative to the pharmacy for the use of hazardous drugs.

Figures 8-13 and 8-14 show examples of pharmacy floor plans and pressurization.

8.6.5 Special Considerations for Chemotherapy Compounding

Chemotherapy compounding typically involves volatile compounds that are extremely hazardous and are not stopped by HEPA filters or rendered harmless by ultraviolet (UV) light from the sun after being exhausted outdoors. In such cases, only a Class 2 Type B2 biological safety cabinet should be used. These are 100% exhausted to the outdoors and often require 2.5 in. of water [625 Pa] or more of static pressure at the duct connection to the cabinet.

Strong consideration should be given to routing the exhaust through a carbon adsorber to collect volatile material before it is discharged to

the outdoors. Multiple test canisters are recommended for periodic testing of the adsorber life, because pressure drop cannot be used to determine adsorber capacity as on a standard filter. Exhaust from a hazardous drug storage room should also be connected to the carbon adsorber. Consider acoustics when sizing the duct branch to the hazardous drug storage room off the main branch that also serves the Class 2 Type B2 hood, because of static pressures.

8.6.6 Laminar Flow Hoods and Biological Safety Cabinets

Laminar flow hoods (typically a vertical or horizontal configuration) are recirculating and do not require ducted exhaust, but they do contribute toward the overall space heat gain. Biological safety cabinets (BSCs) (see Figure 8-15) may be recirculating or ducted and all add heat to the space. BSCs that are ducted may have a thimble (canopy) or hard duct connection, depending on the specific circumstance.

Standard practice is to leave BSCs running continuously, but laminar hoods are often turned off during periods of nonuse and recleaned after being turned on. It is wise to confirm the preference of

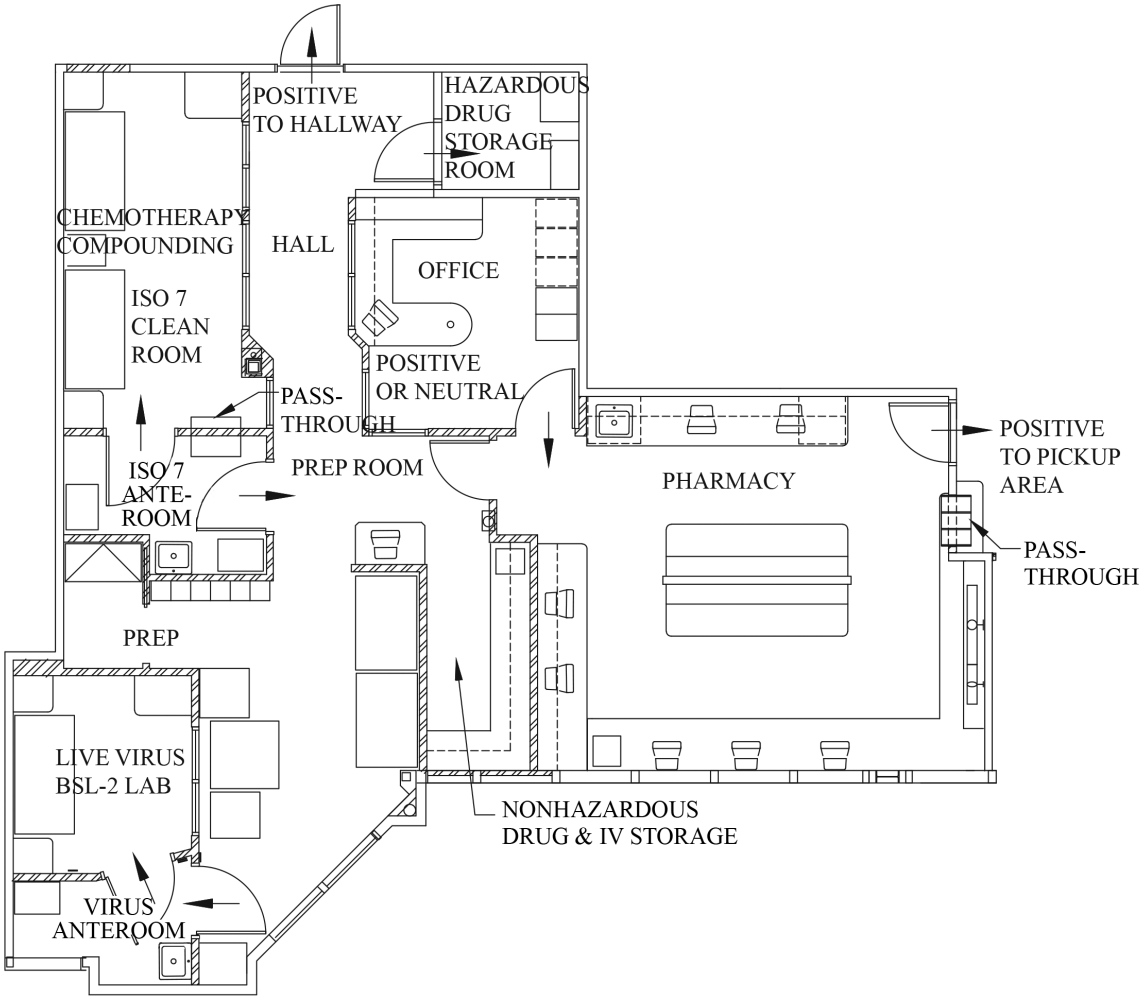


Figure 8-13 *Example Pharmacy Floor Plan and Pressurization*

the facility for the present and possible future use before moving forward with a given design.

8.6.7 Pharmacy-Specific Considerations for HVAC

Some pharmacy areas have robots or automated dispensing equipment that can add significant amounts of heat to the space and should be accounted for. Refrigerators and freezers also add heat to the space. Consider monitoring of temperatures with an alarm if drug costs are high. The pharmacy may have an autoclave for the prep equipment if chemotherapy or antibiotic compounding is desired. This adds heat to the space and may require a capture hood for steam. Consider emergency power and redundancy, especially if compounding hazardous drugs. Many pharmacies are equipped with a pass-through (see Figure 8-16) between compounding areas and either the anteroom

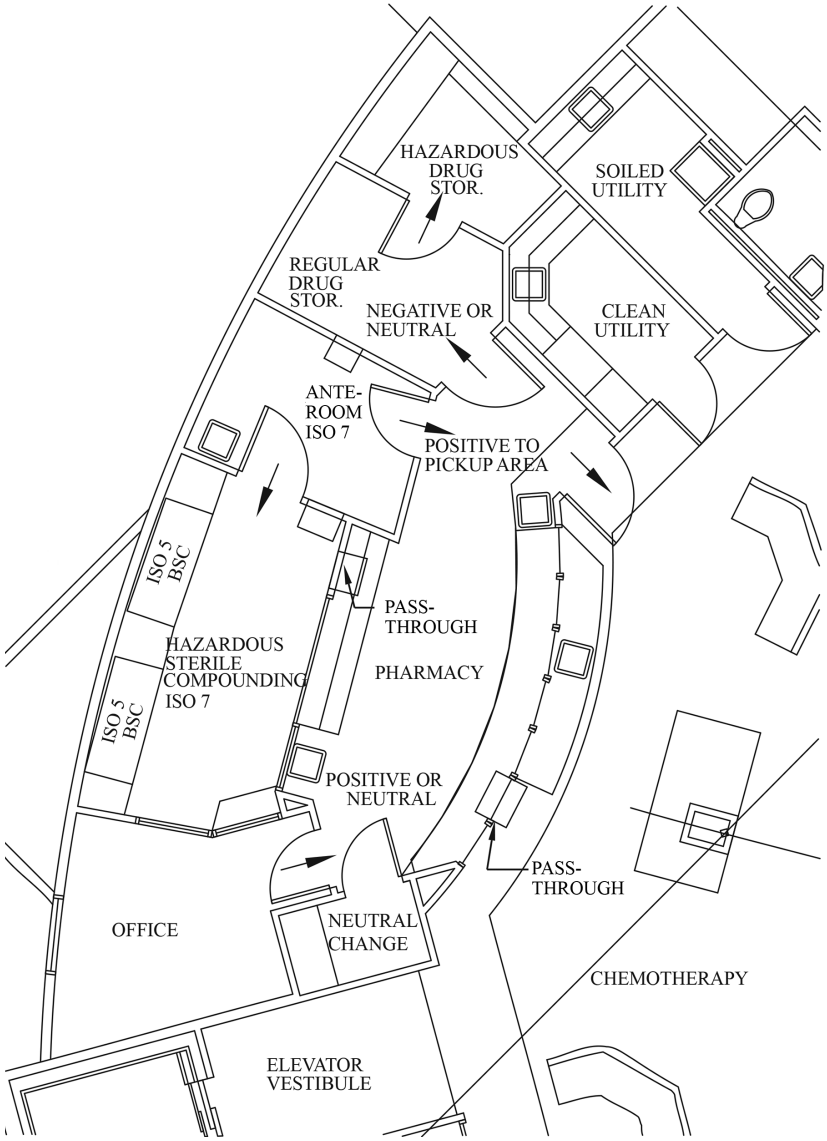


Figure 8-14 *Example Pharmacy Floor Plan and Pressurization*

or pharmacy or the pass-through may be located between the pharmacy and the pickup area.

Figure 8-15 *ISO 5 Biological Safety Cabinet in ISO 7 Chemotherapy Mixing Room*

Figure 8-16 *Pharmacy Pass-Throughs*

The pharmacy may include a transportation elevator or pneumatic-tube system. Clearance with these should be coordinated with pipe and duct routing. Security for the pharmacy typically includes construction of walls that extend to the bottom of structure. Security grilles or other measures may be warranted.

8.7 MORGUE AND AUTOPSY

Autopsy rooms are part of a hospital's pathology department and are susceptible to heavy bacterial contamination and odor. Internal heat gains are high because of the presence of refrigeration units. These areas require special attention.

ANSI/ASHRAE/ASHE Standard 170-2008 requires a variable-range temperature capability of 68°F to 75°F [20.0°C to 23.9°C] and negative pressure in relation to the surrounding area. For ventilation, a minimum of 12 ach is recommended, of which a minimum of 2 ach must be outdoor air. There is no requirement for relative humidity. All air must be exhausted.

The supply air for the Autopsy Room should be introduced to those areas of the room where workers are present, and should then flow to exhaust outlets. It is important that the people in the space are washed with clean air to reduce their chances of coming into contact with contaminants. Supply air outlets in these spaces are typically Group E, nonaspirating, laminar diffusers. The laminar diffusers should be arranged in the ceiling directly above the autopsy tables to produce a downward flow of air over the occupants and autopsy table, and then to low-level exhaust grilles. The designer must verify with the AHJ whether there are specific requirements for airflow per diffuser; if none exist, then using an airflow range of 25 to 35 cfm/ft^2 [127 to 178 L/s per m^2] (as recommended for operating rooms) will work.

Exhaust intakes in the Autopsy Room should be located both at high level (in or near the ceiling) and at a low level (in the sidewall). The high and low exhausts will help to minimize the chance of stagnant air zones in the space or a buildup of gases and contaminants. In areas where large quantities of formaldehyde are used, special exhaust systems can effectively control concentrations below legal exposure limits. Further steps can be taken to control concentrations using localized exhaust or an exhaust system built into the autopsy table. During dissection, an extractor fan in the table draws air across the table top and into table-mounted exhaust openings, thus minimizing the chance of occupants inhaling noxious substances or gases from the body. Exhaust ductwork will run from such a table either through a trench in the floor or in the ceiling space of the room below. When the ductwork is run in a trench, consideration should be given to using a corrosion-resistant material, because the ductwork will not be easily accessible for future repair or replacement.

Autopsy exhaust intakes are typically fixed-blade single-deflection type. There are no special construction requirements for these grilles; however, those installed at low level are often stainless steel for added ruggedness and material strength that will better resist damage. The grilles are held in place with quarter-turn fasteners to allow easy removal for cleaning of the grilles and ductwork.

Though not required by ANSI/ASHRAE/ASHE Standard 170-2008, it is recommended that the pressure differential between an Autopsy Room and surrounding areas be monitored and that there be an alarm or some indication when the pressure differential is lost or, preferably, when it starts to approach a neutral point.

Hydronic radiant panels can be used to provide heating and additional cooling to Autopsy and Morgue Rooms if required.

8.8 ISOLATION ROOMS

Isolation bedrooms may generally be classified into four types:

- *Airborne infectious isolation (AII)* rooms are for patients having an airborne-communicable disease. For an AII room, the HVAC system functions as one of multiple levels of infection control designed to contain patient-generated infectious microbials within the room, to prevent the spread of infection to other patients and staff.
- *Protective environment (PE)* rooms are for patients suffering from weakened immune systems and requiring protection against infectious airborne agents. In this case, it is the patient who must be protected against infectious microbials, including opportunistic pathogens that would normally not pose an infection risk to healthy individuals.
- *Combined AII/PE* rooms are for patients suffering from a weakened immune system who also have an airborne communicable disease. In this type of room, HVAC issues involve a combination of both AII room and PE room considerations.
- *Contact isolation* rooms are for patients having a communicable disease that is not airborne.

Design requirements for each type of isolation room follow.

8.8.1 AII Rooms

AII rooms are used to house patients with suspected or known respiratory diseases, such as tuberculosis. These rooms provide a volume within which airborne particles are contained, diluted, and directed outside. AII rooms have two major ventilation design criteria: (1) negative air pressure relative to all adjoining spaces, and (2) an air distribution pattern within the room designed to reduce airborne infection.

An anteroom is not mandatory in AII rooms, but is highly recommended to maintain pressurization and the air pattern, and minimize transfer of air with the corridor. Within the isolation room itself, the

goal of the HVAC system is to establish an airflow arrangement that reduces exposure of uninfected people who visit or work in the space. The recommended design approach (see Figure 8-17) favors creating maximized air mixing, pressurization, and airflow, thereby minimizing exposure.

While laminar flow systems are of proven efficacy in cleanrooms and other applications involving much higher airflow exchange rates, designers cannot expect to achieve or maintain true unidirectional flow in infectious isolation rooms. One need only consider that at 12 ach, the average air molecule travels around in the space for an average of 5 min before exiting.

The preferred design approach emphasizes air-mixing effectiveness and dilution ventilation without attempting to establish unidirectional airflow. Staff protection is afforded by minimizing the airborne concentration of infectious microorganisms. As discussed in more detail in the *ASHRAE Handbook—Fundamentals* (ASHRAE 2009), ventilation effectiveness is maximized, particularly for perimeter rooms in cooling-dominated climates, by Type A ceiling-mounted, horizontal-throw diffusers with maximum throw reaching the far wall, and with ceiling-mounted exhaust registers. In addition to its contribution to ventilation effectiveness, the exhaust register, if located over the patient bed, has the potential to increase the system's overall efficacy by its location in the path of the patient's cough-induced plume. The designer should be cautious with supply diffuser location and throw design, to avoid high-velocity throw reaching the doorway to the anteroom or corridor and potentially counteracting the desired air transfer pattern. Provide enough conditioned air to satisfy the cooling loads within the room. Considering two room occupants (a patient and a caregiver), lighting, solar loads, and wall conduction, heat gains can easily exceed 4000 Btu/h [1172 W]. This magnitude of gain requires about 185 cfm [87 L/s] of 55°F [12.8°C] air.

Provide more exhaust volume than supply in this type of room. Either the supply airflow, or both supply and exhaust air volumes, should be controlled by a relative-pressure-sensing device or using volumetric offset by reading supply and exhaust flow rates. A sensor should always be located within the wall of the patient room, regardless of the presence of an anteroom. The sensing device will measure pressure relative to the corridor. The room must be operated so the sensing device reads 0.01 in. of water [2.5 Pa] in normal conditions (door closed).

Supply air to the room does not have to be 100% outdoor air. However, supply air must be filtered at least to the levels of the general patient spaces. All air must be exhausted directly to the outdoors. If combined with other exhausts, HEPA filtration must be provided before merging airflows. Locate exhaust grilles or registers directly above, or at the head of, the patient bed. Group A or E outlets should be used for

supply air, and located in the center of the room or slightly toward the entrance. Provide high airflow rates and high air diffusion performance. Air in this room should be well mixed. A 95% air diffusion performance index (ADPI) can be achieved with a good Group A diffuser and a single ceiling return (Riskowski et al. 1996). Exhaust grilles in AII rooms require special design attention. Low sidewall grilles, if used, have the potential to become clogged with lint from bedmaking and gowns. Failure to keep grilles clean often results in overpressurization of the AII room, creating an effect opposite to that desired (i.e., containing infectious disease) (Hermans and Streifel 1993).

The actual airflow volumes for these rooms will depend substantially on the space cooling load and the magnitude of the leakage area. If cooling needs are lower, the air change rate can be lower, down to a minimum of 12 ach. If the leakage area is larger, the exhaust must be greater to achieve the 0.01 in. of water [2.5 Pa] pressure differential. See Figure 8-17 for a diagram of a typical AII room.

Provide an alarm mechanism to alert clinical staff of loss of negative pressure. A differential pressure indicator must be visible

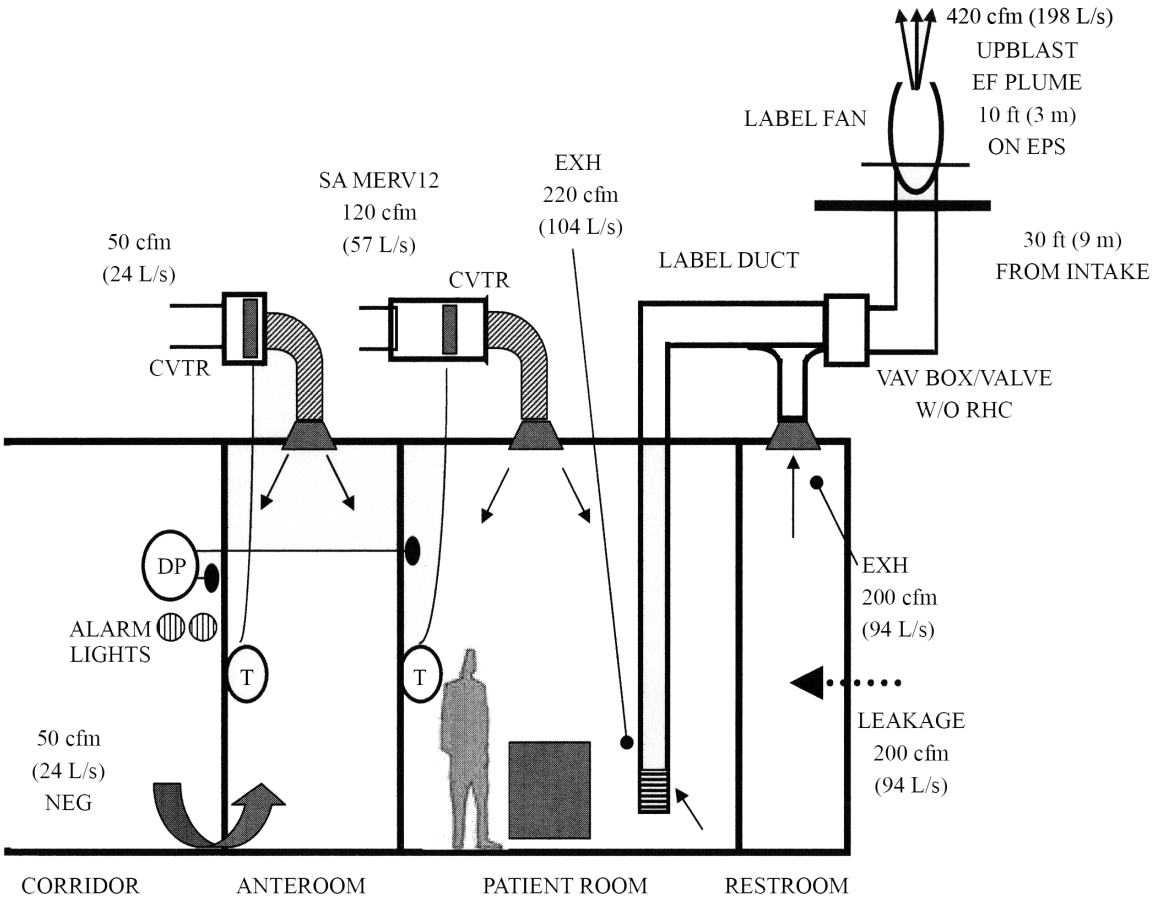


Figure 8-17 *Airborne Infectious Isolation (AII) Room Arrangement*

from outside the room. Negative pressure status of the room must be validated and the controls tested so that room pressure cannot become positive relative to the environment. Room exhaust must be on emergency power, with the exhaust well identified to prevent potential contamination exposure to maintenance and operation staff.

8.8.2 PE Rooms

Protective environment (PE) rooms include those for bone marrow transplant, oncology, hematology, and similar rooms for any condition that leaves a patient immunocompromised. A PE room seeks to protect the patient from all potential airborne infectious organisms, some of which may be benign to those with normal immune systems. Fungal spores are among such otherwise harmless organisms. In many climates, fungal spores are found in the ambient air both inside and outside of environmentally controlled buildings. Spores from *Aspergillus fumigatus,* for example, are ubiquitous and exist in the outside environment. Thermotolerant species (i.e., those that grow in cultures at 98°F [37°C]) are particularly hazardous to the immunosuppressed patient. Low concentrations (~2.0 cfu/m^3) of *A. fumigatus* in the indoor air surrounding such patients may cause aspergillosis (Rhame et al. 1984). Design considerations for a PE room are similar to those for an AII room: (1) room air pressure control, in this case for positive pressure with respect to all adjoining spaces; and (2) an air distribution pattern within the room that is favorable to airborne infection control, in this case for the protection of the patient. See Figure 8-18 for a diagram of a PE room.

Although not mandatory with a PE room, an anteroom is recommended, because it can help maintain the pressurization and the air pattern to protect the patient. Maintaining positive pressure, possibly with anterooms, is required in PE rooms. Seal PE rooms to reduce air leakage area and/or increase differential air volume to maintain a differential pressure of 0.01 in. of water [2.5 Pa].

A unidirectional flow approach is recommended, in which air is introduced at low velocity (100 fpm [0.5 m/s] or less) from ceiling-mounted, non-aspirating-flow diffusers. Use nonaspirating unidirectional-flow diffusers of Group E, with HEPA filters within the diffuser. Air is exhausted at the floor level near the entrance to the room. The intent is to establish a vertically downward wash of clean air through the breathing zone of the patient, picking up contaminants as the air passes through the lower portion of the room and out through the exhaust registers. This approach may require more air than for a well-mixed room to maintain the cleanest air at the patient. In the cooling season, some advantage can be taken by allowing the air to "dump" somewhat down to the bed. In the heating season in colder climates, however, the air must be forced down to bed level at velocities around 50 to 75 fpm [0.25 to 0.38 m/s] without entraining room air. A higher room temperature can allow cooler supply air to fall to the bed (even in the heating season); therefore, a radiant-heat source near the window, controlled independently from the supply air temperature, is an advantage. As an

example, the room supply air temperature might be set at a fixed temperature and the radiant panel varied using a room thermostat to maintain 75°F to 78°F [23.9°C to 25.6°C] in the heating season.

PE rooms require continuous monitoring of pressurization with alarms. A differential pressure indicator must be visible from outside the room. Positive-pressure status of the room must be validated and the controls tested so that room pressure cannot become negative relative to the environment. The supply fan must be on emergency power.

There are no special requirements for labeling of components.

8.8.3 Combined AII/PE Rooms

Combined AII/PE rooms are required for a patient who is immunocompromised and has a suspected or known respiratory disease, such as tuberculosis.

An anteroom is mandatory in combined AII/PE rooms.

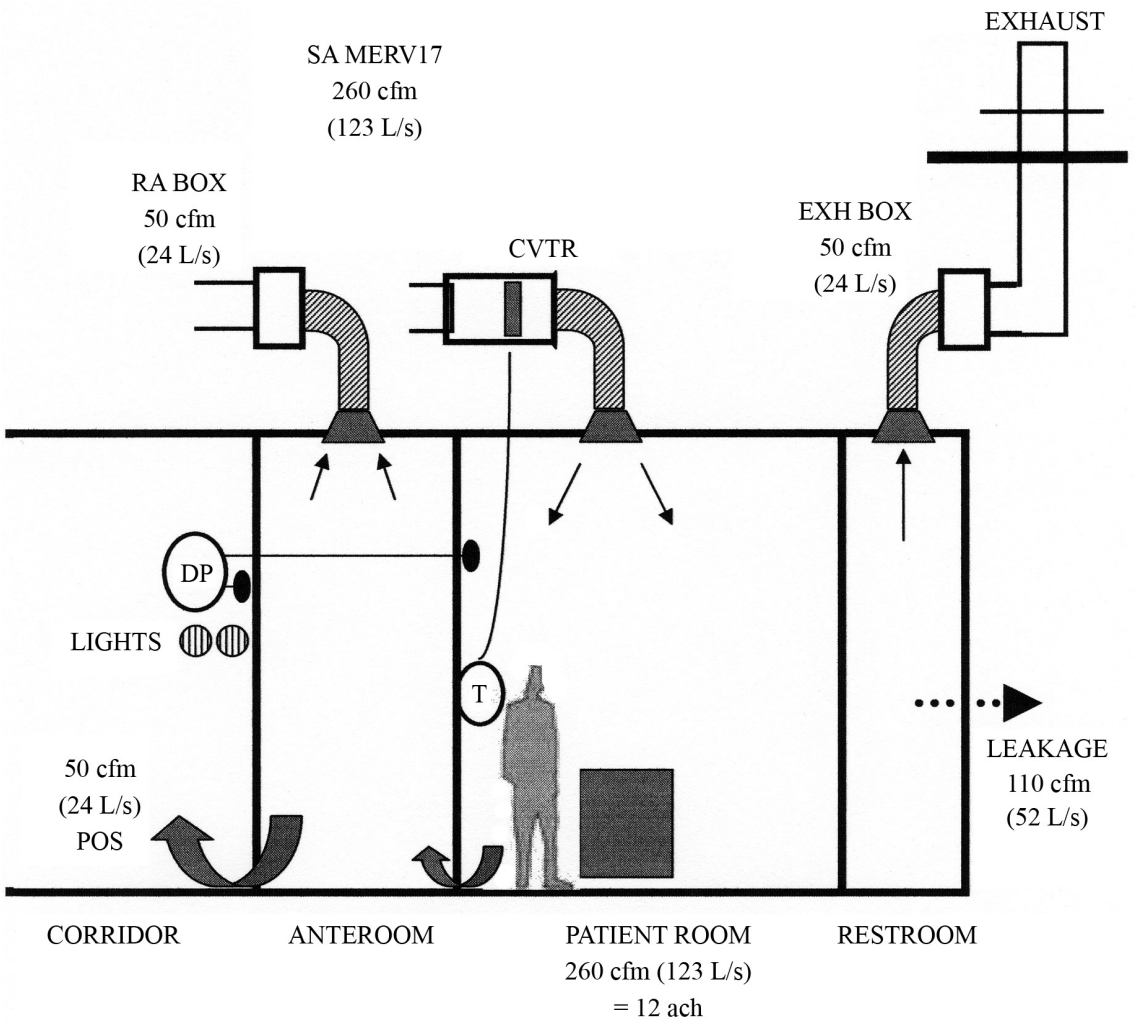


Figure 8-18 *Schematic Diagram of PE Room*

Two options are available for room pressurization: (1) the room is negative to the anteroom with the anteroom positive to the corridor, or (2) the room is positive to the anteroom with the anteroom negative to the corridor.

Continuous monitoring of pressurization with alarms is required in AII/PE rooms. A differential pressure indicator must be visible from outside the room. Sensors and monitoring are required from the patient room to the corridor and from the anteroom to the patient room. Readings for both monitoring arrangements should be available in the corridor outside the combined AII/PE room.

Positive or negative pressure status of the room must be validated and the controls tested so that room pressure cannot overturn relative to the environment. The supply and exhaust system networks must both be on emergency power, and the exhaust well identified to prevent potential contamination exposure to maintenance and operation staff.

8.8.4 Contact Isolation Rooms

A contact isolation room is for patients suffering from a communicable disease, such as chicken pox, that is not airborne. This type of room is a standard patient room and should be treated as such. No special measures must be taken for design of the HVAC system.

8.9 CENTRAL STERILE

The "central sterile" in hospital is a critical area. It is generally composed of three main sections: a dirty section, a clean section, and a sterile section. Material typically flows from the dirty section to the clean section (after being washed) and then to the sterile section (after being sterilized). A physical barrier will separate the dirty and the clean sections; the barrier will include washers with a double door, giving access to materials on each side, so that the washed materials do not come back into the dirty section. The same principle applies to the barrier between the clean and the sterile section, where a double-door autoclave is used. In addition, there is generally an access area for equipment maintenance (related to the mechanical portions of the autoclaves and/or the washers) and a sterile storage area.

Pressurization transitions from positive in the sterile section to negative in the dirty section.

As prescribed in *AAMI Standard 35: Safe Handling and Biological Decontamination of Reusable Medical Devices in Health Care Facilities and in Nonclinical Settings* (AAMI 2003) and in *AAMI Standard 46: Steam Sterilization and Sterility Assurance in Health Care Facilities* (AAMI 2002), temperatures in these areas (except for the equipment access room) should be controlled between 60°F and 65°F [15.6°C to 18.3°C] with a relative humidity range of 30% to 60% (except for sterile storage, where maximum humidity is 70%). The temperature and humidity must be recorded daily.

The air change and filtration requirements in these areas are similar to a surgical suite.

The equipment access room temperature should be controlled between 75°F and 85°F [23.9°C to 29.4°C] or as prescribed by the equipment manufacturer. This room is hot and noisy, and has a great potential for heat recovery, because it generates substantial heat throughout the year.

A special exhaust (canopy hood) must be installed over the outlet door of a steam autoclave and/or washer to capture the hot and humid air that will exit the unit when the door opens at the end of each cycle. The exhaust ducting must be watertight and preferably of stainless steel to limit corrosion; the ducting must include drainage at the lowest point.

For a gas sterilizer, the air is either exhausted directly from the unit or from an ethylene oxide (EtO) disposer that will burn up the gas and exhaust it as hot combustion products.

8.10 RENAL DIALYSIS AND CHEMOTHERAPY INFUSION

Because of concentrations of people and equipment, the air supply to dialysis areas may be greater than for a typical patient room. The location of the supply diffusers is important because patients are seated in reclining chairs throughout the treatment. Air velocities should be well below 50 fpm [0.25 m/s] at the treatment chair.

Environmental conditions for these spaces should be identical to those for a patient room. Consider locating a radiant ceiling heater directly above the treatment chair, provided with a thermostat for individual patient control. Dialysis patients are frequently cold, because they are sedentary as well as anemic because of their condition. On the other hand, staff is typically too warm as they continually move around the treatment area caring for patients. Provide a separate zone of control for staff desk areas.

8.11 ICU

Intensive care units (ICUs) serve seriously ill patients, from postoperative to coronary patients. The level of care and electronic monitoring of patients in these rooms are greatly increased compared to conventional patient rooms. Today, these spaces are often specialized, with common uses including surgical intensive care unit (SICU), medical intensive care unit (MICU), cardiac care unit (CCU), pediatric intensive care unit (PICU), and intensive care nursery (ICN).

ANSI/ASHRAE/ASHE Standard 170-2008 requires a variable-range temperature capability of 70°F to 75°F [21.1°C to 23.9°C], relative humidity of 30% minimum and 60% maximum, and positive air pressure in relation to the surrounding area. For ventilation, a minimum of 6 ach is recommended, of which a minimum of 2 ach must be outdoor air. Recirculation of room air is allowed in ICU rooms to meet the total air change requirements; however, the use of recirculating room HVAC units is not acceptable.

These spaces may be served by reheat induction units in which only the primary air supplied from the central system passes through the reheat unit. Exhaust air is to be discharged to the outdoors. In certain circumstances, special consideration may be required for air exhausted to the outdoors, such as from ICUs in which patients with pulmonary infection are treated. In this case, the exhaust air must be filtered to reduce the chances of spreading infection.

Return and exhaust grilles are often located in the ceiling. These can be eggcrate, perforated-face, or louvered-face grilles. The return and exhaust grilles are typically sized for a core velocity of 300 to 500 fpm [1.5 to 2.5 m/s] to keep noise production and pressure drop low.

Some AHJs prefer to see the return and exhaust grilles placed low in ICU rooms. Low grilles help develop a room airflow pattern that has the air moving down from the supply diffusers, across the patient, and then being exhausted at a low level. A further benefit of a low-level location is that any heavier-than-air gases in the room have a better chance of being exhausted and not escaping to surrounding areas.

Local heating and cooling requirements in ICU rooms can be complemented with hydronic radiant panels mounted in the ceiling. Radiant systems provide an effective method for heating or cooling a space while providing high occupant comfort and energy efficiency. Improved occupant comfort results from radiant heat transfer being more comfortable than convection, because room air velocities are significantly lower. In addition, radiant systems are very quiet.

When radiant cooling panels are used, monitor the dew point in the space. If the supply water temperature is cooler than within 3°F [1.4°C] of the room dew point, the supply water temperature must be reset higher to reduce the chance of condensation forming on the surface of the radiant panel. Use of radiant systems in lieu of filtered airflow is controversial. See section 3.4.6 for additional discussion of controls.

8.12 POSTANESTHESIA CARE UNIT (RECOVERY)

A postanesthesia care unit (PACU), sometimes referred to as post-anesthesia recovery (PAR), is a vital part of hospitals, ambulatory care centers, and other medical facilities. It is an area, normally attached to operating theater suites, designed to provide care for patients recovering from anesthesia, whether general, regional, or local.

These areas may have high equipment heat loads, so the ventilation system must provide sufficient conditioned air to maintain comfort for both staff and patients while also diluting and removing any anesthesia which may be exhaled. ANSI/ASHRAE/ASHE Standard 170-2008 requires a minimum of 6 ach total for recovery rooms with a minimum of 2 ach outdoor air. The temperature in the room must be 70°F to 75°F [21.1°C to 23.9°C], with relative humidity ranging

from 30% to 60%. The PACU must be positively pressurized in relation to the corridor.

Supply air outlets in the PACU are Group A ceiling-mounted diffusers and should provide good mixing in the space. The supply air outlets should be located to provide full coverage of the entire room so that there are no stagnant spots. In addition, care must be taken to ensure air velocities in the occupied zone, especially around the patients, does not exceed 50 fpm [0.25 m/s] to avoid complaints of drafts. Louvered-face directional diffusers, square-cone diffusers, and square-plaque diffusers are often used in these spaces. Such outlets can provide the required performance and air volume at relatively low sound levels and pressure drops, and they are easily cleaned and sterilized. Filtration should be per Table 8-4.

Return or exhaust air inlets must be located in the sidewall near the floor, similar to the placement of OR returns. In this location, the returns are better able to exhaust any anesthesia which may be exhaled. Return/exhaust devices are most often fixed-blade, single-deflection grilles that are held in place with quick-release, quarter-turn fasteners for ease of removal for cleaning and sterilizing. Though there is no corrosion control requirement, these grilles are often of stainless-steel construction for strength and ruggedness.

8.13 EMERGENCY DEPARTMENTS

Hospital and free-standing emergency departments serve a variety of medical conditions, including patients with infectious diseases, lacerations, broken bones, and severe trauma. HVAC equipment serving emergency departments must be reliable and minimize maintenance requirements to address the need for continuous operation. The emergency department is generally the point of entry to a hospital for undiagnosed patients, some of whom may be carriers of dangerous infectious diseases like tuberculosis. Emergency room waiting areas are exhausted, or may be returned if a HEPA filter is used (per Table 3-3, footnote q) on all return air recirculating in the space or to other spaces as a means of protecting patients and staff from infectious patients.

Infectious patients are also a concern in the event of a pandemic in the community. During a pandemic, the emergency department will be a primary point of contact between infected patients and the hospital. Some health care facilities, as an additional safety measure for a pandemic outbreak, provide the ability to switch the HVAC system from return air to 100% exhaust in part or all of the emergency department examination rooms. Coordinate with the owner how pandemic mode will be controlled: should the medical staff have the ability to put the system in pandemic mode or will facility operating and maintenance staff have the capability? Cooling and heating equipment serving the emergency room and associated central boilers and chillers will need to be sized to deal with the increased outdoor air loads under pandemic mode operation.

To deal with the variety of emergency patients seen, a variety of program spaces are typical to many emergency departments. These program spaces include isolation, decontamination, psychiatric, and trauma rooms. Isolation rooms should be designed as discussed elsewhere in this chapter. Decontamination rooms are designed for patients who have been exposed to chemical spills or some type of radiation exposure. Some facilities designate space outside the facility for decontamination and others create a decontamination room inside the facility. All air in decontamination rooms is exhausted to the outdoors and surfaces and materials in the room are designed to get wet or be exposed to higher levels of moisture. Psychiatric, seclusion, and patient-holding rooms are designed for patients who may present a danger to others or themselves. These rooms should typically have security diffusers, grilles, and registers installed for patient safety. Consider mounting temperature controls in inaccessible locations (such as in return air ducts or inside lockable furniture for adjustable thermostats). According to ANSI/ASHRAE/ASHE Standard 170-2008, there are two types of trauma rooms: (1) a room used for emergency surgeries that is designed as a Class B or C operating room, and (2) a room used for first aid or general emergency treatment (which should be provided with Group E, nonaspirating diffusers). Work with the users and owners to understand the intended use of all trauma rooms and consider designing all trauma rooms as Class B or C operating rooms.

8.14 BURN UNITS

This room type requires careful humidity control and, normally, the ability to achieve elevated temperature. Regimens of patient treatment vary between providers, and some institutions use radiant-heating equipment to supplement ambient heating. The owner should be consulted to determine how best to establish the desired conditions in the space, but in general maintain 40% to 60% rh with the capability of heating the space to at least 90°F [32.2°C] during any season. One source requires the ability to heat this type of space to 100°F [37.8°C] (DOD 2012). Treat the room as a protective environment (PE) isolation room with HEPA-filtered (MERV 17) air delivered from nonaspirating Group E ceiling diffusers, achieving an air velocity at the bed level of less than 50 fpm [0.25 m/s]. Use low-sidewall returns near the door of the room, and maintain the room under positive pressurization at all times.

8.15 BONE MARROW TRANSPLANT

Immunosuppressed patient units (also known as protective environment (PE) rooms) have additional HVAC requirements beyond those for the standard hospital in-patient room. Patients in these areas are being treated for bone marrow or organ transplants, leukemia, burns, or AIDS and are highly susceptible to diseases. Such patients are immunosuppressed and generally fall into two categories: contagious and noncontagious. When the patient is noncontagious, positive pressure is maintained between the patient room and the corridor; exam and treatment rooms should be controlled in the same manner. When the patient is contagious, isolation rooms within the unit may be

designated and provided with an anteroom. When an anteroom is provided, the pressure relationship from the patient room is positive with respect to the anteroom, and the anteroom is positive with respect to the corridor. PE rooms are described in section 8.7.

8.16 PSYCHIATRIC

Psychiatric or behavioral health rooms are generally treated the same as patient rooms with a total of 6 ach, of which 2 ach are outdoor air. Solar load from windows can increase the cooling demand such that more than 6 ach may be required. All equipment in these rooms must be suicide- and vandal-resistant, thus containing no wall-mounted thermostats (provide a sensor in the return air duct instead). Diffusers and louvers must be perfectly flush and/or of breakaway design. The air supply and exhaust/return grilles are typically of heavy-gage construction, to resist damage and vandalism and to reduce injury. They are commonly referred to as risk-resistant grilles and are designed to reduce the chance of an occupant threading something through the grille face or using any edge or surface on the grille as an anchor point. Even low-level installations require risk-resistant grilles. The supply outlet is commonly located high in the sidewall or in the ceiling so as to not discharge directly toward the patient's bed, reducing the chance of uncomfortable drafts. Radiant heating and cooling may be used subject to considerations in section 3.4.6.

8.17 PROCEDURE ROOMS

If invasive procedures occur in this type of room, ventilation must be provided in accordance with the ventilation requirements for Class A surgery. If anesthetic gases are administered, ventilation must be provided in accordance with the ventilation requirements for Class B or C surgery, including a waste anesthesia gas disposal (WAGD) system. See Table 8-3 for a classification of surgeries.

Endoscopy is a minimally invasive diagnostic procedure that allows examination of the inside of a person's body using an endoscope. An endoscope is a medical device consisting of a long, thin tube with a light and a video camera. Images can be seen on a screen.

The endoscopy room consists of two areas: (1) the endoscopy procedure area and (2) the endoscope cleaning/sterilization area. In some facilities, these two areas may be contained within the same room; however, because of the difference in activities and in ventilation requirements for these areas, these should be two separate rooms.

8.17.1 Endoscopy Rooms

The endoscopy room should be maintained at a positive pressure in relation to all adjacent spaces. This requirement is currently under review by the ASHRAE Standard 170 committee.

Scopes are sterilized in the endoscope cleaning/sterilization room. Chemical disinfection, or low-temperature sterilization, is used in these rooms, because the scopes can be damaged when exposed to temperatures exceeding 140°F [60°C], which is far below the temperature required

for thermal disinfection. Many of the sterilizing chemicals have a pungent odor; combined with the presence of dirty scopes, this means odor control is very important in these rooms. The required air change rate can be found in Table 3-3. These rooms are maintained at a negative pressure to the adjacent spaces to reduce the chance of odor migration. All air from the endoscope cleaning/sterilization room is exhausted outdoors; there is no recirculation of air from these spaces.

Supply air to procedure rooms must be filtered. Filtration requirements are found in Table 6-1, Minimum Filter Efficiencies, of ANSI/ASHRAE/ASHE Standard 170-2008. Filtered supply air is introduced into the space above the procedure table in such a way that the flow of air is over the staff and patient and is then exhausted from the room at a low level. Supply air outlets are typically Group E, nonaspirating laminar diffusers arranged over the procedure table to produce a downward flow of air. The designer must confirm any specific airflow requirements with the AHJ; if none exist, then use 25 to 35 cfm/ft^2 [127 to 178 L/s per m^2], as recommended for operating rooms, in the endoscopy room.

Exhaust intakes should be located low in the room, similar to an operating room. These are typically a fixed-blade, single-deflection type device. There are no special construction requirements for these grilles; however, because they are installed at a low level, stainless-steel construction is often used for ruggedness and material strength to better resist damage.

8.18 OUTPATIENT/AMBULATORY CARE

Many of the chapters in this book are presented from the point of view of an inpatient hospital. This section provides key considerations for medical services provided in an ambulatory or outpatient setting. These considerations are not all-inclusive but give HVAC designers enough examples to help them ask and uncover the unique project design considerations for these types of facilities, especially if they are familiar with these areas in an inpatient setting.

Health care organizations deliver services to their customers in facilities unlike many others, such as office buildings, that just house employees. Currently, and in the foreseeable future, there is fierce competition for patients and staff. Having patients or staff who are dissatisfied with the indoor environment runs counter to the goals of health care organizations. HVAC design solutions should be robust and of sufficient quality to deliver reliable temperature control and indoor environmental quality (IEQ) under all possible weather conditions. Determining the appropriate indoor quality would include consideration of factors such as

- type of medical services to be delivered;
- special patient, staff, and medical equipment IEQ requirements;
- 24/7 operation;

- code requirements for the building occupancy classification;
- code requirements compared to the specific organization's standard of care;
- qualifying for Medicare/Medicaid reimbursement (use of hospital's license);
- building operation and maintenance staff capacity and competence;
- who pays for maintenance and utility costs;
- health care organization business requirements and constraints; and
- accreditation.

Designers of HVAC systems for ambulatory health care facilities need to determine the appropriate basis for design and the most cost-effective methods to deliver the intended results. Judgment must be exercised when ambulatory-facility code requirements are less stringent or differ from those for a hospital (and/or the owner's typical standard of care). For example, an organization may choose to provide a higher-than-required level of air filtration for a medical office building containing areas for immunocompromised patients. The HVAC designer should discuss codes/standards and differences with key stakeholders within the organization. Do not assume that the owner knows or understands the IEQ requirements that relate to HVAC design. Nor should a designer assume that he/she knows an organization's standard of care for IEQ elements such as air filtration, sound, temperature, and humidity (to name a few).

Different building codes and standards typically apply to hospitals versus ambulatory care facilities. In addition, different (or additional) code authorities review and inspect the facilities. Whether the services offered qualify for Medicare/Medicaid reimbursement can impact the HVAC system design scope. Although not always the case, outpatient facilities commonly fall under business occupancy in the building code, and facility requirements affecting HVAC design do not involve the state health department. These facilities are often not required to follow the health care requirements of NFPA 101 (NFPA 2012), the FGI *Guidelines* (FGI 2010), and ANSI/ASHRAE/ASHE Standard 170-2008 (ASHRAE 2008). The HVAC systems serving these facilities are not required to provide hospital-specific air change and filtering requirements. As a result, variable-air-volume (VAV) systems are commonly applied as a means of saving energy. Plenum return systems are also commonly used, because they cost less to install and operate.

The following sections provide more detailed information and considerations for specific medical services and HVAC applications in outpatient settings.

8.18.1 Ambulatory Surgery Centers or Suites

Ambulatory surgery or outpatient surgery facilities serve patients who arrive, receive treatment, and leave in less than 24 h. These facilities have code and standard requirements similar to those for a

surgical suite in a hospital. It is important to clearly identify and understand which codes and standards apply for a specific project, and which are handled at the state (and sometimes local) level in the United States. Some unique aspects that can impact HVAC system design are discussed in the following paragraphs.

Outpatient facilities may involve one operating room or more than 20 operating rooms (ORs) in a variety of suites within one building. Typically, outpatient surgeries are scheduled well in advance. But the scheduling can vary from one facility to another, from 7 days/week and 12 to 14 h/day to only one afternoon per week. The number of ORs and the schedule intensity can play a role in deciding the number and type of HVAC systems. Operating rooms require, by code, a higher level of air filtration and air exchanges, positive air pressure, and different temperature and humidity ranges than other areas in an outpatient facility.

Another key design factor, even in outpatient surgeries, is the surgeon's common requirement for low operating room temperatures. Sub-65°F [18.3°C] conditions are common and sub-60°F [15.6°C] is not an unheard of request. The designer must understand the reason for such a request. The request is often made by a surgeon to assist in controlling sweating, because surgeons are under tremendous pressure and are fully gowned. But temperature and humidity requests can also be related to the procedures. Some research is beginning to surface that relates undesirable patient outcomes, such as longer recovery times, to cold ORs, but this information is not widely known or accepted at this time. The challenge with lower than 63°F to 64°F [17.2°C to 17.8°C] space temperature is maintaining the humidity level using conventional vapor-compression cooling versus the added cost to use chilled water or desiccant dehumidification technology. The design professional should be ready to explain the psychrometrics that demonstrate why just adding another "unit" or more airflow will not work. Lower space temperatures require colder supply air temperatures. A 50°F [10.0°C] supply air temperature is a common design criterion. If chilled water is the source of cooling, lowering the water temperature may come with an energy penalty. For many ambulatory surgery centers, direct-expansion (DX) cooling is a significantly more affordable option than chilled water, and has been found acceptable when adequate staging is provided to avoid noticeable swings in the supply air temperature. However, DX systems do not provide good humidity control in applications with significant outdoor air requirements. In addition, constant supply temperature is difficult to maintain with DX systems, often causing premature compressor failure.

Determining which areas in a facility will be served by specific air-handling (and associated cooling) equipment can be complicated and involve joint decision making between the design team and facility owner. Consider the impact of lower OR temperature and humidity on the supply air temperature and reheat requirements for both the OR and

other areas to be served by that cooling system. Consider the higher outdoor air and filtration requirements and the impact on pressure drop and energy use. Will humidification be required in winter? These issues involve significant implications for performance as well as initial and operating costs. The decision comes down to a question: which other areas does it make sense to place on the systems serving the ORs and sterile areas? The design team and owner must understand that there are first- and operating-cost trade-offs related to expanding an air-handling system to service areas beyond the ORs. The trade-off involves having a dedicated system serving the OR areas and, therefore, more air systems, that will give better temperature control and use less energy, versus fewer systems. It is common to find small facilities (with one or two ORs) with either a single air handler serving the entire facility or with one small system serving the ORs and recovery area and a second unit serving the rest of the facility. Facilities with more than two ORs usually have a dedicated air handler and cooling for the ORs and sterile area. The recovery room and remaining patient care areas will be served by another air-handling system. The size of the remaining areas (those not associated with surgery) will dictate whether this other system is extended beyond the surgery suite. Selecting among these options will impact the mechanical/electrical space requirements and probably the emergency power load.

Another consideration is the desired level of reliability or redundancy for the systems serving the surgery suites. Other than a requirement for multiple heating devices, the code has no other redundancy requirements. Considering the varying sizes and types of surgeries, there is no design practice that fits all situations. Shutdowns for preventive maintenance can obviously be scheduled to avoid impacting a surgery. The appropriate level of redundancy for unpredictable failures/shutdowns varies from facility to facility and from organization to organization.

Cosmetic surgery design requirements can often be difficult to sort out. Under some circumstances, a cosmetic surgeon may not seek Medicare/Medicaid reimbursements, and at times may not feel that the procedures warrant the typical operating-room HVAC or electrical systems. One approach to sorting this out is to first determine the classification of procedures as defined in ANSI/ASHRAE/ASHE Standard 170-2008, specifically Class A, B, or C (see Table 8-2). Also determine whether the health department will require any specific design standards, such as the FGI *Guidelines*. Consider advising the health care organization and facility owner that patients must not be misled into believing a procedure room is an operating room unless it actually has all the required elements.

8.18.2 Endoscopy

Design considerations for endoscopy rooms have changed several times over the past decade. In many cases, their requirements are now similar to those for ORs; therefore, much of the previous discussion would apply. Determining the AHJ's requirements is a key first step

that then must be checked for alignment with the standard of care from the physicians and health care organization. This is especially critical if the jurisdiction has recently adopted the current version of the FGI *Guidelines* with ANSI/ASHRAE/ASHE Standard 170-2008.

One design challenge is controlling odor while keeping the room pressure positive, as is now required in jurisdictions following ANSI/ASHRAE/ASHE Standard 170-2008. If there is a scope-cleaning room opening into the procedure room, one technique is to make the procedure room slightly positive to the corridor but negative to the scope-cleaning area. For more information, see section 8.17.1 on inpatient endoscopy rooms.

8.18.3 Intensive Diagnostic Imaging Procedures and Equipment

Large or intensive medical imaging equipment will have specific HVAC requirements that must be considered, many of which can be found in section 8.4. This section discusses a few differences that apply to an outpatient imaging suite.

The first difference is that the main HVAC systems for an outpatient imaging suite are not operating 24 h/day, 365 days/year. They typically are not operating in the evenings and on weekends. Therefore, instead of the common practice of using the main system for some equipment cooling during unoccupied times, an independent 24 h/day system is needed. These systems commonly have no outdoor air and are operated only to maintain strict temperature and humidity requirements during the unoccupied periods. The imaging areas are also served by the main systems and provide the appropriate level of outdoor air during the occupied times.

Consider the reliability and redundancy requirements for the medical equipment. Increasingly, medical equipment manufacturers are asking for tighter temperature and humidity tolerances. It is not clear what happens when these conditions are not met for short versus long durations. To avoid having the manufacturer shift undue risk to the HVAC designer, all parties should discuss the requirements for the medical equipment and expected performance of the HVAC system. Address what happens when an unexpected failure of the HVAC system occurs: what level of redundancy is needed and affordable?

8.19 DATA CENTERS

Many health care facilities, both inpatient and outpatient, are large enough to contain some type of data center, especially with the growth of electronic medical records. For a data center in a hospital, the redundancy and cooling capacity of the cooling plant is often acceptable to serve the data center with dedicated AHU, fan-coils, or water-cooled racks. If using a DX system in cold climates, be sure to provide low-ambient control. Future flexibility and load increases are other important considerations. ASHRAE's Datacom Series of publications provides detailed guidance on data centers that the designer will find useful.

REFERENCES

AAMI. 2003. *AAMI Standard 35: Safe handling and biological decontamination of reusable medical devices in health care facilities and in nonclinical settings.* Arlington, VA: Association for the Advancement of Medical Instrumentation.

AAMI. 2002. *AAMI Standard 46: Steam sterilization and sterility assurance in health care facilities.* Arlington, VA: Association for the Advancement of Medical Instrumentation.

ACS. 2000. *Guidelines for optimal ambulatory surgical care and office-based surgery.* Chicago: American College of Surgeons.

ASHRAE. 1971. Chapter 15, Hospitals and related health facilities. *ASHRAE Guide and Data Book—Applications*. Atlanta: ASHRAE.

ASHRAE. 1987. Chapter 23, Health facilities. *ASHRAE Handbook—HVAC Systems and Applications*. Atlanta: ASHRAE.

ASHRAE. 1999. Chapter 7, Health care facilities. *ASHRAE Handbook—HVAC Applications*. Atlanta: ASHRAE.

ASHRAE. 2003a. Chapter 7, Health care facilities. *ASHRAE Handbook—HVAC Applications*. Atlanta: ASHRAE.

ASHRAE. 2003b. *HVAC design manual for hospitals and clinics*. Atlanta: ASHRAE.

ASHRAE. 2008. *Ventilation of health care facilities.* ANSI/ASHRAE/ASHE Standard 170-2008. Atlanta: ASHRAE.

ASHRAE. 2009. Chapter 16, Ventilation and infiltration. *ASHRAE Handbook—Fundamentals*. Atlanta: ASHRAE.

ASHRAE. 2011a. Chapter 8, Health-care facilities. *ASHRAE Handbook—HVAC Applications*. Atlanta: ASHRAE.

ASHRAE. 2011b. Chapter 14, Laboratories. *ASHRAE Handbook—HVAC Applications*. Atlanta: ASHRAE.

DOD. 2012. *Unified facilities criteria (UFC) design: Medical military facilities* (UFC 4-510-01). Washington, DC: U.S. Department of Defense.

FGI. 2010. *Guidelines for design and construction of health care facilities.* Dallas, TX: Facility Guidelines Institute.

Hayden, C.S., et al. 1998. Air volume migration from negative pressure isolation rooms during entry/exit. *Applied Occupational and Environmental Hygiene* 13(7):518–27.

Hermans, R.D., and A.J. Streifel. 1993. Ventilation designs. In *Proceedings of the Workshop on Engineering Controls for Preventing Airborne Infections in Workers in Health Care and Related Facilities*, DHHS (NIOSH) Publication No. 94-106. Beirbaum, P.J., and M. Lippmann (eds.). Washington, DC: U.S. Department of Health and Human Services.

Koenigshofer, D. 2009. Method of testing and data collection for energy characteristics of healthcare equipment. Final Report, ASHRAE research project RP-1343. Atlanta: ASHRAE.

McIntosh, I.B.D., C.B. Dorgan, and C.E. Dorgan. 2001. *ASHRAE laboratory design guide.* Atlanta: ASHRAE.

Memarzadeh, F. and A. Manning. 2002. Comparison of operating room ventilation systems in the protection of the surgical site. *ASHRAE Transactions* 108(2).

Murphy, J. 2006. Temperature & humidity control in surgery rooms. *ASHRAE Journal* 48(6).

NFPA. 2002. *NFPA 99: Standard for health care facilities*. Quincy, MA: National Fire Protection Association.

NFPA. 2005. *NFPA 99: Standard for health care facilities*. Quincy, MA: National Fire Protection Association.

NFPA. 2012. *NFPA 101®: Life safety code®.* Quincy, MA: National Fire Protection Association.

NIH. 2008. *National Institutes of Health design requirements manual for biomedical laboratories and animal research facilities*. Bethesda, MD: National Institutes of Health.

Rhame, F.S. et al. 1984. Extrinsic risk factors for pneumonia in the patient at high risk of infection. *American Journal of Medicine*, May 15:42–52.

Riskowski, G.L., R.G. Maghirang, and W. Wang. 1996. Development of ventilation rates and design information for laboratory animal facilities: Part 2—Laboratory tests. *ASHRAE Transactions* 102(2):195–209.

Straub, H.E. and M.M. Chen. 1957. Distribution of air within a room for year-round air conditioning—Part II. University of Illinois Engineering Experiment Station *Bulletin* 442.

Straub, H.E., S.F. Gilman, and S. Konzo. 1956. Distribution of air within a room for year-round air conditioning—Part I. University of Illinois Engineering Experiment Station *Bulletin* 435.

USP. 2012 (annual). Pharmaceutical compounding—Sterile preparations. USP–NF *General Chapter* 797. Rockville, MD: United States Pharmacopoeial Convention.

CHAPTER 9

BUSINESS OF HEALTH CARE

9.1 INTRODUCTION

This chapter covers a variety of topics aimed at providing background in health care business acumen as well as information on topics relevant to the HVAC engineer's responsibility and/or expertise. It is important that design professionals dealing with health care facilities understand the business considerations facing facility owners and operators, and recognize the relationship of engineering design to the goals of the health care organization. Chapter topics include defining the variety of health care facility types to provide background to aid in communication between design and health care professionals. Design professionals should have current knowledge of health care business and design trends and the driving forces behind them. Evidence-based design (EBD) is a topic with which HVAC designers in this industry need to be familiar, and it is covered later in the chapter.

9.2 HEALTH CARE FACILITY CLASSIFICATIONS

In the United States, there is no easy way to define or classify health care facility types. The following are common classifications for health care facilities that summarize information provided in the Center For Health Design's EDAC Study Guide 1, *An Introduction to Evidence-Based Design: Exploring Health Care and Design* (CHD 2008):

- **Ownership**
  - *Public Hospitals:* owned by federal, state, or local government agencies.
  - *Federal Hospitals:* maintained primarily for specific groups of federal beneficiaries, such as Native Americans, military personnel, and veterans.
  - *Not-for-Profit Hospitals:* privately owned hospitals operated on a not-for-profit, tax-exempt basis.

- › *Proprietary Hospitals:* For-profit, proprietary hospitals (also referred to as investor-owned hospitals) are owned by individuals, partnerships, or corporations.

- **Length of Stay**
  - › *Short-Stay Hospitals:* most hospitals are short-stay hospitals in which the average length of stay is less than 30 days.
  - › *Long-term-care Hospitals:* hospitals in which the length of stay exceeds 30 days are referred to as long-term-care hospitals.
- **Type of Service**
  - › *General Acute-Care Hospitals:* provide a variety of services, including general and specialized medicine, general and specialized surgery, and obstetrics to meet the general medical needs of the community they serve.
  - › *Specialty Hospitals:* admit only certain types and ages of patients or those with specified illnesses and conditions.
- **Public Access**
  - › *Community Hospitals:* nonfederal, short-stay, acute-care general, or specialty hospitals whose facilities and services are available to the general public.
  - › *Noncommunity Hospitals:* include hospitals operated by the federal government, such as VA hospitals, prison hospitals, college infirmaries, and log-term-care hospitals.
- **Location**
  - › *Urban Hospitals:* located in a county that is part of a metropolitan area.
  - › *Rural Hospitals:* not located in a metropolitan area.
- **Size**

  Hospital classification by size has not been standardized; however, size is generally viewed in the following manner:
  - › *Small:* fewer than 100 beds
  - › *Medium:* 100 to 500 beds
  - › *Large:* more than 500 beds
- **Other Types of Hospitals**
  - › *Teaching or Academic Hospitals:* have approved residency programs for physicians.
  - › *Critical-Access Hospitals:* rural, limited-service hospitals that have been converted to the special designation of critical-access hospitals under the Medicare Rural Hospital Flexibility Program (a federal initiative). They have a 25-bed maximum.
  - › *Health Care System:* according to the American Hospital Association (AHA 2010), a health care system can have multiple hospitals that are owned, leased, sponsored, or contract-managed by a central organization or a diversified hospital system.
  - › *Health Care Network:* a health care network is a group of hospital physicians, other providers, insurers, and/or community agencies that work together to provide a broad complement of services to their constituents (AHA 2010).

- **Primary and Outpatient Care Services**
  - *Primary Care:* regarded as essential health care, and typically includes the first point of consultation for patients. It involves the widest scope of health care, from wellness programs to acute and chronic care.
  - *Outpatient Services:* require less than a 24-hour stay. They are also referred to as ambulatory care.
  - *Private Practice:* physicians, as office-based professionals, form the backbone of ambulatory care and provide the majority of primary care services.
  - *Medical Homes:* a relatively new concept for providing comprehensive primary care through partnerships with physicians and patients. The term is used to identify a team-based health-care-delivery model that provides comprehensive and continuous care.
  - *Alternative Care Models:* new models of care, emerging as traditional care gives way to alternatives based outside of physicians' offices and hospitals. There is an expected increase in the number and scope of services offered at such alternative-care work sites, and a broader definition of health care environments (Zensius 2010).
- **Hospital-Based Outpatient Services**
  - *Clinical Services:* correspond to services provided by private physicians in their offices.
  - *Surgical Services:* hospital-based ambulatory surgery centers provide same-day surgical care. Patients are discharged after a few hours of recovery following surgery.
  - *Emergency Services:* more than 90% of all community hospitals in the United States provide emergency services. The main purpose is to have services available around the clock for patients who are acutely ill or injured, particularly those with serious or life-threatening conditions requiring immediate attention. Recent trends show nonemergency patients, often those without insurance, using emergency services for routine health problems.
  - *Home Health Care:* hospital home health departments provide postacute care and rehabilitation therapies.
  - *Women's Health Centers:* women's health centers specialize in meeting the health care needs of women and, sometimes, children.
- **Freestanding Facilities**
  - *Walk-in Clinics:* provide basic primary care to urgent care; they are generally used on a non-routine, episodic basis.
  - *Urgent Care Centers and Emergicenters:* open 24 h/day, 7 days/week, and accept patients with no appointments.
  - *Surgicenters*: freestanding ambulatory surgery centers; often independent of hospitals.
  - *Mobile, Medical, Diagnostic, and Screening Services:* transport health care services to patients.

- **Long-Term-Care Services**
  - *Institutional Long-Term Care:* provided to individuals whose needs cannot be met in a less acute, community-based setting.
  - *Independent Living:* 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:* defined as "a long-term care alternative that involves the delivery of professionally managed personal and health care services in a group setting that is residential in character and appearance in ways that optimize the physical and psychological independence of residents"(Regnier 1994).
  - *Nursing Homes:* also called skilled nursing facilities, are designed for seniors who are in need of 24 h nursing care.
  - *Continuing Care Retirement Communities:* residential campuses that provide a continuum of care, from private units to assisted living and skilled nursing care, all in one location.
  - *Alzheimer's Disease/Dementia Care:* although many assisted living communities and nursing homes cater to individuals with Alzheimer disease and other related memory disorders or dementia, the trend is toward facilities that provide specialized care and housing tailored to the special needs of individuals with such conditions.

9.3 DEMAND, DRIVERS, AND TRENDS FOR HEALTH CARE

According to the U.S. Census Bureau (2008), the population of the United States continues to grow, but is forecast to grow at a slower rate than in the recent past. Total population is forecast to increase from 316 million to 341 million between 2012 and 2020. As shown in Table 9-1, the population is forecast to grow across all but one age cohort between 2010 and 2020.

The most dramatic shift anticipated is the +27% growth in individuals over the age of 65. Health care reform in the United States is anticipated to provide insurance to an additional 32 million Americans. With a population that is both growing and aging, and with an increase in those insured, the demand for health care services is expected to continue to rise. In addition to population growth and health care

Table 9-1 *Projections of Population and Components of Change for the United States*

Age Range	Percentage Change from 2010 to 2020
under 18	8
18 to 24	0
25 to 44	7
45 to 64	4
65 and over	27

Source: U.S. Census Bureau (2008).

reform, other trends,such as the increase in obesity, will likely increase the need for treatment of related diseases, including cardiovascular disorders, diabetes, and stroke.

The Association of American Medical Colleges, Center for Workforce Studies, is predicting a shortage of 45,000 primary care physicians and 46,000 surgeons and medical specialists between 2010 and 2020. This projection includes consideration of advances in technology and other efficiency measures, such as the Patient Care Medical Home (PCMH) delivery model (PCPCC 2008). The U.S. federal government is promoting a more coordinated, cost-effective, high-quality care model for its Medicare patients through a voluntary program called Accountable Care Organizations (CMS 2012). Shortages are also predicted in other health care occupations, such as physician assistants and nurses. The Bureau of Labor Statistics projects increased demands of 30% for physician assistants and 22% for nurses between 2010 and 2020 (BLS 2012).

Health care systems will likely be focused on retention and recruitment of patient care service staff. HVAC design and operation can certainly impact retention as it affects the satisfaction levels of staff as well as patients.

Table 9-2 shows a breakdown of registered hospitals developed from the American Hospital Association's 2010 annual survey.

Table 9-2 *Information on Registered Hospitals in the United States*

Total Number of Hospitals	**5754**
U.S. Community Hospitals	4985
Nongovernment, Not-for-Profit Community Hospitals	2904
Investor-Owned, For-profit Community Hospitals	1013
State and Local Government Community Hospitals	1068
Rural Community Hospitals	1987
Urban Community Hospitals	2998
Community Hospitals that are in a System	2941
Community Hospitals that are in a Network	1508
Federal Government Hospitals	213
Nonfederal Psychiatric Hospitals	435
Nonfederal Long-Term-Care Hospitals	111
Hospital Units of Institutions (prison hospitals, college infirmaries, etc.)	10
Total Staffed Beds	**941,995**
Staffed Beds in Community Hospitals	804,943
Total Admissions	**36,915,331**
Admissions in Community Hospitals	35,149,427
Total Expenses	**$750,602,099,000**
Expenses for Community Hospitals	$677,968,038,000

Source: Adapted from AHA (2012).

According to several sources, hospital construction is expected to grow over the next decade in response to the increase need for services, new technology, new methods for delivering patient care, and replacement or renovation of the aging U.S. hospital facility stock. However, with the effects of the 2008 recession still being felt, when and how such growth will occur is unpredictable. Many construction publications are maintaining an optimistic forecast over the next decade, despite the lingering effects of the recession.

9.4 EVIDENCE-BASED DESIGN

Evidence-based design (EBD) is defined as the process of basing decisions about the built environment on credible research, to achieve the best possible outcomes (Hamilton 2004; CHD 2008). In some cases, health care organizations may require their design team to be accredited and certified.

EBD has evolved over the last 30 years. Pioneers within this discipline include Roger Ulrich, now a professor of architecture at Texas A&M University. His 1984 article in *Science,* entitled "View Through a Window May Influence Recovery from Surgery" (Ulrich 1984), is widely considered one of the first authoritative research studies to examine the link between the physical facility and patient outcomes. He found that patients who had a window view of nature, as opposed to a brick wall, had a shorter length of stay, needed less pain medication, and had fewer negative evaluation comments in nurses' notes.

This research began a shift away from the traditional hospital design approach, in which decisions were based on the last design experience of the engaged firm, the personal preferences of the client, or the latest technology. Instead, EBD decisions are made using empirical evidence, and in doing so, aim to reduce stress on facility users, improve safety and productivity, reduce resource waste, and enhance sustainability.

In the last decade in particular, the number of rigorous scientific studies that support using an EBD process has grown, several excellent books about EBD have been published, and benchmarks have been established for measuring a professional's understanding of the most current thinking and research in this area. As a result of this activity, the evidence base has grown; there is wider practice of EBD; more resources are available; and the use of EBD methodologies for new health care facilities is growing.

More information on EBD is available from The Center for Health Design (CHD), a prominent advocate for EBD that is helping lead an international effort to improve the quality of health care facilities worldwide.

REFERENCES

AHA. 2010. *Fast facts on U.S. hospitals*. Chicago: American Hospital Association.

AHA. 2012. *Fast facts on U.S. hospitals*. http://www.aha.org/research/rc/stat-studies/fast-facts.shtml. Chicago: American Hospital Association.

BLS. 2012. *Occupational outlook handbook, 2012-13 edition* (physician assistants). http://www.bls.gov/ooh/healthcare/physician-assistants.htm. Washington, DC: Bureau of Labor Statistics, U.S. Department of Labor.

CHD. 2008. *An introduction to evidence-based design: Exploring health care and design (EDAC study guide, volume 1, 2nd ed.)*. Concord, CA: Center for Health Design.

CMS. 2012. https://www.cms.gov/Medicare/Medicare-Fee-for-Service-Payment/ACO/index.html. Baltimore, MD: Centers for Medicare & Medicaid Services.

FGI. 2010. *Guidelines for design and construction of health care facilities.* Dallas, TX: Facility Guidelines Institute. 2010.

Hamilton, D. K. 2004. Four levels of evidence-based-practice. *AIA Journal of Architecture*. http://www.arch.ttu.edu/courses/2007/fall/5395/392/students/garay/Research/Research.pdf.

PCPCC. 2008. Patient-centered medical home. Building evidence and momentum. A compilation of PCMH pilot and demonstration projects. http://www.pcpcc.net/content/pcpcc_pilot_report.pdf. Washington, DC: Patient-Centered Primary Care Collaborative.

Regnier, V. 1994. *Assisted-living housing for the elderly: Design innovations from the United States and Europe*. New York: Van Nostrand Reinhold.

Ulrich, R. 1984. A view through a window may influence recovery from surgery. *Science* 224 (4647):420–21.

U.S. Census Bureau. 2008. Projections of the population and components of change for the United States: 2010 to 2050. NP2008-T1 (August 14). Washington, DC: Population Division, U.S. Census Bureau.

Zensius, N. 2010. The center for health design's reality check. *Healthcare Design*, February 1.

CHAPTER 10

DISASTER PLANNING AND EMERGENCY MANAGEMENT

10.1 INTRODUCTION

Health care institutions must plan, prepare, and respond to any conceivable form of emergency, whether it impacts the community at large or only the hospital. These institutions must be prepared to react to emergencies in all forms and continue to serve the needs of the patients and the community. Although disaster planning and emergency management are generally operational issues, design professionals must understand the objectives and policies of their client hospital.

10.1.1 Internal Disasters

Health care facilities are subject to many scenarios that may impair the functioning of mechanical systems. Typical disaster scenarios include institutional emergencies, such as fire, water intrusion from ruptured water or fire mains, and/or loss of power or other essential utilities. Events that strike within a facility but not the community at-large are classified as internal disasters. Internal incidents that could potentially result in a facility emergency requiring emergency and/or backup planning include the following:

- Fire
- Power disruption
- Water supply disruption or contamination
- Ventilation system failure or contamination
- Heating system failure
- Fuel supply disruption
- Medical gas system disruption
- Steam supply disruption resulting in inoperable autoclaves and humidification failure

- Nosocomial infection outbreaks
- Loss of internal communications
- Loss of external communications
- Structural failure (earthquake, flood, tornado, explosion)
- Supply chain interruption (food, drugs, linens, medical gases, blood products)
- Terrorist attack on the hospital itself (chemical, biological, explosive)
- Elevator failures

10.1.2 External Disasters

Disasters such as bus or multiple-vehicle accidents, accidental release of gaseous chemicals into the community, and multiple trauma caused by natural disasters and/or large fires can happen in any community. Natural events, such as an earthquake, tornado, hurricane, flood or blizzard, are also the cause of many external disasters.

Some communities may bear a greater risk for external disasters, if they are near chemical plants, nuclear plants, or other industrial complexes that increase the possibility of an accident that could predispose the community to contamination or to industrial injuries with potential for mass casualty. External disasters have the potential to produce so many victims that the normal hospital treatment areas and protocols are overwhelmed and alternate emergency spaces and procedures must be used.

A disaster impacting the community (e.g., earthquake, tornado, flood), or a mass casualty incident (e.g., bus/plane/train accident, chemical spill, act of terrorism), can present an added set of considerations, primarily the designation of emergency spaces to serve larger-than-usual numbers of victims. A disaster of this type could result in damage to the facility itself, potentially limiting its response to the community while simultaneously dealing with the impacts to the facility and its occupants.

The following are examples of external disasters and their classification:

- *Multiple trauma disasters*
  - › Accidents (vehicular pile-up; bus, plane, or train accident)
  - › Natural disasters (hurricane, tornado, wildfire, flood, earthquake)
  - › Acts of war or terrorism (explosion)
  - › Apartment fire
- *Chemical disasters*
  - › Accidents (wreck involving chemical rail car or tanker truck)
  - › Act of terrorism using a chemical agent (water supply contamination, airborne dispersal, explosive detonation, or food source contamination)

- *Biological disasters*
  - › Unidentified severe illness, potentially infectious (see Pandemic Diseases)
  - › Epidemic of known disease with capability for mass transmission by waterborne dispersal, airborne dispersal, or spread by insect, vermin, or avian sources
  - › Act of terrorism using a biological agent (water supply contamination, airborne dispersal, explosive detonation, or food source contamination)
- *Nuclear disasters*
  - › Industrial accident involving a nuclear facility or transportation of nuclear materials
  - › Act of war
  - › Act of terrorism
- *Evacuation disaster*
  - › Accommodation of patients and staff from an evacuated health care facility
  - › Internal or external incident resulting in the need to evacuate patients and staff to another facility

10.1.3 Terrorism and Acts Of War

In the aftermath of the September 11, 2001 attack on the World Trade Center, disaster preparation for institutions and communities is no longer an afterthought. A terrorist attack is frequently directed at the most vulnerable, populous, and emotionally charged targets of a community; therefore, facilities such as schools, buses, and hospitals should be considered high-value terrorist targets. Attacks can take multiple forms: (1) an act of war by an identifiable threat (nuclear, chemical, biological bombs); (2) sabotage or contamination of water, food, or air; and (3) suicide attacks.

Planning for war-like disasters is typically addressed through the recommendations of appropriate homeland security agencies and the resulting requirements for facility design, construction, and operation need no further mention here. On a smaller scale, acts of sabotage or terrorism may share a commonality to acts of war in the method of delivery and/or similarity of outcomes. A terrorist attack or act of sabotage could be directed at a specific target that would maximize the number of casualties with a low probability of detection. Preventing or limiting damage from sabotage is extremely difficult and costly, requiring extensive planning to assess potential targets and ameliorate risks. These scenarios could range from something as seemingly uncomplicated as placing a chemical or biological agent near a building's air intake, to an all-out attack on a facility. The possibilities are limited only by the terrorist's capabilities, which make prevention through building design a difficult task.

10.1.4 Pandemic Diseases

In recent years, there have been instances in which new strains or variants of known infectious diseases develop, evade the usual controls (such as immunization or antibiotics), and possess the ability to expose

and strike large numbers. These are called pandemic outbreaks. Examples of pandemic outbreaks include Severe Acquired Respiratory Syndrome (SARS), which impacted Southeast Asia and Canada in 2003, and Avian Flu (H1N1 and H5N1), with outbreaks reported throughout the world in 2007 and in parts of North America in 2008-2009. Under extreme conditions, pandemic disease outbreaks can virtually shut down a hospital's normal functions during the effort to constrain the spread of the outbreak while treating infected patients. Failure of ventilation systems could result in loss of pressurization between isolation rooms and the general population and lead to the spread of diseases.

10.2 DISASTER PLANNING

Mass-casualty incidents can strike anywhere, including in areas where few suspect such threats. The Joint Commission on Accreditation of Healthcare Organizations (JCAHO) advises in its standards overview that "planning and designing is consistent with the hospital's mission and vision" (JCAHO 1997). When disasters occur, the quality of a facility's response is commensurate with the planning that went into equipping the facility and its staff to respond to the crisis at hand. Disaster planning is the art of studying the potential impacts of different scenarios on a facility, and tailoring an effective defensive strategy to each. Many of the basic strategies are required by codes, but codes provide only a minimum level of protection. Additional protections are frequently unique to the facility and its specific functions. An example might be providing emergency power to ventilation systems that serve an administrative meeting room, so that the room can be adapted to provide overflow areas for patient care during mass casualties. Hospital staff are generally well trained to react and respond to emergencies of all kinds. However, their ability to deliver care can be greatly improved when health care facility planners and designers improve on the capabilities of lobbies, meeting rooms, and other large-capacity spaces to provide overflow for waiting/holding, triage, and treatment areas. This is valuable when a disaster results in mass casualties in the community, or when an internal disaster results in damage to patient care delivery spaces.

Disasters of all types present different levels of hazards. Hospitals and long-term care facilities, with their large populations of infirm or immobile patients, can't easily evacuate when disaster strikes. The facility systems need to be robust and with levels of redundancy not typical of other facility types.

10.3 EMERGENCY MANAGEMENT

When disaster strikes, emergency management is the organizational strategy (in the form of policies, procedures, and directives) for responding to the disaster at hand. Emergency management establishes a line of communications and command throughout all of the involved functional units to maintain an appropriate and disciplined response.

Many institutions now use the incident command structure developed by the Federal Emergency Management Agency (FEMA).

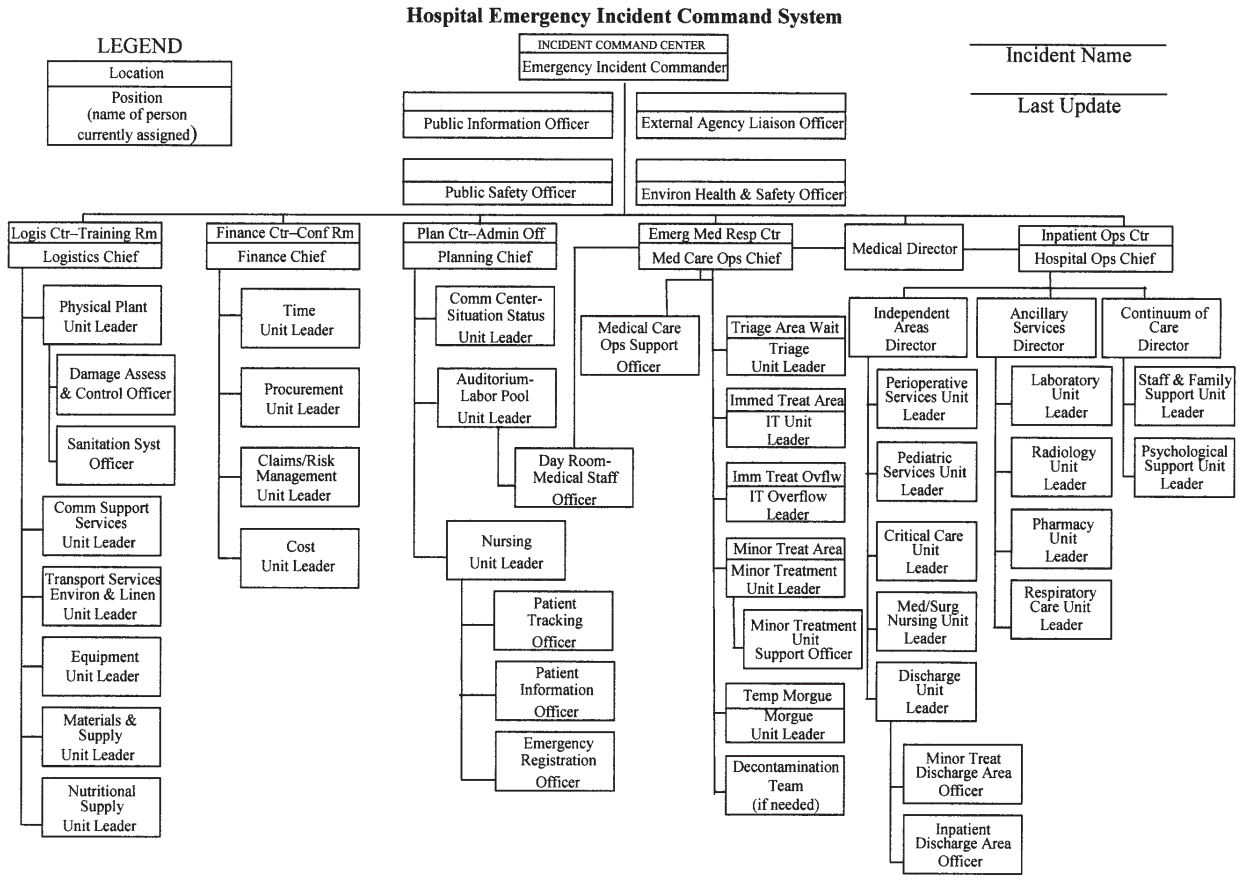


Figure 10-1 *Hospital Emergency Incident Command System Organization Chart*

Figure 10-1 is a typical hospital incident command structure. Use of the incident command approach in preparing to manage a disaster also helps in identifying adjunct space needs, such as emergency triage rooms, communication centers, and areas for storage of emergency supplies and equipment.

The value of any emergency management plan is diminished without building facilities that are able to cope with disaster. Therefore, disaster planning and emergency management must be conducted jointly to assure that the facility is capable of the expected response action.

10.4 DISASTER PREPAREDNESS

10.4.1 Natural Disaster Response

A hurricane is one example of an external disaster that may also inflict substantial damage on a hospital or to its infrastructure, such as the power supply. Under such a scenario, a hospital's abilities to meet the community's needs would be impaired. For this reason, the FGI *Guidelines*, section 1.2-6.5.1 (FGI 2010), requires a needs assessment to evaluate the ability to withstand a regional disaster and maintain operation under the likelihood of loss of externally supplied power, gas, water, and communications. In addressing such a case, internal disaster contingencies would be initiated, and the emergency generators operated to meet basic needs.

10.4.2 Trauma Disaster Response

Readiness for trauma disasters is a basic and minimum degree of preparation for disaster readiness, and is mandated by the JCAHO (JCAHO 1997). A sudden volume of trauma victims, larger than can be normally accommodated by the hospital's emergency facilities, requires areas for temporary triage and treatment (first aid, medical, surgical, and casting); space for observation of patients and convalescent care; and additional services, such as sterilization capability, internal and external communications, transportation of patients within and to/from the hospital, and supplies of water, medicines, cots, stretchers, food, fuel, clothing, medical gases, and first aid.

10.4.3 Chemical Disaster Response

Readiness for chemical disasters requires the basic (trauma) preparations plus decontamination (wash) and special waste containment capabilities. Preparation of the decontamination area is clearly outlined in *Managing Hazardous Materials Incidents, Volume II, Hospital Emergency Departments,* obtainable from the Centers for Disease Control (DHHS 1992).

Although diseases due to chemical exposure are not contagious, ventilation isolation is advisable to prevent deleterious chemicals from contaminated clothing, debris, or air from entering the hospital or spreading within.

10.4.4 Biological Disaster Response

A pandemic disease outbreak involves multiple victims of a contagious disease. This situation requires basic preparations (section 10.4.2) as well as isolation protocols, waste isolation, and separate ventilation. Patients should be isolated from the general hospital population but not necessarily from each other. A temporary 'ward' type environment involving a single large space with multiple beds (and screens) may be deployed. Action may need to be taken to prevent patient contact and airborne contamination from reaching uninfected inhabitants. Preparations may include a plan to cohort infected patients and staff from the rest of the facility.

Under a cohorting plan, designers planning for a pandemic outbreak should assess the ventilation systems of an existing facility to ensure that the systems are zoned to isolate flow from one area of the building to another. Areas at high risk should be designed with the flexibility to segregate large numbers of patients and staff from the rest of the facility. Multiple air-handling systems will provide the greatest flexibility, and each system should be designed so that all air normally returned can be fully exhausted. HEPA filters may be an effective deterrent to infections that are bacterial or transmitted by droplet nuclei, such as tuberculosis, but will be largely incapable of stopping viruses, which are smaller than 1 μm. Other considerations may include providing an airlock capability in corridors connecting different treatment areas. This might be accomplished through use of an auxiliary exhaust fan and door controls in areas where the air systems are independent of one another. Because a pandemic outbreak has the potential to quarantine a large number of staff, a cohorting plan must

also include preparations for converting existing spaces on the clean side of the quarantine area into storage spaces for isolation controls (such as protective clothing) and also creating a holding area on the contaminated side for temporary storage of contaminated materials until they can be properly disposed.

The preparations for a bioterrorism disaster are similar to those for chemical disasters. Requirements include basic preparations (see section 10.4.2), plus decontamination (wash) procedures, waste containment, and ventilation isolation (Simon 1997).

10.4.5 Nuclear Disaster Response

Wash/decontamination facilities are the central component of nuclear disaster readiness. As in chemical disasters, specialized protective gear and clothing are necessary for workers in the wash area; in this case, radiation protective gear and clothing are needed. As in chemical disasters, everyone in the community exposed to the radiation must be decontaminated and supplied with safe clothing. Basic preparations (see section 10.4.2) and nuclear waste containment capabilities are also required. Communication with outside authorities and community rescue teams is essential (FEMA 1984; Ricks 1984).

10.4.6 Evacuation Response

A hospital may become dysfunctional and require evacuation due to destruction or failure of internal services. Special areas within the facility are obviously not required, but communication and patient transportation capabilities are critical. Elevator service in a multistory building is essential.

A nearby hospital may become nonfunctional and need to evacuate its patients to a receiving facility. The receiving facility may already be full with its own patients and, therefore, need to provide alternative patient care spaces. These spaces require all of the mechanical and supply services that are necessary in ordinary treatment and convalescent areas. Communication and transportation capabilities are paramount.

In either evacuation case, the movement of patients, staff, or equipment may overwhelm the ability to meet a patient's particular needs. Removal of critically ill patients from their protective environments may expose them or other patients to greater risks. These factors must be taken into account when developing an evacuation plan.

10.5 FACILITY NEEDS FOR DISASTER PLANNING AND EMERGENCY MANAGEMENT

10.5.1 General Principles

The mechanical services required to manage various disaster scenarios are remarkably similar for each situation. Several general considerations are helpful in planning for such occurrences:

- Designate alternative diagnostic and treatment areas for use when ordinary hospital areas are overrun or out of commission.
- Install exhaust capability in areas that might be used to treat people who have communicable diseases and in areas accessible to the general public.

- Designate large areas that already have ventilation isolation, such as lobbies or waiting areas, for alternative use.
- Install external wash and/or decontamination capability with containment.
- Provide redundant storage of ordinary supplies, food, water, medicines, cots, etc.
- Provide redundant communication and transportation capabilities.
- Provide redundant sterilization capability.
- Use existing smoke control systems and defend-in-place procedures in cases of internal chemical or biological contamination.
- Provide security for hospital air intakes, mechanical equipment, and for the entrance of people and materials.

10.5.2 Essential Services for Emergency Response

Power must be supplied to all of the designated auxiliary emergency treatment areas. The triage area requires power for lighting, ventilation, communication, diagnostic equipment, suction machines, defibrillators, monitors, portable X-ray machines, IV pumps, respiratory therapy equipment, and possibly for sterilization equipment. Power outlets for these uses must be available in the spaces designed as alternative treatment areas. Power systems are described in greater detail in section 10.6.

Power

Water

Uncontaminated water is necessary for washing (hands, patients, instruments, and medical equipment), food preparation, sterilization, and possibly for medicinal preparation. Disruption or contamination of the ordinary hospital water supply will require access to an alternate supply. This alternate supply can be from a well or from storage tanks or trucks. The capacity should be sufficient for 96 h of operation (FGI 2010).

Ventilation

The FGI *Guidelines* require that the triage area of an ordinary hospital emergency facility "be designed and ventilated to reduce exposure of staff, patients and families to airborne infectious diseases." This is best accomplished by 100% exhaust and the transfer or intake of uncontaminated air. Recirculated 99.7% HEPA-filtered air is an acceptable alternative, but would require more fan power. ANSI/ASHRAE/ASHE Standard 170 specifies that a triage area be maintained at 12 ach (air changes per hour), with a minimum of 2 ach of outdoor air, and negative pressure relative to adjacent spaces (ASHRAE 2008).

Sterilization

Sterilization can become a problem if a hospital's steam generation capability is interrupted. Autoclaves that use an alternative energy source should be provided to maintain operations when the main plant is offline. Sterilization is necessary for surgical instruments, fluids, linens, and reusable equipment. Most sterilization equipment operates at pressures ranging from 40 to 50 psig [276 to 345 kPa]; this is higher

than available from low-pressure steam boilers. Some jurisdictions restrict unmanned boiler operation to pressures less than 15 psig [103 kPa]. Consult local codes for such requirements.

Waste Isolation

Waste isolation requirements for various scenarios are discussed in the following:

- *Trauma disasters:* Waste/clothing can be disposed of in the usual manner.
- *Chemical disasters:* Waste/clothing must be held in such a manner that all personnel are safe from contact with the waste. With chemical terrorism, the waste must be retained and made available for examination by the proper authorities.
- *Nuclear disasters:* Waste/clothing must be held in a radiation-shielded area and disposed of later in a manner dictated by the proper authorities. Incineration is not an option because of the possibility of introducing radioactive molecules into the air.
- *Biological disasters:* In an epidemic involving an identified disease, waste/clothing can be disposed of according to standard isolation and disposal techniques. With bioterrorism, waste must be held and isolated for examination by the proper authorities. In the case of unidentified infective agents, waste must be isolated for examination by the proper authorities and by appropriate laboratories.

10.5.3 Specialized Spaces for Providing Emergency Services

Triage Space

Victims of a disaster are brought to a triage area where those who have the most life-threatening injuries are identified for immediate treatment. In cases of nuclear or chemical exposure, victims must first be brought through an area for total body cleaning and clothing disposal before entering triage. Workers in the cleaning area must have appropriate protective clothing. The triage area of a hospital is usually the emergency room. The emergency room's waiting room and/or other hospital waiting rooms can be used for additional triage space if they are accessible to the outside and are equipped with isolated ventilation, electricity, water, communications, etc.

Wash Area (Decontamination)

Nuclear disasters require total body washing and total clothing change for all exposed victims (ambulatory and nonambulatory), whether admitted into the facility or not. Decontamination facilities are located outside of the medical facility and can be collapsible, tentlike enclosures.

Total body washing and new clothing are also necessary in massive chemical exposures and in biological terrorism exposures. Special protective gear and clothing are necessary for wash area personnel. Not only will victims require decontamination but also those in the community who have responded to the emergency, such as firefighters, EMS personnel, and other civil agents.

Isolation Space

A space other than the triage area or the general hospital can be designated for isolation of patients thought to be infectious. A designated isolation area should have total exhaust and negative pressurization. Care must be taken that air is exhausted well away from habitable areas.

Treatment Space

Ordinarily, emergency rooms and operating rooms serve as treatment areas and should adequately serve as disaster-treatment areas, unless they are damaged by the disaster. Delivery rooms can be taken over as disaster treatment and operating rooms. If the hospital medical staff is large (having more available doctors than existing treatment rooms), auxiliary areas can be designated as disaster-treatment areas; such areas should be equipped with clean air and emergency power.

Sterilization capability (autoclaving) is a critical component of the treatment area. Designated auxiliary treatment areas, as well as existing treatment areas, must have access to fail-safe sterilization capability. This may consist of an emergency autoclave powered by the emergency electrical system or by liquid petroleum. Gas sterilization systems (ethylene oxide) are unacceptable as the only method of sterilization in disaster situations because of the increased time they require for sterilization and for evacuating the gas.

10.6 POWER

10.6.1 Background

Electrical power is an essential element in the care and treatment of patients. Nearly every service needed to provide patient care requires power to operate. Many of these essential devices are small appliances (such as monitors for displaying a patient's vital signs, or infusion pumps) and get their power from receptacles. As the number of appliances used in patient care increases, a larger burden is placed on the power system. Because of this, reliability and redundancy of power systems is of maximum importance. All hospitals have defined minimum requirements regarding what must operate in a power emergency; but these are not the same for all situations. Where a hospital is located (with respect to climate) can significantly impact its minimum power demands. Emergency power needs frequently go well beyond basic code requirements and will reflect the mission of the institution and the role it serves in its community.

A redundant source of normal power should be considered for most large hospitals, and particularly for acute-care and trauma centers. Redundant normal power is delivered by double-ended main switchgear (Figure 10-2). Should a fault occur in the on-line feeder circuit, an automated tie breaker will close and transfer the load to the backup feeder circuit(s). When properly programmed, the transfer occurs in milliseconds. This will result in a detectable "blink," but not enough for contact relays to fully open; thus, most inductive loads, such as motors, will continue to operate through the transfer. Double-ended services are highly reliable, depending on the quality of the utility provider's distribution network. When redundant normal power

systems are used, backup power is needed only if both sources of normal power are lost at the same time. Ideally, each feeder is supplied from substations in different locations to minimize the likelihood of an interruption due to equipment failure. In the worst case, an outage might be the result of a disaster that caused major damage to the electric utility distribution system (such as hurricane, tornado, or flood), but it could also be the result of an act of terrorism.

10.6.2 Essential Electrical System

Primary and redundant normal power, and generator-supplied emergency power, comprise the Essential Electrical System as defined by *NFPA 99: Health Care Facilities Code* (NFPA 2012). Generators may be used exclusively for emergency purposes or they may also be used for peak demand control, internal voltage regulation, load relief for the local utility, or cogeneration. When used for other than emergency purposes, two or more generators are required to meet the connected loads, including the essential components of the emergency electrical system (e.g., generator fuel pumps) and essential auxiliary equipment (e.g., medical air compressors, medical vacuum pumps, fire pumps).

The emergency power system must also provide essential services for the space or room housing the generators, including lighting, ventilation, and heating, if the ambient temperature in the space could be less than 40°F [4.4°C]. All dampers and components of the ventilation system must be supplied by the emergency power system.

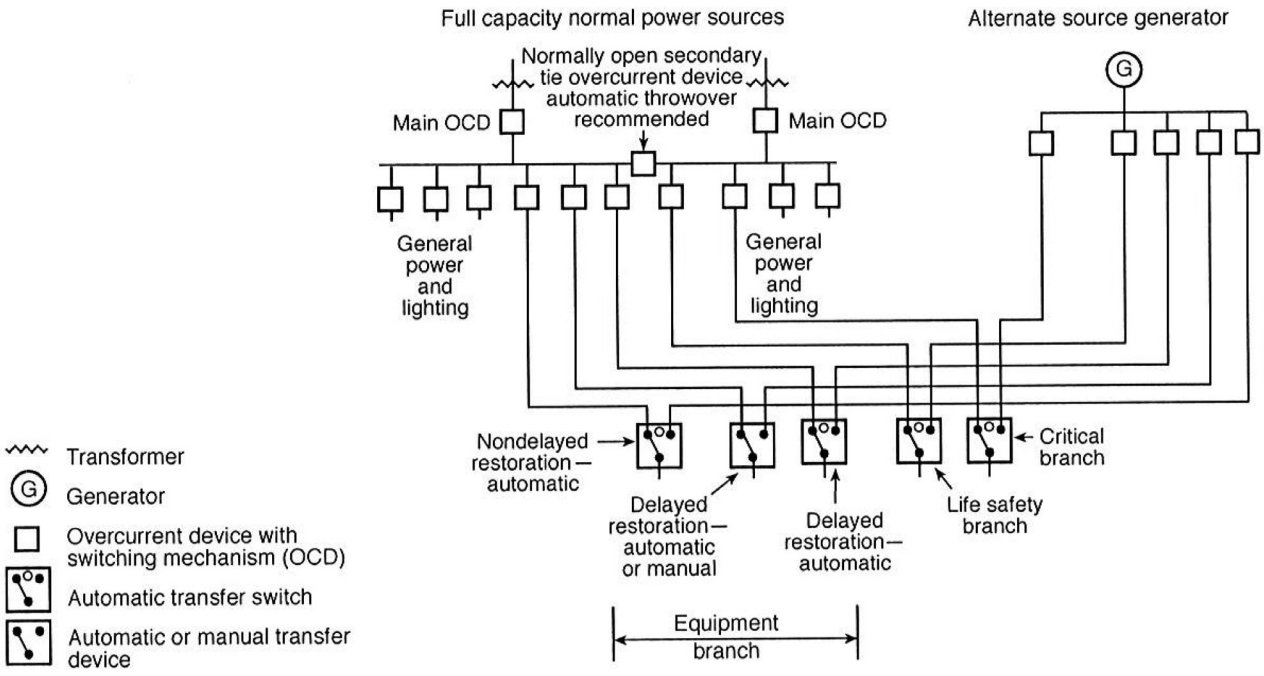


Figure 10-2 *Typical Hospital Normal and Emergency Main Distribution Diagram*

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Emergency Power Systems

In the event of a loss of power, an alternative source of power is required to serve the emergency electrical system. This consists of the life safety and critical branches and the equipment system that supplies the major equipment necessary for patient care and basic Type 1 operation (see Table 10-1).

On-site backup generators are the usual source of emergency power. When the generator(s) start, switching relays called automatic transfer switches close according to defined protocols to pick up the building's electric loads.

As the name implies, the life safety branch provides power for required life safety services, including the fire alarm system; lighting for egress; emergency communications; services for the generator and generator room; elevator lighting, control, and communications; automatic doors for building egress; and smoke dampers and components complying with NFPA 72 (NFPA 2013a).

Critical branch loads include essential patient care services that could result in loss of life or serious injury. These may be divided into two one or more branches and should include power for task illumination, fixed equipment, and selected power circuits serving the patient care areas and functions as described in NFPA 99.

Table 10-1 *Emergency Power Services*

Life Safety Branch	Critical Branch	Equipment: Nondelayed and Delayed Automatic Start	Equipment: Delayed or Manual Start
Fire alarm system, lighting for egress, exit lighting, emergency communications; services for the generator and generator room (as described in NFPA-99); elevator lighting, control, and communications; automatic doors for building egress; smoke and fire dampers and components; medical gas alarm systems	Nurse-call systems, task illumination, fixed equipment; selected power circuits serving the patient-care areas; other functions in accordance with the range and level of specific services offered by the facility	Medical vacuum, medical air compressor, and anesthesia evacuation (WAGD) systems; pumps and other systems required to maintain safety of major apparatus; smoke control and evacuation systems, kitchen hood ventilation systems (if required to operate during a fire in or beneath the hood); ventilation systems including airborne infectious isolation rooms, protective environment rooms, fume hood exhaust fans, fans for systems where radioactive materials are in use	Heating for operating, delivery, labor, recovery, intensive care, coronary care, nurseries, emergency treatment rooms, general patient rooms, and jockey or make-up water pumps for fire protection; elevators providing patient transfer to patient care, surgical, obstetrical, and ground floors during interruption of normal power; ventilation systems for surgery and obstetrical suites, intensive care, coronary care, nurseries, and emergency treatment spaces; hyperbaric and hypobaric facilities; autoclaving and sterilization equipment

Because hospitals vary in the level of care and services they provide, critical branch loads will vary by facility. An acute-care hospital, with a large number of patients requiring greater levels of life support and advanced or critical care, may have significant critical care loads; small general hospitals may have very few. It is frequently a challenge meeting the demand for critical branch power in large, acute-care hospitals.

Equipment System

Equipment loads are typically auxiliary loads that are necessary to keep the facility operating at a defined level of service. These loads include medical vacuum systems, medical air compressors, elevators, boilers, pumps, ventilation equipment, cooling equipment, and other devices. These are frequently motor loads which, if enough motor starts were to occur simultaneously, could overload the emergency power system. Equipment loads connected to the emergency power system must be stared at appropriate intervals after the emergency system has been energized.

As required by NFPA 99, the life safety and critical branch loads must be picked up within 10 s of an outage. Multiple generator systems can be independent when they supply transfer switches serving dedicated load components. Most plants using multiple generators are paralleled, whereby they are automatically synchronized so they can operate together to increase capacity. When operating a paralleled plant, NFPA 110 mandates that the emergency system loads not exceed

Figure 10-3 *Emergency Load Transfer Switch*

the capacity of one generator, so that the system will not overload should the paralleled plant not be up to capacity within 10 s of the first generator start (NFPA 2013b). Transfer switches may have manual bypass capability so they can be switched to another generator should it be necessary to take a generator off line for maintenance or repair.

After the life safety and critical loads have been supplied, the emergency system can begin acquiring equipment loads at an appropriate rate that will prevent overloading of the generator. Equipment loads can be transferred via delayed automatic or manual transfer. Loads that are allowed to be subject to delayed automatic transfer include medical vacuum, medical air compressor, and waste anesthesia gas disposal (WAGD) systems; pumps and other equipment required to maintain the safety of major apparatus; smoke control and evacuation systems; kitchen hood ventilation systems that are required to operate during a fire in or beneath the hood; and ventilation systems, including airborne infectious isolation rooms, protective environment rooms, fume hood exhaust fans, and fans for systems where radioactive materials are in use. These loads may also be connected to the critical branch if a delayed connection is not appropriate.

Loads that may be either delayed automatic or manually transferred to the emergency system include heating for operating, delivery, labor, recovery, intensive care, coronary care, nurseries, emergency treatment rooms, general patient rooms, and jockey or makeup water pumps for fire protection; elevators providing patient transfer to patient care, surgical, or obstetrical areas and the ground floor during interruption of normal power; ventilation systems for surgery and obstetrical suites, intensive care, coronary care, nurseries, and emergency treatment spaces; hyperbaric and hypobaric facilities; autoclaving and sterilization equipment; controls for all equipment covered under this section; and other selected loads that are essential to the facility operational plan.

Heating of general patient care rooms during disruption of normal power is not required when

- the outdoor design temperature is greater than 20°F [–6.7°C]; or
- the outdoor design temperature is less than 20°F [–6.7°C], but selected heated rooms are maintained for confined patients; or
- the facility is provided with a redundant source of normal power.

Emergency Power for Cooling Systems

Because of high power demand, air-conditioning equipment is generally not served by emergency power. However, in facilities in cooling-dominated climates, inability to cool the facility may impair the delivery of services and put patients at risk.

An HVAC design approach that segregates critical process loads to smaller dedicated systems, such as imaging equipment rooms, can

help hold down emergency power needs. If a large cooling load is anticipated or planned during extended emergency operations, it is worth considering alternative utility sources for one or more of the cooling plants, such as direct-fired reciprocating or absorption chillers.

The majority of HVAC equipment will be served by the equipment power branch and, therefore, may not transfer within the 10 s period during which the life safety and critical branch loads are picked up. An extended delay can cause many motor starters and control devices to fail open and not automatically reclose, requiring them to be manually restarted. Direct digital control (DDC) panels may also fail or lose critical data, requiring them to be reset; in the worst case, control programs may fail completely and need to be reloaded. During and while recovering from an emergency, there may not be enough skilled maintenance staff available to restore equipment on a timely basis. Designers should, therefore, require that DDC panels serving high-priority equipment be provided with uninterruptible power supplies. To allow remote restarting, motor starters should be equipped with addressable relays that can be commanded by the building management system.

Most facilities will lack the resources to provide enough emergency power generation to supply all operational needs. Generally, except when it is the result of a large-scale failure of the building's electrical system, most extended outages will be the result of a natural disaster impacting the community and its electric utility. In such a case, many normal services such as outpatient treatment may be curtailed, and the utilities for these services can be redistributed to those areas of the facility that are involved with emergency care. See section 4.3.3 for discussion on prioritizing redistribution on power ("cooling triage"). The designer should always confer with the facility managers to understand the planned emergency requirements for the project, and thus to ensure that the owner's expectations are met.

REFERENCES

ASHRAE. 2008. *Ventilation of health care facilities.* ANSI/ASHRAE/ASHE Standard 170-2008. Atlanta: ASHRAE.

DHHS. 1992. *Managing hazardous materials incidents, Volume II, Hospital emergency departments.* http://wonder.cdc.gov/wonder/prevguid/p0000019/p0000019.asp. Washington, DC: U.S. Department of Health and Human Services, Public Health Service Agency for Toxic Substance and Disease Registry.

FEMA. 1984. *Hospital emergency department management of radiation accidents*. Washington, DC: Federal Emergency Management Agency.

FGI. 2010. *Guidelines for design and construction of health care facilities.* Dallas, TX: Facility Guidelines Institute.

JCAHO. 1997. *Hospital accreditation standards, overview.* Oakbrook Terrace, IL: Joint Commission on Accreditation of Healthcare Organizations.

NFPA. 2012. *NFPA 99: Health care facilities code.* Quincy, MA: National Fire Protection Association.

NFPA. 2013a. *NFPA 72: National fire alarm and signaling code.* Quincy, MA: National Fire Protection Association.

NFPA. 2013b. *NFPA 110: Standard for emergency and standby power systems*. Quincy, MA: National Fire Protection Association.

Ricks, R.C. 1984. *Hospital emergency department management of radiation accidents*. Oak Ridge, TN: Oak Ridge Associated Universities.

Simon, J.D. 1997. Biological terrorism. *Journal of the American Medical Association* 278:428–30.

CHAPTER 11

OPERATIONS AND MAINTENANCE

11.1 INTRODUCTION

This chapter describes how facilities operate and maintain their equipment, with a focus on HVAC design considerations. Building operation and maintenance costs are collectively one of the largest costs over the life of a building. In today's environment, every facility is looking for ways to save money by lowering operational cost expenditures. With assistance from the design team, continued operations and maintenance programming can ensure success for the facility's core mission and vision of health care.

With this in mind, it is important that consultants designing or modifying facilities have detailed discussions with facility personnel at the start of the project. A complete understanding of current operations and the abilities of the staff maintaining the equipment is important to the long-term success of the project. For example, if the organization has a staff of skilled trades dealing primarily with older equipment, it is fair to say that the staff may require extensive training on operations and maintenance at the time of owner turnover of new buildings or newer technology. This requirement can be added to the project specification. Of course, if the organization outsources its maintenance, then owner turnover training can focus on equipment operation. It also falls on the facility to know when to call in a specialty contractor with the required abilities when problems arise above and beyond the skills of the in-house personnel.

As current construction trends push for green and sustainable building design, it is important that the designer (or commissioning authority) involves the facilities maintenance staff throughout the process and provides an accurate operations and maintenance (O&M) manual, including submittals, upon completion of the project. As these

trends become requirements for design and construction, the maintenance staff will evolve and learn the new technologies and a complete O&M manual with detailed information will be used frequently by the staff as they discover the unique traits of the equipment.

11.2 REGULATORY CONSIDERATIONS

Regulatory agencies monitor health care facilities and physicians, ensure legal compliance, promote safety, deliver quality services, and provide information about industry changes. Federal, state, and local agencies establish rules and regulations for health care facilities. This oversight is mandatory. Some of these regulatory agencies are the following:

- Agency for Healthcare Research and Quality (AHRQ)
- Centers for Disease Control and Prevention (CDC)
- Centers for Medicare & Medicaid Services (CMS)
- U.S. Food and Drug Administration (FDA)
- Occupational Safety & Health Administration (OSHA)

Pursuing an accreditation from an appropriate organization is voluntary but important because accreditation can provide national rankings or a certification of quality assurance. Some insurance company reimbursements to a health care facility depend upon accreditation. Accrediting agencies differ from a regulatory agency in that they set standards and conduct thorough on-site inspections at prescribed intervals. These inspections review practices and records to ensure that the quality of care and compliance meets safety standards. Some of these agencies include the following:

- Accreditation Commission for Health Care (ACHC)
- Foundation for the Accreditation of Cellular Therapy (FACT)
- National Committee for Quality Assurance (NCQA)
- The Joint Commission (TJC)

11.2.1 The Joint Commission

The Joint Commission (TJC) is a nonprofit accreditation and certification organization dedicated to maintaining a standard of quality and safety in the health care industry. This organization provides services to more than 19,000 hospitals. The standards set by TJC can very easily be cross-applied to the other accrediting organizations as applicable.

There are eight areas of accreditation, each with maintenance documentation requirements. Accreditation is earned by the entire organization in any one of the following areas:

- Ambulatory Care
- Behavioral Health
- Critical Access Hospital
- Home Care

- Hospital
- Laboratory Services
- Long-Term Care
- Office-Based Surgery

Such accreditation is separate from a certification from The Joint Commission, which is earned by a program or service within or associated with a specific health care organization. The following two certifications can be obtained:

- Disease-Specific Care
- Health Care Staffing Services

11.2.2 Statement of Conditions

TJC requires that health care facilities keep up-to-date information on the condition of the facility. This information resides in a document called the Statement of Conditions (SOC), which lists all corrective measures in a Plan for Correction. The SOC is a living document that should be continuously updated as a facility is changed, renovated, and improved. The maintenance department plays a central role in preparing the SOC document and carrying out the Plan for Correction.

11.2.3 Plan for Improvement (PFI)

Ongoing inspection to comply with the SOC and with the facility's life safety plan will identify deficiencies. These deficiencies will go into the facility's work order system for repair. When these repairs take more than 45 days to correct, regardless of the reason, a PFI is created and reported to TJC. The deficiency is identified, and the facility is responsible for providing a plan for improvement, implementation, and correction.

11.2.4 Interim Life Safety

Creating a safe building environment is the goal of the life safety codes and standards. Life safety covers means of egress, stairs, fire detection devices, and general occupancy. As long as the building design remains unchanged, and the life safety systems are maintained per the applicable codes and standards, the design integrity of these systems remains. However, health care facilities are always undergoing renovations and construction, and the integrity of life safety systems may diminish during these activities. This potential for a decrease in life safety results in the creation of interim life safety measures (ILSM).

Interim life safety is generally overlooked during the design of renovations, and is often not dealt with until construction actually begins. It is never too late to make necessary adjustments to the design and construction process. The maintenance department may be called upon to support additional safety measures. An example of an ILSM is when a maintenance department issues a flame/burn permit to an outside contractor and secures (as required) the fire alarm zones by disabling the affected zone. Upon completion of the activity, the fire alarm system is reenabled to its normal operating condition. While the system is disabled, it is in a state of diminished capacity, causing a

demand for an ISLM. For this example, the ILSM will outline specific items or tasks that the facility feels are necessary during the time when the fire system is disabled; these could be increased fire surveillance rounds or posting a safety officer in the disabled zone.

In addition to an Infection Control Risk Assessment (see section 11.3.1), an ILSM assessment is necessary for all projects. An ILSM assesses the impact of a construction project on fire protection systems and exit passageways. Many hospitals have established protocols for maintaining interim life safety measures.

A fire watch must be established if fire alarm or fire detection systems are disconnected or impaired. The fire watch personnel must be familiar with the hospital fire watch protocol and provide documentation to show that hospital procedures were followed. Hospital protocol may require additional firefighting equipment in the construction area and daily inspections for fire hazards. Generally, these are the responsibility of the general contractor.

Temporary construction walls must be of fire-resistive materials with all joints taped and caulked to make them smoketight. Stored materials must be minimized and the site cleaned daily to minimize fire hazards. Debris must be removed daily.

If the construction project will block or restrict exit passageways, then alternate passageways must be established and identified with proper signage. An 8 ft [2.4 m] clearance must be maintained in hospital corridors at all times.

11.2.5 Disaster Emergency Operations Plan

Health care facilities are required to have a Disaster Emergency Operations Plan (DEOP) in addition to a Joint Commission environment-of-care mandate. The maintenance department plays an important role in formulating and implementing such a plan. This is another example of the close collaboration required between the maintenance department and other departments.

Coordination in preparing for unexpected shutdowns and system failures is essential. Careful planning for those who will be available during an emergency (and addressing how they will communicate with health care staff) is essential. The management decision chain must be clearly defined, and contingencies must be built in for personnel absences. See Chapter 10 for more detail.

Life Safety Compliance

As part of TJC or CMS inspections, a facility is required to maintain and demonstrate compliance with the intent of the life safety standards, regardless of whether it is an existing facility or new construction. The objective is to ensure compliance with the NFPA *Life Safety Code*® (NFPA 2012). Some of its safety requirements that directly impact the HVAC systems include the following:

- UL-approved fire, smoke, and combination fire/smoke dampers are installed in the ductwork at identified barriers.
- Testing documentation shows the activation of such dampers by the local detection system.
- Fire-stopping is required of all through-penetrations in identified barriers.
- Doors are free of louvers, with the exception of bathrooms, toilets, and sink spaces not containing combustible or flammable materials.
- Emergency power is provided.
- Kitchen-grease-producing equipment is provided or served by exhaust hoods, exhaust ductwork systems, and associated fire system controls; there is documentation of all testing and maintenance to ensure cleanliness, operability, and reliability of these systems.

The design of life safety systems is described in Chapter 5.

11.3 RISK ASSESSMENTS

Risk assessments are used in different ways and for different applications, ultimately attempting to achieve the same goal: a safe environment for patients, visitors, and staff. A risk assessment can evaluate a piece of equipment, such a as portable biomedical device, an air- handling unit, a fire pump, other pieces of fixed equipment, or policies and procedures. A facility risk assessment can be used to establish guidelines for a work permit, and will include infection control, life safety, and utility risks.

11.3.1 Infection Control Risk Assessment

Renovation plans must include a strategy for protecting interior areas adjacent to the construction project from dust and debris. Special measures must be taken during construction to reduce the spread of contaminants from the construction area to occupied areas. This includes the floors above and below the project. Dust is a potential source of hospital-acquired infections (see Chapter 2 for further discussion); *Aspergillus* (a genus including molds) is commonly found in the ground and occasionally on dust particles above a ceiling.

An Infection Control Risk Assessment (ICRA) is used to document the criticality of patients and processes in the vicinity of a construction project, the extent of construction, and the measures to be taken by the contractor to reduce the risk of hospital-acquired infections. The Joint Commission requires that copies of ICRAs be kept on file and available for inspection at all times. There is no national standard ICRA form; each hospital develops its own, tailored to its specific needs. A sample ICRA matrix is shown in Table 11-1.

The development of an ICRA involves the owner's project manager, a representative of the infection control department, the contractor, the architect, and the engineer. It is becoming common practice to include an Infection Control drawing in the design documents. Be sure that the

mechanical sheets reference the ICRA drawing. The contractor must keep a written record of the ICRA measures taken, including a daily log of the negative pressure in the construction zone. Some items typically addressed in an ICRA include the following:

- Ensure that air supplied to the construction zone is not recirculated to other parts of the hospital; this might be accomplished by closing all return air grilles in the construction area; carefully placing filters over all return air grilles is acceptable, but blocking returns is preferred.
- Designate an entry/exit path for contractor personnel, materials delivery, and debris removal, including a dedicated elevator; require contractor to drape elevator with moving pads to prevent damage.
- Designate hours of the day during which certain areas are available.
- Specify methods of maintaining and monitoring negative pressure in the construction area, typically using a properly sized fan exhausting air from the construction area to the outdoors at least 30 ft [9 m] from any air intake. HEPA filters may be used to pull air from the construction area for exhaust to the hospital, but direct exhaust to the outdoors is much preferred; a negative-pressure monitoring device should be installed in the wall between the construction area and the adjacent interior areas of the hospital, with readings taken and recorded twice a day.
- Specify placment of portable 100% recirculating HEPA filter units throughout the construction space to reduce dust.
- Barriers between the construction area and surrounding hospital areas are normally fully taped sheetrock walls extending to the floor deck above; plastic sheeting is acceptable for small projects involving minor dust-generating activities.
- The entrance to the construction area should have a steel-framed door with closer and dust seals.
- The construction entrance should have an anteroom where workers can change clothes or vacuum clothes before leaving; work clothes should be vacuumed before leaving.
- Use covered carts to transport debris through the hospital on a preassigned route; mist the debris to minimize dust.
- Require damp carpets or sticky mats at all construction area exits for cleaning shoe soles. Damp carpets are more effective (sticky walk-off mats quickly fill with dirt and lose their effectiveness unless changed frequently). Carpets need to be replaced or cleaned daily.
- Construction zone signs should direct staff and visitors away from the construction area to alternate routes.
- Particle counts from representative areas should be taken before and after the construction project.

11.3.2 Fixed Equipment

Each piece of equipment in a health care setting must be assessed for level of risk. It is up to the facility to determine the risk that it is willing to assume. For each piece of equipment regardless of size or service,

a risk assessment is utilized to minimize equipment failures, extend service life, and ensure safe and efficient operation for the implementation of planned preventive maintenance. Most computerized maintenance management systems (CMMSs) include a prescribed methodology for assessing equipment. One such formula is

$$\text{Total} = E + A + [(P + F + U)/3]$$

This formula is based upon the following five risk categories. Each of the following categories includes specific subcategories that are assigned points:

- Risk Category A: clinical application; lists the potential patient or equipment risk during use
- Risk Category E: equipment service function; includes various areas in which therapeutic, diagnostic, analytical, and miscellaneous equipment are found
- Risk Category F: likelihood of failure; documents the anticipated mean-time-between-failure rate, based upon equipment service and incident history
- Risk Category P: manufacturer's recommended maintenance; describes the level and frequency of preventive maintenance required
- Risk Category U: the environment of use; lists the primary equipment use area

Based upon the total score, equipment can be identified with a priority level that will define the maintenance interval and the degree of risk. The Joint Commission's recommended levels are the following:

- Priority 1: this equipment is given the highest priority for testing, calibration, and repair; equipment in this priority group is tested on at least a quarterly basis and is noted as "Highest Priority" in the computer system.
- Priority 2: every effort should be made to test, calibrate, and repair promptly, but only after Priority 1 equipment requirements have been completed; equipment in this priority group is tested on at least a semiannual basis and is noted as "Medium Priority" in the computer system.
- Priority 3: every effort should be made to test, calibrate, and repair promptly, but only after Priority 1 and 2 equipment requirements have been completed; equipment in this priority group is tested on at least an annual basis and is noted as "Low Priority" in the computer system.
- Hazard Surveillance: fixed equipment devices in this category are placed in equipment inventory but are visually inspected on an annual basis during the hospital hazard surveillance rounds.
- The lowest ranking priority is possible removal from the management program.

The point allocations between these levels are prescribed by the facility and its level of risk. Each piece of equipment within the system should be reevaluated at regular intervals. Thus, the score will accurately depict a failure or a change in service function, which in turn can potentially impact the priority rating.

The facility will have a standard operating procedure that outlines the approved formula and risk assessment that is to be used. Discuss this with the facility staff and provide the required documentation pertaining to particular items of equipment.

11.3.3 Facility Risk Assessments

Another type of risk assessment takes place when work is to be done within the boundaries of an existing hospital or health care facility. This assessment evaluates infection control measures, life safety interruptions, and service interruptions specific to that project site and surrounding areas. This will be done as part of an established program; each facility will have a different program and set of procedures. Low, medium, high, or extreme risks can be shown in a matrix format that determines a specific level of precautions that need to be followed. Areas of the health care facility are identified with a risk level based upon the occupancy/usage:

- Low risk: staff office or public area
- Medium risk: a minor treatment area
- High risk: a nursing unit or a clinical laboratory
- Extreme risk: an immunocompromised patient care area, intensive-care unit, or a surgery care area

The type of construction work that might occur in these types of spaces could be classified in the following manner:

- Inspection and minimally invasive activities
- Small-scale, short-duration activities that create minimal dust
- Work that generates a moderate to high level of dust or requires demolition or removal of any fixed building components or assemblies
- Major demolition and construction projects

A risk assessment matrix example is shown in Table 11-1.

A risk assessment evaluates activities for infection control measures and precautions. Precautions, which, again, are facility specific, may deal with issues such as:

- dust created by removals, construction, traffic, or investigations;
- release of dormant contaminants by moving, altering, or removing existing construction, ceiling tiles, etc.;
- water damage and subsequent growth of various microbes; and
- contamination of piped and ducted systems.

Table 11-1 *Risk Assessment Matrix Example*

Guidelines		**Project:**			**Project No:**
Healthcare space: all those areas that are included in Joint Commission Accreditation Programs. This includes the entire hospital building, any patient care area, patient care support departments such as pathology, lab medicine, central sterile processing, laundry, food services, etc. **Covered activities:** all activities that alter or disrupt the physical environment in the covered areas that do not qualify as Exempted Activities. This may include inspection, maintenance, and preparatory activities. 1. Heating, ventilating, and air conditioning (HVAC), including temperature control 2. Plumbing: domestic water and waste and/or medical gases and vacuum systems 3. Electrical: normal & emergency power and/or data/communications or television 4. Pneumatic tube system 5. Noise, vibration, odor, or other activity that disrupts normal operation **Exempted activities:** those activities that meet ALL of the following conditions are exempted from the Construction Review Process but not necessarily exempt from a work permit. 1. No planned or anticipated interruptions of the normal delivery of services, supplies, or operations 2. No concerns that would indicate a need for special monitoring of project activities		Occupant Risk Group			
		Low Risk	**Moderate Risk**	**Severe Risk**	**Extreme Risk**
		Staff-only areas where there is a low density of occupancy; staff office areas	Public areas; cafeteria; staff work areas	Surgical nursing units; outpatient clinics; clinical laboratories; pharmacy (general areas); central sterile supply	Medical nursing units; pediatrics; intensive care unit; negative pressure isolation units; surgery; post-anesthesia care; pharmacy (compounding area)
Work Activity Type					
TYPE A	**Minor disruption of short duration, including but not limited to:** ● A utility shutdown or interruption that affects a single room or horizontally adjacent rooms ● Routine inspections or maintenance that requires a shutdown or transfer of services ● Noise, vibration, or disturbance that can be completed and restored within a single work shift	Class I	Class I	Class II	Class II
TYPE B	**Major disruption of short duration, including but not limited to:** ● A utility shutdown or interruption that affects a group of rooms or zone, either vertically along a riser or horizontally on a single floor ● Noise, vibration, or disturbance that cannot be contained within a single space but is transmitted to adjacent rooms, either horizontally or vertically ● An activity that can be completed and restored within a single work shift	Class II	Class II	Class III	Class III
TYPE C	**Minor interruptions of a duration exceeding one work shift, including but not limited to:** ● A utility shutdown or interruption that affects a single room or horizontally adjacent rooms ● Maintenance that requires a controlled and limited shutdown ● Noise and vibration that can be contained within a single space ● Any activity that cannot be completed within a single work shift	Class III	Class III	Class III or IV	Class IV
TYPE D	**Major interruptions of a duration exceeding one work shift, including but not limited to:** ● A utility shutdown or interruption that affects a group of rooms or zone, either vertically along a riser or horizontally on a single floor ● Maintenance that requires a shutdown of an entire zone or group of zones or an entire system ● Noise and vibration that cannot be contained within a single space but is transmitted to adjacent rooms either horizontally or vertically ● Activities that require consecutive work shifts	Class III	Class III or IV	Class IV	Class IV

Similar to infection control evaluation activities, a life safety evaluation will determine interim life safety measures, including items such as the following:

- Fire alarm system: detection and notification
- Fire suppression: standpipe, sprinkler, and chemical systems
- Means of egress: exits (stairs and horizontal), corridors, signage, illumination, etc.
- Smoke/fire barriers: corridor walls, stairwells and horizontal exits, smoke/fire walls, doors, in-duct dampers, etc.

When life safety systems are compromised during construction, the hospital will typically "post a watch" and notify the local fire department.

Another activity that impacts hospital or health care operations is utility or service interruptions.

These can be evaluated for mitigation measures as well. Mitigation would include infrastructure that may require isolation or be partially impaired during a project. This could involve an impact to

- HVAC systems, including controls;
- domestic water and waste and/or medical gases and vacuum systems;
- electrical power, both normal and emergency;
- data, communications, or television;
- pneumatic tube system; and
- elevators.

11.3.4 Work Permits

Each facility will have a different process for obtaining a work permit. As a designer, knowledge of these requirements and the potential impact that they may have on the specifications is very important. If there is a requirement within the permit process that has not been accounted for, the contractor can ask for a change order. Figure 11-1 shows an example of a facility work permit.

11.4 OPERATIONS

Facility operations can be challenged with balancing operational issues such as downtime for maintenance and repairs, maintaining regulatory requirements, and maintaining a comfortable environment for patient care and staff in the diverse areas within a facility. Many hospitals and clinics face a variety of resource and staffing issues when it comes to operating and maintaining equipment within the facility. All medical facilities have a low tolerance for unexpected disruptions. This section explores some of these challenges so that the design team can better understand the nature of daily operations before, during, and after a project is complete.

Hospital or Health Care Facility Work Permit

A. INSTRUCTIONS

Project No:	Project Title:	Project Start Date:
Project Location:		Estimated Duration:
Project Coordinator:		Project Expiration Date:

1. Complete a Risk Assessment Matrix for Infection Control, Life Safety, and Service Interruption **(Form RA-1)** and enter the results in the chart on this page by putting an "X" in the appropriate boxes.
2. Complete the Work Permit form and submit it to the **Construction Risk Evaluation Committee** along with the Risk Assessment and other supporting drawings and documents.
3. The Committee will distribute copies of the approved Permit, one of which the Project Administrator or Construction Manager shall post on the jobsite.
4. An approved, signed Work Permit and distribution of the ***Notification of Intent Work*** **(Form RA-1)** are required 48 hours prior to the setup or commencement of any on-site work.
5. Furnish a list of contractors and subcontractors that will be working on the Project to the Planning Department.

B. PROJECT DESCRIPTION

General Description and Overall Intent:					
Intrusive or Disruptive Activities:					
Intended Work Shifts:					
Work Anticipated Outside the Primary Area: This list should include such items as data/communications lines run from a remote closet, work on the floor above or below the Project Area, MEP services run to other floors or areas, etc. Indicate what areas of concern may be impacted by the work. The task number and measures specific to the Task should be included within the Work Permit where applicable. Separate setup and completion inspections may be required.			Impact: Infection Control	Life Safety	Service
Task No.	Description:	Location:			
1					
2					
3					
4					
Authority Having Jurisdiction (AHJ):			Not Applicable:		

C. RISK ASSESSMENT SUMMARY

Work Activity	Occupant Risk Group											
	Low Risk			Moderate Risk			Severe Risk			Extreme Risk		
	Infection Control	Life Safety	Service	Infection Control	Life Safety	Service	Infection Control	Life Safety	Service	Infection Control	Life Safety	Service
Type A Inspections, noninvasive work and/or life safety systems and/or service interruptions of short duration affecting an isolated area.	Class I	Class I	Class I	Class I	Class I	Class I	Class I	Class II	Class II	Class II	Class II	Class II
Type B Small scale, short duration, moderate levels of dust and/or life safety systems and/or service interruptions affecting a small area.	Class II	Class II	Class II	Class II	Class II	Class II	Class II	Class III	Class III	Class III or IV	Class III	Class III
Type C Moderate to high levels of dust and/or life safety systems and/or interruptions greater than one work shift.	Class III	Class III	Class III	Class III	Class III	Class III	Class III or IV	Class III or IV	Class III or IV	Class IV	Class IV	Class IV
Type D Significant demolition, construction and/or life safety systems and/or service interruptions of long duration.	Class III or IV	Class IV	Class III	Class IV	Class IV	Class III or IV	Class IV	Class IV	Class IV	Class IV	Class IV	Class IV

Figure 11-1 *Sample Health Care Facility Work Permit*

Maintaining continuity of services is difficult when trying to accomplish preventive maintenance or repairs. Health care organizations need dynamic facilities and systems that allow for maintenance shutdowns and future upgrades or modifications to the systems. This is best achieved first by providing a means of redundancy to the areas that are most critical or have the greatest need to remain operational 24 hours a day, 365 days annually. When designing redundancy into health care facilities, duplicated systems must have the ability to be completely isolated from each other.

Internal teamwork is necessary in health care facilities to preserve building systems operations. The maintenance department needs to work closely with infection control, respiratory therapy, biomedical engineering, public safety and security, and environmental services departments. Some critical considerations that require collaboration between departments include air filtration systems, area pressurization, water systems, system shutdowns, and cleanup.

11.4.1 Capital Planning

Careful attention must be paid to assessing a facility's need for future growth as presented in a capital budget. Capital projects are also developed when maintenance departments request funding for repairing and/or replacing mechanical and electrical equipment that is approaching the end of its usable life cycle. See Chapter 7 for information regarding facility assessments.

Major facility projects inevitably include HVAC renovations or additional HVAC equipment. Many facilities now consider long-term energy savings when planning capital projects, as well as initial cost, reliability, performance, and maintenance. As owners become more educated regarding energy-efficient design, engineers will find the owner wanting more involvement and input into equipment selections. Depending on the nature of the project, other areas of owner concern are things such as weight, size, or noise of the equipment, placement/location of the equipment as it relates to adjacent spaces, and expansion of or tie-in to the existing utility services.

When upgrading systems or equipment a complete understanding of the needs of the facility is important to the success of the project. For example, if an inpatient unit is being renovated, the project would require that patients be relocated to another area. Infection control precautions would be initiated and verified prior to proceeding into construction. After project completion, the hospital will require final infection control inspections before allowing patients to return to the unit. There is a cost associated with the relocation and temporary housing of the patients during construction. There may also be additional cost for the infection control precautions. These types of costs must be included in project planning and budgeting.

Most facilities have limited storage space. Try to specify common equipment manufacturers to reduce the required stock of repair parts.

11.4.2 Downtime Coordination

Hospitals are a 24-hour operation, which makes construction, repairs, or preventive maintenance very difficult to complete without redundant systems. When systems are renovated, an assessment is completed to determine the global impact of an outage. Extensive internal planning takes place before shutdowns, repairs, projects, or system improvements are started. Planning for the scope of work can include Interim Life Safety Measures (ISLM), infection control precautions, location and layout of associated areas, and a detailed schedule of the work that needs to be completed. Once a project scope is defined, consultants or contractors become involved to assist the facility through project completion.

11.4.3 Utilities Management

Utilities management traditionally includes the monitoring of utility consumption, distribution, and acquisition of utility services. It has grown to include the management of associated risk; providing reliable services in emergencies; and the inspection, testing, and maintenance of utility systems, including medical gases and vacuum. Within each of these concerns are multiple items that require documentation and/or continuous monitoring. Safety-related items are more closely monitored.

Managing risk associated with utility systems involves more than electricity, natural gas, and water. It requires documentation on issues, including

- keeping a written inventory of all fixed equipment, inclusive of inspections, maintenance, schedules, and work performed;
- minimizing aerosolizing water systems;
- ensuring proper air exchange rates;
- verifying that filtration efficiencies are appropriate;
- continually monitoring space and zone pressure relationships;
- maintaining accurate utility distribution maps with systems clearly labeled, and identifying isolation and changeover controls for emergency shutdowns; and
- documenting written procedures to isolate or shut down systems in the event of an emergency, including procedures for notification and intervention when these shutdowns affect clinical operations.

It is a utility manager's responsibility to provide emergency power to meet the life safety code. Documentation of testing and maintenance of reliable services during emergencies includes alarm systems, illumination of exit routes and signage, communication systems, elevators, and patient equipment (such as life support systems).

Inspecting, testing, and maintaining the equipment and systems within a facility requires a significant manpower commitment. For each piece of equipment there are manufacturer-recommended tasks

to be performed at periodic intervals. All service-related work should be documented when completed so that an historical-asset record can be assembled. Using institutional knowledge, the facility evaluates the area that utility equipment serves, performs a risk assessment, and creates a criteria-specific schedule specific for the equipment. Equipment could be organized using the following categories:

- Life support utilities
- Infection control utilities
- Non-life-support utilities

11.4.4 Indoor Air Quality and Filtration

Hospital acquired infections (HAIs) are discussed in Chapter 2. ANSI/ASHRAE Standard 62.1-2010 defines acceptable indoor air quality as "air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction" (ASHRAE 2010). Indoor air quality (IAQ) problems can originate from outdoor air or from many different sources within a facility. Interior sources may involve building systems, processes and procedures, management practices, furniture, fixtures, equipment, patients, and employees. Maintenance departments usually get the first call regarding IAQ problems, and they need to follow a systematic investigative process. Proper filtration of air for a health care facility is critical. Air filtration requirements for health care facilities are not a new development. The original requirements were published in 1947 with the Hill-Burton Act. In the years since, the requirements have been modified to incorporate current technologies for filtration and microbial contamination control. The filter performance classification of MERV 1 through MERV 17 is outlined in ANSI/ASHRAE Standard 52.2-2007 (ASHRAE 2007). The National Air Filtration Association (NAFA) publishes a good resource in the *NAFA Guide to Air Filtration* (NAFA 2007). See Chapters 2, 3, and 8 of this manual for more information on filtration and air changes.

It is important to understand the areas within a facility, because different areas have different filtration requirements. Focus on the actual uses of a space before determining the efficiency of filtration required. HEPA filtration is expensive to install, maintain, and certify. Consideration of facility preferences for types of filters can be just as important as the rating of a filter. Does it prefer using a cartridge or a bag filter? These filters have the same rating, but differ in size, cost, and maintenance intervals.

The life of a filter is difficult to estimate, mostly because it is dependent on the climate and environment. The following are a few considerations for selecting an appropriate filter:

- Particle size distribution of contaminants is dependent upon the environment, and can change on a daily or hourly interval.

- If a facility is located where there is a lot of construction taking place, particulates may load the filters faster; this requires a closer supervision of the intake plenums to maintain cleanliness.
- Is the facility in a location that is affected by high pollen counts in certain seasons, thus requiring closer monitoring of the filters during that season?
- Ensure that filters have gaskets; the filter box frame requires a tight seal to ensure that air is filtered and contaminants are removed.
- Ensure that the filter rack is robust, to avoid bending and resultant cracks around the filters.
- When selecting or replacing filters, match the filter with the appropriate air velocity and static pressure; this is related to the filter's MERV rating.
- It is recommended that differential pressure gages be installed for visual monitoring of the filter bank, in addition to a sensor that reports to the control system.
- Provide access doors for visual inspection on both sides of a filter bank.

11.4.5 *Legionella*

It is the responsibility of every health care facility maintenance department to create standard operating procedures that include established guidelines for the management of pathogenic agents in cooling towers and in internal water systems. *Legionella* is a bacterium. Its name and that of the associated disease, legionellosis, are derived from a 1976 outbreak at an American Legion convention in Philadelphia that was attributed to a cooling tower. This bacterium occurs naturally in water and municipal water systems in low or undetectable concentrations. Under certain conditions, the concentration of the bacteria may increase dramatically, a process called "amplification." Conditions favorable for amplification include

- presence of *Legionella,*
- water temperature of 77°F to 108°F [25.0°C to 42.2°C],
- stagnation,
- scale and sediment, and
- biofilms.

Transmission to humans occurs when water that contains the organism is aerosolized in respirable droplets (1 to 5 μm) and inhaled by a susceptible person. Infections initially occur in the upper or lower respiratory tract. The risk is greater for older people as well as those who smoke, have chronic lung disease, or are immunosuppressed. Promising technologies for *Legionella* abatement or control include treatment with chlorine dioxide, chloramines, or silver-copper ion injection in the domestic water supply. Proposed ASHRAE Standard 188P, *Prevention of Legionellosis Associated with Building Water Systems,* is intended to provide more details on *Legionella*.

Key recommendations for minimizing the risk from cooling towers involve clean surfaces and a biocide program. Engaging a chemical-treatment specialist is recommended. Mechanical filtration should be considered to minimize fouling. Drift eliminators should be regularly inspected, cleaned, and repaired as needed. It is sound practice to alternate the biocides used for cooling water treatment to avoid developing resistant strains of microbes. Weekly changes in dose and frequency are recommended.

Shutting down and starting a cooling tower system requires particular attention. When a system is shut down for more than a few days, draining the entire system is recommended. When not practical to do so, stagnant water must be pretreated with a biocide regimen before tower start-up. Consider keeping a sweeper system operational in the tower basin during the down time, creating continuous movement of the water and not allowing stagnation to occur. Circulation of water for up to 6 h, after adding biocide and before tower fans are operated, is suggested for both drained and undrained system shutdowns. Butkus et al. (1999), ASHE (1993), ASHE (1994), and ASHRAE Guideline 12, *Minimizing the Risk of Legionellosis Associated with Building Water Systems* (ASHRAE 2000), provide excellent discussions of this problem and potential solutions. Specifications should spell out the procedures that contractors must perform during construction and startup; this should include pipe-cleaning methods.

11.5 MAINTENANCE

Maintenance in a health care facility is performed by in-house skilled trades, external contractors, or a combination of both. Maintenance is reportable to the accrediting agency during an inspection, and accurate documentation must be provided if the regulatory inspector asks for it. A service schedule is developed by the facility and is usually established by doing a fixed-equipment risk assessment.

When maintenance is performed in occupied areas, some hospitals require the use of an infection control containment barrier or cube. Containment barriers provide a temporary enclosure for smaller construction projects and day-to-day maintenance tasks. These barriers are maintained at a negative air pressure relative to the occupied space via a HEPA vacuum or negative air machine. Containment cubes to accommodate workers, ladders and tools are readily available for purchase.

It is helpful to categorize maintenance into severity levels, such as reactive, scheduled, predictive, preventive, and productive maintenance. These categories are described in the following sections.

11.5.1 Reactive Maintenance

Reactive (also known as corrective) maintenance is an approach in which equipment is repaired or replaced only upon failure. When a failure occurs, necessary repairs are made, or equipment is replaced, so that the system can return to normal operation. Historically, reactive

maintenance tends to be more costly but should be evaluated on a case-by-case basis for nonrisk applications.

The downsides of reactive maintenance are

- potential safety hazards could be as serious as catastrophic failures;
- critical downtime occurs when equipment fails without warning, putting a whole system out of service for a period of time while replacement parts are acquired; and
- reactive maintenance generally results in a higher cost of operations, because the repair service becomes an emergency by requiring expedited delivery of parts and/or paying contractors or in-house personnel overtime to complete repairs.

11.5.2 Scheduled Maintenance

Scheduled (also known as fixed-time) maintenance is an approach that uses a set schedule based on run-time or a calendar interval to perform service. If the schedule is too short, maintenance will be performed while the equipment is in good operational order. If the schedule interval is too long, the equipment may fail before the next scheduled maintenance. Scheduled maintenance is common and is a default methodology in several commercially available computerized maintenance management software packages.

11.5.3 Predictive Maintenance

Predictive (also known as condition-based) maintenance is an approach in which service is performed based on monitoring of system operating conditions. Maintenance under a predictive method must be inclusive of changes in equipment sound or vibration, the temperature of system components, and/or color changes of system fluids (such as grease). This type of maintenance requires the detailed observation of equipment and systems by a controls system, the service mechanic, and/or the equipment operator.

11.5.4 Preventive Maintenance

Preventive maintenance is an approach that includes regular inspections, monitoring, correction, calibration, and cleaning to ensure that operational quality is maintained. This is viewed by many as a balance between the reactive and proactive approaches. This form of maintenance may be a worthy goal, but it comes with potentially higher operational costs. Preventive maintenance does not prevent all failures.

11.5.5 Maintenance Management Systems

All facilities need some level of maintenance management organization to monitor staff work load and fixed-asset control. Computers can be useful in implementing any of the previously described maintenance approaches. A computer-aided facility management system (CAFM), also known as a computerized maintenance management system (CMMS) is used in a hospital or health care organization to encompass the total functionality of the facility. Multiple aspects of building maintenance can be automatically generated, recorded, and monitored; including

- asset management and inventory;
- implementation of required maintenance on any system, whether it is preventive, predictive, or scheduled;
- inclusion of complete equipment history;
- service requests from the staff and building occupants;
- inventory control of spare parts and consumables; and
- efficient allocation of available manpower to required tasks.

Computerized systems provide the ability to communicate information to proper trade personnel, monitor the status of a specific event from incident to completion, and track event timelines. On completion of each maintenance event, the facility maintenance staff needs to add, modify, or remove the record of any assets that were impacted by the project. Saved information should include make, model, and serial number of the equipment along with the location of the equipment and the area served. Recommended maintenance procedures can also be entered, along with an associated risk-assessment for that equipment.

Building information modeling (BIM) systems have been used to input common data such as make, model, and capacity, as well as links to maintenance and parts websites. Many hospital IT departments will not allow large drawing and equipment files to be located on the hospital's servers. Therefore, some hospitals are using CMMS located on third-party cloud servers. Another advantage of a third-party server is that the hosting firms have the manpower and expertise to deal with the data-filing and software systems.

11.5.6 Cleaning Existing Ductwork

Studies have shown that dust accumulated in ductwork contains large amounts of organic materials, such as human and animal hair, skin flakes, fungal spores, insect parts, and plant materials (Brosseau et al. 2000a). These materials can provide nutrition for microbe growth and can themselves cause allergic reactions in sensitive persons. Dust buildup occurs to a much greater degree in unfiltered duct systems, such as return or exhaust ducts, and in particular on fittings against which the airstream impacts or that cause high-turbulence eddies, such as fan plenums, elbows, turning vanes, airflow sensors, and dampers.

Duct-cleaning operations can release large quantities of airborne particles and high levels of chemical compounds (Brosseau et al. 2000b). Standard cleaning procedures place the duct being cleaned under negative pressure (vacuum) during the procedure. The surrounding area can become contaminated (even with negative pressurization), however, by not providing adequate time for disinfecting or encapsulant chemicals to dry or by work done outside of the duct to gain access for the procedure. An increase in the number of airborne particles may increase the risk of nosocomial infections, particularly among the immune-compromised. Chemical applications, particularly when improperly applied or mixed, can result in occupant complaints of irritation or adverse health effects. At least one hospital investigation

correlated a higher incidence of occupant health complaints during a duct-cleaning/disinfection procedure with symptoms corresponding to Material Safety Data Sheet (MSDS) information for the chemicals being used (Carlson and Streifel 1996). For these reasons, a number of authorities and industry associations strongly advocate that duct-cleaning projects be carefully coordinated with the facility staff beforehand, that the procedures be carried out only by properly trained and qualified personnel, and that all necessary containment and protective measures are carefully adhered to.

To facilitate duct cleaning, designers should provide duct access door openings in accessible locations at periodic intervals in major ductwork and at those fittings where dust is likely to most heavily accumulate (as discussed above). Duct-cleaning companies also recommend that, to minimize dust accumulation, designers avoid the use of interior duct linings or glass-fiber ductwork.

The Centers for Disease Control and Prevention (CDC) and U.S. Environmental Protection Agency (EPA) advise that there are no indications that duct cleaning results in a lower incidence of infection or other health problems (CDC 2001). Cleaning can result in improved air system performance. Routine duct cleaning may be justified on exhaust systems, and perhaps on return systems, because of their greater potential for dust accumulation and the lesser risk of redeposition of dust into the facility. Coils should be cleaned frequently (including reheat coils). Debris buildup greatly reduces system performance and may contribute to HAIs.

11.6 FIRE AND SMOKE DAMPERS

NFPA has many publications that address the requirements for fire and smoke dampers, as well as the associated control systems. This section highlights maintenance and testing considerations for these systems. Figure 11-2 is an example of a fire/smoke damper checksheet that could be used for the testing outlined in this section.

A service opening that will facilitate required maintenance must be provided in the ductwork at all dampers. The access must be large enough to permit required maintenance, resetting of the device, and visual verification that the damper closes completely. Such openings must be identified using minimum 0.5 in. [12.7 mm] tall letters that note the location as a fire, smoke, or combination fire/smoke damper.

Fire dampers must be tested at least every six years to verify that they close fully, in accordance with *NFPA 90A: Standard for the Installation of Air-Conditioning and Ventilating Systems* (NFPA 2012a). Moving parts must be lubricated as necessary.

Smoke dampers must be tested at least annually, following the guidelines of *NFPA 92: Standard for Smoke Control Systems* (NFPA 2012b). Smoke detectors used in conjunction with smoke dampers

FIRE/SMOKE DAMPER MAINTENANCE RECORD

Date: _____ Inspector: _____

Location: _____

This is to certify that the following testing and maintenance was performed on the dampers listed. Any modifications or repairs made are described below.

Y = Satisfactory N = Unsatisfactory N/A = Not applicable

Damper Number or Location	Damper Type	Tested	Fully Closed	Latch Checked	Fusible Link Removed	Moving Parts Lubricated

COMMENTS:

_____

_____

_____

_____

Figure 11-2 *Sample Fire/Smoke Damper Maintenance Checksheet*

must be maintained in accordance with *NFPA 72: National Fire Alarm and Signaling Code* (NFPA 2013).

Fire damper maintenance includes replacing the heat-responsive element, operating it to demonstrate that the damper closes fully, and checking that the latch (if provided) functions properly.

REFERENCES

ASHE. 1993. *Facilities Engineering; Management Series.* Chicago: American Society for Healthcare Engineering.

ASHE. 1994. *Facilities Engineering; Management Series.* Chicago: American Society for Healthcare Engineering.

ASHRAE. 2007. *Method of testing general ventilation air-cleaning devices for removal efficiency by particle size*. ANSI/ASHRAE Standard 52.2-2007. Atlanta: ASHRAE.

ASHRAE. 2010. *Ventilation for acceptable indoor air quality*. ANSI/ASHRAE Standard 62.1-2010. Atlanta: ASHRAE.

ASHRAE. 2000. *Minimizing the risk of legionellosis associated with building water systems*. Guideline 12-2000. Atlanta: ASHRAE.

Brosseau, L.M. et al. 2000a. Methods and criteria for cleaning contaminated ducts and airhandling equipment. *ASHRAE Transactions* 106(1):188–99.

Brosseau, L.M. et al. 2000b. Duct cleaning: A review of associated health effects and results of company and expert survey. *ASHRAE Transactions* 106(1):180–87.

Butkus, A. S. et al. 1999. *Grumman/Butkus Bulletin* (September).

Carlson, N.G. and A.J. Streifel. 1996. Quality assurance methods used during remediation of fiberglass lined duct work with fungal contamination. Presented at the American Industrial Hygiene Conference and Exposition, Washington, DC. Unpublished.

CDC. 2001. *Draft guideline for environmental infection control in healthcare facilities*. Atlanta: Centers for Disease Control and Prevention.

NAFA. 2007. *Guide to air filtration*, 4th ed. Virginia Beach, VA: National Air Filtration Association.

NFPA. 2013a. *NFPA 72®: National fire alarm and signaling code.* Quincy, MA: National Fire Protection Association.

NFPA. 2012a. *NFPA 90A: Standard for the installation of air-conditioning and ventilating systems.* Quincy, MA: National Fire Protection Association.

NFPA. 2012b. *NFPA 92: Standard for smoke control systems.* Quincy, MA: National Fire Protection Association.

NFPA. 2012. *NFPA 101®: Life safety code®.* Quincy, MA: National Fire Protection Association.

CHAPTER 12

SUSTAINABILITY IN HEALTH CARE FACILITIES

12.1 INTRODUCTION

Health care facilities have a profound impact on our natural resources, on our community's health and wellness, and on the economy. The sustainability/green movement has gained attention and popularity over the past 10 years, generating a new language for applying natural-resource-conservation concepts to the built environment. In the most generic form, sustainable building practices balance three key elements: environmental, social, and economic factors. Putting these into practice in a health care facility project commonly involves conservation of resources through building methods and materials; consideration of the facility's impact on the community infrastructure and wellness services; and balancing decisions and choices such that the project is economically viable for the health care organization.

Discussions of trends and resources on this dynamic and changing field are included in this chapter. This chapter should be considered an introduction to concepts and ideas.

Sustainable design practices were initially slow to be adopted in the heath care building sector. That trend seems to have been overcome. Nearly all health care organizations have some level of commitment to implementing these practices in their operations, including facility design and construction projects.

It is imperative that the HVAC project team have an understanding of sustainable/green concepts and terminology and how they apply to the specific needs and requirements of health care facilities. In addition, the HVAC design team will be expected to provide in-depth professional expertise for concepts that involve the HVAC systems.

In the United States, the green movement was accelerated by the popularity of the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED®) green-building certification program. Evidence that health care is catching up is found in the number of specific programs aimed at this building sector. LEED added a health-care-specific certification in late 2010. Other organizations are dedicated to support of sustainable health care building and operational practices. In the United States, these include Practice Greenhealth; Green Guide for Healthcare™ (GGHC); CleanMed, and similar organizations. ASHRAE, in partnership with USGBC and the Illuminating Engineering Society (IES), is developing Standard 189.3, *Design, Construction, and Operation of Sustainable, High-Performance Health Care Facilities,* which will be adoptable by jurisdictions and define a minimal level of sustainability. At press time for this manual, the standard was undergoing public review.

During the conceptual phase of a project, the health care organization and design team leadership need to discuss sustainable objectives and goals. It should be determined whether certification or external recognition is a project goal. If so, what certification program(s) is going to be pursued? Even if certification is not intended, project teams can use the format of LEED or Standard 189.3 to provide an organized way of sorting through the various sustainable concepts and options that may best align with the project owner's goals and budget.

12.2 SUSTAINABILITY TRENDS AND ECONOMIC CONSIDERATIONS

12.2.1 Sustainability Trends

The sustainability (or green) movement has now entered all building types and business markets. Health care was one of the last areas to adopt because of many diverse factors. Health care may have been slow to start, but green is growing at a rapid pace and is encompassing areas that are unique to the industry, such as medical waste and food waste reduction. Sustainability and the mission of health care organizations are aligned at the most fundamental level. The health care mission involves the wellness of the communities being served. The sustainability movement in the design and construction industry is focused on the community environment and building occupant wellness, using improved means, methods, and materials. For any measure to be sustainable, it must be economically viable.

Because of the alignment of health care organization missions with patient and community wellness, most organizations want to provide a green facility. But sustainability is a relative measure—more sustainable than what? It is difficult to answer a CEO's question: "I want a green facility and how much more is that going to cost?" One method is to use the framework of existing certification programs to demonstrate a level of green and the associated cost. The certification programs all establish a basis from which to determine if a material or method is deemed sustainable.

There are several sustainability trends unique to health care. Examples include providing access to the natural environment for

patients and staff; reducing toxic medical waste and its exposure to patients and staff; and incorporating sustainable practices into food delivery and the handling of associated waste.

A few health care designers and facility owners are leading the way in implementing new concepts that support more sustainable solutions. There are hospitals now operating with a variety of sustainable systems, which only a decade ago would have not even been considered as a philanthropic measure. Some of these facilities use natural ventilation, renewable energy systems, extensive daylighting, green roofs, ground-source and geothermal HVAC, new ideas on combined heat and power systems, LED lighting, displacement ventilation, and chilled beams, to name a few examples. These facilities are great resources for reducing the learning curve and bettering the ability to evaluate risks and costs for future projects.

12.2.2 Economic Viability and Considerations

With the cost of health care in the headlines on a regular basis, the economics of sustainability within the industry will be scrutinized more closely than ever. Advanced economic techniques beyond first cost and simple payback are needed to assist CEOs in making better-informed decisions involving more-integrated and complex systems. It is also critical that operation and maintenance be included in any economic analysis.

With health care costs facing great scrutiny, project teams must be prepared to make thorough and convincing economic justifications for potential sustainability measures. At this point, the arguments for many sustainable concepts are based largely upon qualitative information. For example, there is no research or data that correlates improving air quality with improved patient or staff outcomes. Project team members must be aware of evidence-based design (see Chapter 9) research efforts and other resources that may provide quantitative data for use in economic analyses. Consider presenting a qualitative approach in terms of how much improvement would be needed in staff retention/recruitment or patient satisfaction to justify the additional cost for a more sustainable solution. For energy conservation or improved efficiency, use a quantitative approach. Experience and expertise must be applied for the best results.

12.2.3 Life Cycle Cost

Life cycle cost (LCC) economics should be considered over simple payback (the traditional method of evaluating design options). A life cycle analysis shows the full impact of design decisions, considering fuel escalation costs, maintenance costs, replacement costs, and the value of investment dollars over time. Finding maintenance and service costs for use in the analysis will be challenging, especially for newer equipment/applications; therefore, care must be taken in evaluating new technology. Complex systems, such as combined heat and power plants with multiple inputs and outputs, when compared to grid-purchased sources, provide for complex life cycle cost equations that must consider the variability of fluctuating markets and the impacts of

greenhouse gas emissions. A new generation of LCC analysis should consider the cost of emission mitigation into a full lifetime analysis. A new metric of sustainability can include the investment cost per carbon dioxide equivalent (CO_2e) avoided per year or over the lifetime of a project.

In some cases, more sustainable solutions are less costly than traditional methods. Those solutions are easy to adopt. Evaluation of the complex interaction of architectural impacts on HVAC and lighting systems must consider the enhanced savings with integrated approaches. Solutions that increase cost will require an acceptable cost/benefit outcome acceptable to the health care organization, whether it comes from a dollar invested, climate change mitigation, or maintenance savings perspective. Quantifiable costs and benefits are first and foremost, including realistic maintenance and service costs over the life cycle.

12.3 ENERGY BENCHMARKING

Business trends over the past decade have focused on measured performance metrics. The driver is a desire to compare performance between facilities and/or against specific energy use targets. However, comparing energy use between hospitals in a relevant and meaningful way is complicated and not easily done. That should be easy to imagine when considering the numerous types of hospitals and clinics (see Chapter 9) and the variety of functions and services provided and their impact on energy use. Efforts are underway to improve the data reservoir that will support this need. This section presents some benchmarking background and data from a variety of sources. Those interested in benchmark information should investigate the sources to understand the data collection techniques before using any data for analysis or comparison.

There are two reasons to benchmark energy use: (1) for comparison to other facilities, and (2) for internal use to ensure optimized energy efficiency. Comparing energy use from facility to facility to demonstrate a competitive advantage is a great idea. In most cases, however, making a relevant comparison is impossible because of the many factors that impact energy use and the lack of an extensive database that has captured usage and normalizing factors. Nevertheless, benchmarking is essential to managing a facility's energy. Collecting the necessary data from month-to-month and year-to-year can provide an effective tool to ensure the proper and optimized operation of the energy use systems. Such data are also useful when looking at efficiency upgrades and measuring their impact. Figures 12-1 and 12-2 provide examples of energy use tracking data from a community hospital in the central United States.

The hospital implemented a number of changes in HVAC system operations and the resulting energy use reduction was monitored. Figure 12-2 shows a running 12-month comparison. This type of monitoring and tracking provides a simple way of ensuring that nothing

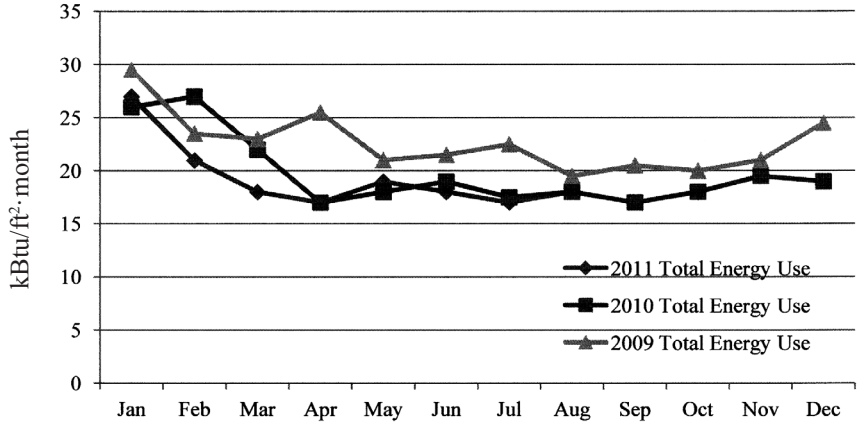

Figure 12-1 *Example of Energy Tracking Data*

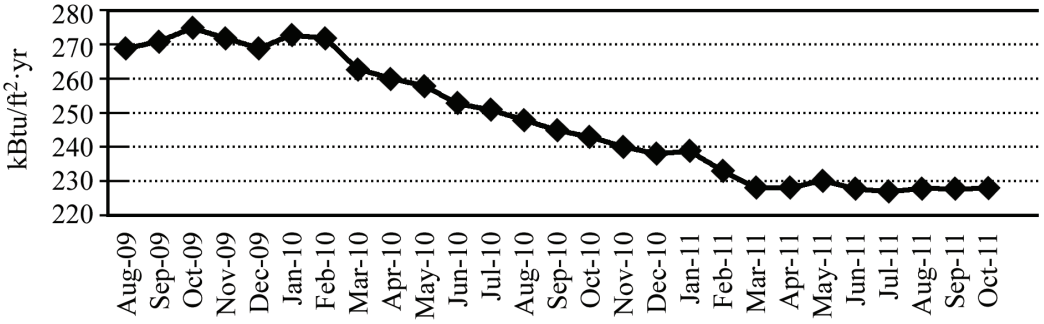

Figure 12-2 *Example of Energy Tracking Data*

has changed to adversely impact energy use. As facilities get larger and energy systems more complex (including, for example, central plants), then more effort should be spent in submetering and developing methods to validate proper operation. Organizations desiring to set up a benchmarking protocol or program will find a useful reference in *Hospital Energy Benchmarking Guidance* (LBNL 2009).

Another useful resource is a publication from the American Society for Healthcare Engineering (ASHE) titled *Health Care Facilities Operations and Maintenance Benchmarks* (ASHE 2010a). This report covers all areas of operation and presents utility costs and usage in a variety of ways, along with all data sources. Tables 12-1, 12-2, and 12-3 are examples of a few of the charts in the report; readers are encouraged to review the report for more detailed breakdowns and numerous groupings and sortings of data.

The most common energy benchmarking metric is the energy use index (EUI). EUI is the total annual energy use from all fuel sources divided by the gross floor area of the facility. Typical units are thousands of Btu per square foot, kBtu/ft^2·yr [kWh/m^2·yr]. EUI users must understand whether the energy is expressed on a site- or source-energy basis. Site energy is energy use as measured at the utility meters on the facility site; essentially, this is what appears on the bills the hospital

Table 12-1 *Average Utility Costs by Facility Type*

Facility Use	N	Total Utilities	Electricity	Fuel Oil #2	Natural Gas	Steam	Water	Sewer
AcuteCare	84	4.81 [51.78]	2.33 [25.08]	0.14 [1.51]	1.27 [13.67]	1.11 [11.95]	0.26 [2.80]	0.18 [1.94]
Critical Access	6	4.57 [49.19]	2.96 [31.86]	—	1.28 [13.78]	—	0.27 [2.91]	0.11 [1.18]
Medical Center	28	4.46 [48.01]	2.31 [24.87]	0.10 [1.08]	0.95 [10.23]	1.26 [13.56]	0.21 [2.26]	0.19 [2.05]
Rehabilitation Center	7	3.44 [37.03]	1.82 [19.59]	—	1.00 [10.76]	—	0.25 [2.69]	—

Source: Adapted from ASHE (2010a). **Note:** costs are expressed in \$/gross ft^2 [\$/gross m^2].

pays. Source energy takes into account the amount of primary fuel that is required to deliver the various forms of energy to the site. The key distinction is between electricity and primary fuels (such as natural gas, propane, coal, or fuel oil). Every unit of electrical energy delivered to a site typically requires roughly three units of primary fuel (at the power plant or source of electrical generation) for generation and delivery. The precise amount varies with the sources used by any particular utility.

The U.S. Environmental Protection Agency's (EPA) ENERGY STAR® program is another energy benchmarking resource. The EPA first used data collected in the 2010 ASHE survey for the benchmarking of health care building types. Previous benchmark data were taken from the Electric Power Research Institute's (EPRI) 1997 Energy Benchmarking Survey. In 2011, ENERGY STAR moved to a new baseline building scale. The more current data (from 191 buildings) will be used as the baseline for hospitals in an effort to make the ratings more meaningful and accurate. Each parameter in each survey was analyzed to determine which showed the most correlation with hospital energy use and a new equation for predicting energy use was developed. Two parameters that showed a high correlation to energy use were added: (1) number of workers (full-time equivalent staff) and (2) number of MRI machines. The licensed beds parameter was replaced by beds set up and staffed for use. Analysis showed that cooling degree days have a much higher correlation to energy use than heating degree days; consequently, EPA will base its new hospital model on cooling degree days only. Other parameters that were shown to have no correlation and will no longer be used include number of floors and on-site tertiary care. Unfortunately, there are no meaningful ratings for facilities with outpatient surgery. The requirement, in these facilities, that the HVAC system provide 24 h/7 day air pressurization and substantial air exchange rates leads to reheat energy use that results in outpatient surgery areas using 3 to 4 times the energy of a typical diagnostic and treatment suite.

Table 12-2 *Energy Use Index Distribution (Site-Based)*

Percentile	Electricity, kBtu/gross ft² [MJ/gross m²]	Gas, kBtu/gross ft² [MJ/gross m²]
99	224 [2545]	355 [4033]
95	192 [2181]	213 [2420]
90	157 [1784]	178 [2022]
75	118 [1341]	167 [1897]
50	94 [1068]	124 [1409]
25	74 [841]	64 [727]
10	48 [545]	6 [68]
5	9 [102]	2 [22.7]
1	0.9 [10.2]	0.1 [1.1]
Mean	98	114
N =	121	112

Source: Adapted from ASHE (2010a).

Table 12-3 *Energy Use Index by Facility Type and Climate Zone*

Institution Type	N	Electricity, kBtu/gross ft² [MJ/gross m²]	Gas, kBtu/gross ft² [MJ/gross m²]
Acute Care	82	106 [1204]	119 [1352]
Critical Access	5	76 [863]	165 [1874]
Medical Center	28	85 [966]	91 [1034]
U.S. Climate Zone			
1 (coldest)	20	87 [988]	144 [1636]
2	29	79 [897]	88 [1000]
3	18	102 [1159]	119 [1352]
4	38	115 [1306]	127 [1443]
5 (warmest)	10	76 [863]	66 [750]

Source: Adapted from ASHE (2010a).

So far, these benchmarking resources only provide information at the whole-building level, not at the system level. Little information is currently available at the system level. The National Renewable Energy Laboratory is conducting a research project to collect such information at several hospital sites; the results should be published upon completion. One detailed study, *Targeting 100! Energy Use and Model Calibration Study: Legacy Salmon Creek Medical Center Vancouver, Washington* was published by the University of Washington (IDL 2011). The energy use breakdowns from this study, shown in Figure 12-3 and Table 12-4, were based on utility data provided by the hospital, adjusted in conjunction with power monitoring and calibrated model outputs.

Another resource for energy benchmarking and, more importantly, energy-efficient design, is the A*dvanced Energy Design Guide for Large Hospitals* (AEDG) (ASHRAE 2012). This design guide provides the means and methods to reduce hospital energy use by 50%. As with many elements of sustainable design, it takes an integrated team approach to do so in a cost-effective manner.

Figure 12-4, developed in support of the AEDG, shows energy use by climate zone for a typical hospital, based on actual energy use and calibrated modeling.

12.4 COMMISSIONING

The commissioning process is useful in helping the design and construction aspects of a project deliver what is expected. Commissioning is viewed as a best-practice measure that assists the project team and facility owner in dealing with the common complexities and features of a health care facility. This chapter does not restate these accepted practices; they are widely used and published. ASHE's *Health Facility Commissioning Guidelines* is an excellent commissioning reference specific to health care facilities (ASHE 2010b). The ASHE guidelines include a section on establishing commissioning scope and a table that lists various building subsystems, many of which are unique to health care facilities. The guideline covers all types of systems, not just those that are energy related, including life safety systems such as stairwell pressurization; specialty exhaust; operating room/anesthetizing location ventilation; AII and PE air pressurization; sterile-compounding pharmacy rooms; medical-gas systems; and specialty refrigeration systems (both food service and clinical).

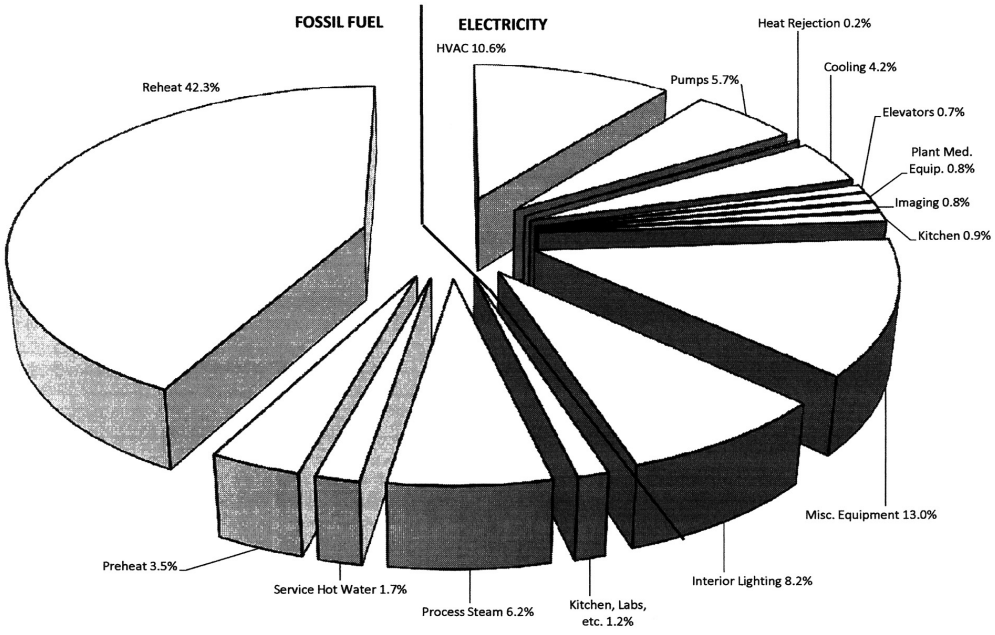

Figure 12-3 *Energy Use Distribution*

Source: Adapted from IDL (2011).

12.5 ENERGY MODELING

High-profile reports and, in some cases, legal action have resulted from building owners' dissatisfaction with buildings that were designed to be energy efficient but did not perform as the energy models predicted. These situations resulted partly from misconceptions of what energy modeling tools were designed to do, current industry practices, what various standards require to be modeled, and/or what is a "regulated" load. Building owners typically expect that the actual on-site energy use should be in line with energy model predictions. An effort needs to be made to educate clients, owners, and design teams about the purpose of energy models, their benefits and limitations, and which critical components need to be well defined to get accurate results. A comparison of energy model design predictions to actual energy use must take into account any design changes made during construction (including commissioning adjustments), actual building occupancy or use during the comparative time period, and the actual weather versus historical average weather used for simulation. Comparing actual to simulated performance in a hospital setting is

Table 12-4 *Documented Annual Energy Use Summary*

Legacy Salmon Creek Medical Center – 2010								
Fuel	**End Use**	**EUI, kBtu/ft²·yr [kWh/m²·yr]**	**10⁶ Btu [kW]**	**%**	**Therms [MJ]**	**kWh**	**Avg. kW**	**Avg. W/ft² [W/m²]**
Natural Gas	Reheat	90.4 [285.2]	42,112 [12 343 027]	42.2	421,115 [44 427 633]			
	Preheat	7.6 [24.0]	3533 [1 035 522]	3.5	35,334 [3 727 737]			
	Service Hot Water	3.7 [11.7]	1705 [499 736]	1.7	17,053 [1 799 092]			
	Process Steam	13.3 [42.0]	6187 [1 813 410]	6.2	61,871 [6 527 391]			
	Kitchen, Labs, etc.	2.6 [8.2]	1229 [360 220]	1.2	12,291 [1 296 701]			
Electricity	Interior Lighting	17.5 [55.2]	8146 [2 387 593]	8.2		2,386,815	272	0.59 [6.35]
	Misc. Equipment	27.9 [88.0]	12,981 [3 804 731]	13.0		3,803,263	434	0.93 [10.01]
	Kitchen	1.9 [6.0]	891.2 [261 210]	0.9		261,105	30	0.06 [0.65]
	Imaging	1.7 [5.4]	782.1 [229 234]	0.8		229,167	26	0.06 [0.65]
	Plant Med. Equip.	1.8 [5.7]	829.2 [243 039]	0.8		242,958	28	0.06 [0.65]
	Elevators	1.5 [4.7]	706.9 [207 192]	0.7		207,132	24	0.05 [0.54]
	Cooling	9.1 [28.7]	4238 [1 242 158]	4.2		1,241,746	142	0.30 [3.23]
	Heat Rejection	0.5 [1.6]	228.5 [66 973]	0.2		66,950	8	0.02 [0.22]
	Pumps	12.2 [38.5]	5675 [1 663 343]	5.7		1,662,877	190	0.41 [4.41]
	HVAC Fans	22.8 [71.9]	10,610 [3 109 791]	10.6		3,108,591	355	0.76 [8.18]
Total		**214.4 [676.4]**	**99,854 [29 267 207]**	**100**	**547,665 [57 778 658]**	**13,210,605**	**1508**	**3.24 [34.88]**

Source: Adapted from IDL (2011).

compounded by varying occupancies and/or natural disaster responses (such as the 2009 H1N1 pandemic), high concentrations of intermittently-used medical equipment (such as MRI and X-ray machines, etc.), and whether kitchen and laundry services are integrated into the design. High-energy-intensity device/equipment use fluctuates with occupancy.

Typically, there are four traditional uses for modeling results that take into account architectural, mechanical, and electrical loads, in addition to process energy. The first is a code compliance model that can be used to compare the architectural, mechanical, and lighting designs against a prescribed benchmark. This model may not involve an accurate accounting of "unregulated" loads, which usually consist of medical equipment, food service equipment, process refrigeration, and other large energy users that are normally exempt from energy codes. These models are, at best, a benchmark for code compliance and perhaps utility incentive calculations; they cannot be relied on to produce an accurate prediction of on-site energy use. The second use is in the context of LEED® or other green-building rating systems, that requires a higher-level accounting of process loads, and allows for but does not require the use of actual building use schedules. This type of modeling effort produces further-refined results, with careful attention to process load accounting and detailed schedules of building operation. Such a well-developed design model can be used to perform life cycle cost analyses that allow the design team to investigate design alternatives and provide feedback on energy efficiency measures. The final two types of models are created in preparation for the measurement and verification (M&V) process: a pre-M&V model and a post-M&V model. M&V energy models should focus on actual building operations,

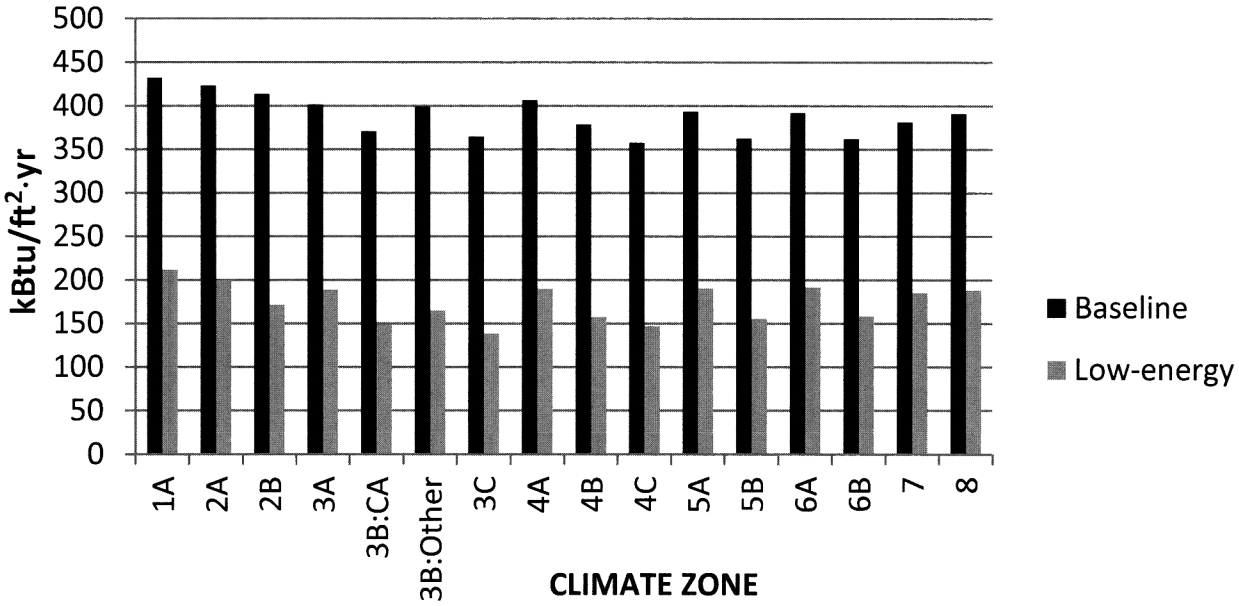

Figure 12-4 *Typical Hospital Energy Use by Climate Zone*
Source: Adapted from NREL (2010).

including accurate simulations of building warm-up and cooldown periods; zone temperature setpoints, detailed occupancy schedules that define lighting and plug-load usage; updated information from as-built drawings that include changes made during construction; and, finally, current utility charges to enable cost comparisons. After the prescribed year of measurement of actual energy use (following substantial occupancy), this M&V model can be updated to include comparative-year weather data and actual occupancy patterns. Then, a true benchmark of performance can be finalized. The M&V-quality model should be the only model used to compare simulation results with actual on-site energy use.

If modeling results are going to be used as an estimate for actual energy use, then M&V-level simulations should be prescribed by the design team up front to manage the expectations of the clients. The right tools should be selected for the building type as well. Some simulation tools cannot simulate the effects of complex mechanical systems, whereas others can. It is very important to involve experts who know the tools, have a deep understanding of the standards, and know how to apply them to the specific project.

12.6 ENERGY EFFICIENCY

A wide range of energy efficiency and conservation strategies could apply to a new or existing health care facility. Project teams, along with the building owner and operations staff, should work closely in developing a clear understanding of the project energy reduction goals. The project team may need to assist the building owner in understanding which resources are needed to reach those goals, as well as the methods needed to test or measure the results. Teams can use the available energy-benchmarking data to help establish realistic goals and also explore where the opportunity to save the most energy lies.

The extent of analysis needed to compare energy efficiency alternatives varies with the complexity of the facility and the applications being considered. A potential sorting strategy starts with simple, passive strategies first, and then works toward the more complex and expensive ones. Passive strategies include improving the building envelope or duct design. After looking at passive strategies, consider implementing proven technology strategies. The building owner needs to have a good understanding of the various technology applications, their maintenance needs, and their expected reliability (to ensure alignment with the downtime-sensitivity of the patient care area being served). The HVAC designer should help the building owner understand the level of maintenance staffing and competence that a proposed system will require to realize the intended energy reduction. The complete cost of maintenance for an energy-reduction strategy should be included in any economic analysis of alternatives. As the strategies begin to include newer and/or more complex equipment and control strategies, it is imperative that the building operations staff understand what is required to realize the associated

energy reduction. It is good practice to determine which variables can be measured/monitored and to develop a program identifying how appropriate parameters are going to be measured, who is going to analyze the data, and how the results are going to be communicated. Designing energy-saving features is only step one in a multiple-step process to realize the savings. Building owners and HVAC designers should consider developing a strategic energy management plan. A template plan for a hospital can be found on the BetterBricks website (BetterBricks 2012).

Means and methods for reducing or conserving the energy used in buildings is a vast, constantly evolving subject area. Currently, ASHRAE has several publications, including its series of Advanced Energy Design Guides (AEDGs), that are focused on energy savings, with several specific to health care applications:

- *Advanced Energy Design Guide for Small Hospitals and Healthcare Facilities: 30% Energy Savings* (ASHRAE 2010c)
- *Advanced Energy Design Guide for Large Hospitals: 50% Energy Savings* (ASHRAE 2012*)*
- *ASHRAE GreenGuide* (ASHRAE 2010d)
- ASHRAE Standard 189.3*, Design, Construction and Operation of Sustainable High Performance Health Care Facilities* (in development)
- *High Performing Buildings,* an ASHRAE magazine

In addition, NREL produced an AEGD support document: Technical Report #TP-550-47867, *Large Hospital 50% Energy Savings: Technical Support Document* (NREL 2010).

12.7 FINANCIAL INCENTIVES FOR ENERGY EFFICIENCY

Project teams should be aware of the financial incentives available to business owners interested in improving energy efficiency or reducing energy use from fossil fuel sources. Financial incentives come in many forms, such as direct compensation for alternatives, or tax credits that can be used at a later date. The funding can come from a variety of sources, including utility providers; local, state, and federal agencies; and others. Financial incentives are typically in the form of rebates, grants, low-interest loans, and/or tax incentives. Construction projects with incentives may include building projects (both new and renovation), on-site renewable energy (solar, wind, geothermal), combined heat and power plants, fuel cells, and mircoturbines.

The assistance programs and their funding vary greatly from state to state. Some utility companies and states have no financial assistance programs, whereas others have hundreds of thousands of dollars available. Some states require utility companies to support an independent energy consortium that creates and administers financial assistance for energy efficiency and renewable programs (e.g., Focus on Energy in Wisconsin). Some federal tax incentives are available for all locations.

These tax incentives are either a tax deduction or a tax credit that is applied in the tax year the project becomes operational. Facility projects associated with a nonprofit organization are typically not eligible for tax incentives. In such cases, they are sometimes available to the project design organization. In some locations, incentive funding can come from multiple sources; for example, a utility company provides rebates and the state/federal government provides tax incentives. In these cases, ensure that each program will allow additional funding from other sources.

Financial assistance from a utility or energy consortium usually comes in the form of rebates, grants, or low-interest loans. Rebates are common in building construction and are typically funded on a prescriptive, per-unit basis. A common example is a rebate per high-efficiency light fixture installed. These programs do not typically require any preinstallation communication with the agency providing the rebate. Grants provide a higher level of funding and are more complex. The method for determining the level of funding varies. In general, the amount of the incentive is proportional to the estimated energy savings. A grant-funding agency will likely require an agreement with the design organization and business owner. The funding agency will offer and sometimes require the ability to provide input regarding energy-saving alternatives and be involved in estimating the energy savings. They will typically require some form of verification that the measures were designed, installed, and are operating per the agreement. Care needs to be exercised with respect to understanding the agency resources to ensure that incentive funding is available at the completion of the project. There have been cases in which a funding source has been depleted or discontinued during the construction phase.

Various resources can help a project team locate available incentives. Electric and gas utility providers are a starting point; find out what incentive programs they provide. Utilities are also likely to know about other funding sources. Check the Database of State Incentives for Renewables and Efficiency (DSIRE™ 2012). This is a comprehensive resource on federal, state, and local incentives and policies related to renewable and energy efficiency. For tax incentives, check the Tax Incentive Assistance Project (TIAP 2012). For more information on commercial building tax incentives, check the Commercial Building Tax Deduction Coalition website and its Frequently Asked Questions section (NEMA 2012).

12.8 INDOOR ENVIRONMENTAL QUALITY

12.8.1 Overview

It is easy to understand that indoor environment quality (IEQ) is of significant concern and interest for health care organizations. The IEQ of a building should support the mission of patient care. Indoor environmental quality is likely to impact staff comfort and satisfaction and could indirectly impact the quality of patient care the staff provides. New practices in design, products, materials, and construction practices, developed over the past 20 years, can improve IEQ. The elements of

IEQ presented in this section include a review of designing health care spaces to ANSI/ASHRAE Standard 55-2010, acoustic design considerations for background noise, and design considerations and construction practices to improve indoor air quality. Subjects affecting IEQ that are not covered here include lighting controllability, daylighting, and views of the outdoors.

12.8.2 Applying ANSI/ASHRAE Standard 55-2010 to Health Care Areas

ANSI/ASHRAE Standard 55-2010, *Thermal Environmental Conditions for Human Occupancy,* defines thermal indoor conditions that a majority of occupants will find comfortable (ASHRAE 2010a). In hospitals and medical office buildings, occupants often have a relatively wide variation in the amount of clothing worn. Doctors may wear multiple layers, while patients may only wear a hospital gown. Therefore, it is important to consider all types of clothing levels for occupants of a space and strive to keep the space temperature comfortable for as many occupants as possible throughout the day. In some situations, such as an operating room, physician comfort is a key design consideration; in others, such as in a recovery area or patient room, patient comfort is the key driver. Each space can be analyzed and optimal temperatures calculated based on occupant loads as outlined in ANSI/ASHRAE Standard 55-2010.

The first step to determine operative temperature requirements is to find the average clothing insulation value, expressed as "clo" units, for occupants in each room type. To find the clothing insulation value for each person, we can use Appendix B and Table B1 or Table B2 of ANSI/ASHRAE Standard 55-2010. Clothing values for each person in a room cannot simply be averaged; the average clothing value in the room at any given time is important. For the exam room example shown in Table 12-5, assume the patient is in the space at all times, the nurse is generally only in the space for one quarter of the time, and the doctor one quarter of the time (and rarely are the nurse and doctor in the room together). In this way, the average clothing insulation values can be estimated so that, at any random time during the day, the estimate is as close as possible to the average clothing insulation values for people in the room.

Table 12-5 *Average Clothing Insulation Values*

Occupant	Clothing Insulation Value, clo	1 h, clo				Average, clo			
		:00	:15	:30	:45				
Doctor	1	—	1	—	—	—	1	—	—
Nurse	0.51	0.51	—	—	—	0.5	—	—	—
Patient	0.67	0.67	0.67	0.67	0.67	0.7	0.7	0.7	0.7
Average per Time Segment		0.59	0.835	0.67	0.67	0.69			

This analysis can be repeated for each of the four seasons in each room type to be analyzed. The process leads to the results shown in Table 12-6.

Average metabolic rates also need to be considered. An occupant's metabolic activity can be characterized in terms of heat production per unit area of skin. For a resting person, this is about 18.4 Btu/h·ft^2 [50 kcal/h·m^2] and is called 1 met. The table in Appendix A of ANSI/ASHRAE Standard 55-2010 can be used to find metabolic rate values for each type of occupant, and these can be averaged (see Table 12-7) in the same way as the clothing insulation values.

If a space has different activity levels based on the seasons (or during portions of the year), multiple analyses of metabolic rate values may be appropriate, but in most cases one is sufficient.

Section 5.2.1.1 of ANSI/ASHRAE Standard 55-2010 provides a chart of acceptable operative temperature and humidity for spaces when clo is between 0.5 and 1.0 and met is between 1.0 and 1.3, which is the case for many space types. Procedures are given to deal with acceptable operative temperature and humidity for spaces with different clo and met values if necessary, and software programs are available to calculate comfort ranges.

Because modern systems are capable of operating across a range of temperatures and humidities based upon their setup, it is appropriate to overlay a system operating range to document compliance with ANSI/ASHRAE Standard 55-2010. Figure 12-5 is an enlargement of the ASHRAE comfort zone overlaid on a system operating range to demonstrate system compliance for space temperature and humidity.

Table 12-6 *Seasonal Average Clothing Insulation Values*

Room	Average per Season, clo			
	Spring	Summer	Fall	Winter
Exam	0.69	0.55	0.69	0.90

Table 12-7 *Average Metabolic Rate Values*

Occupant	Metabolic Rate, met	1 h, met				Average, met			
		:00	:15	:30	:45				
Doctor	1.2		1.2				1.2		
Nurse	1.7	1.7				1.7			
Patient	1	1	1	1	1	1	1	1	1
Average per Time Segment		1.35	1.1	1	1	1.11			

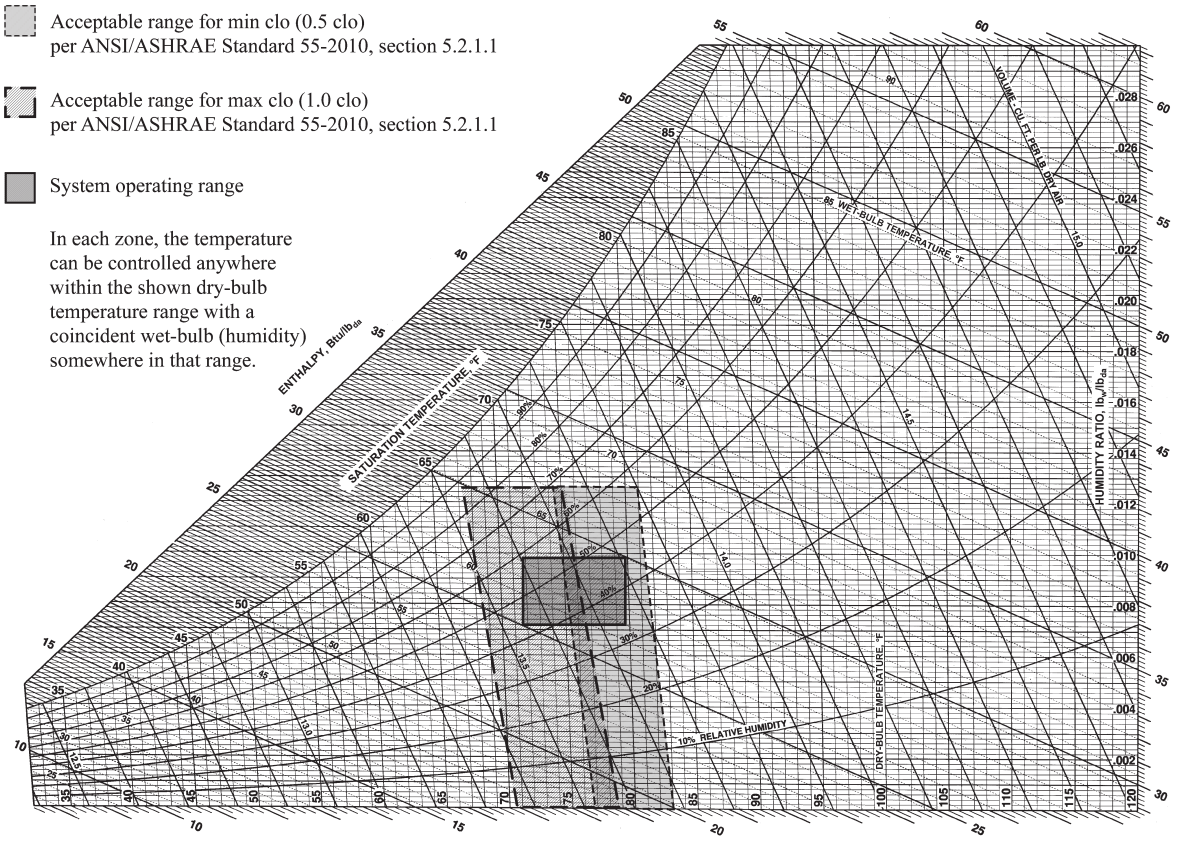

Figure 12-5 *Comparison of System Operating Range to Comfort Zone*

Table 12-8 *Percentage Dissatisfied (PD) Because of Local Discomfort from Draft or Other Sources*

Draft, PD	Vertical Air Temperature Difference, PD	Warm or Cool Floors, PD	Radiant Asymmetry, PD
<20%	<5%	<10%	<5%

Source: ANSI/ASHRAE Standard 55-2010.

It is generally easy to keep spaces comfortable for a range of clothing levels and metabolic values as long as the HVAC system can operate across a wide range of temperatures. However, it is important to look at potential sources of thermal discomfort, which are presented in Table 12-8. The first consideration is radiant temperature asymmetry. For example, based on an energy model of a space, on a design day the plenum temperature in a room located below a roof is 76.6°F [24.8°C]. This is only a 1.6°F [0.76°C] difference from the space temperature, leading to less than 1% PD, based on the data in Figure 12-6.

Considering the walls, a steady-state analysis of winter and summer design conditions leads to the situation shown in Figure 12-7. Both summer and winter conditions have less than a 6°F [2.8°C] difference from the space temperature, leading to less than 1% PD based on Figure 12-6.

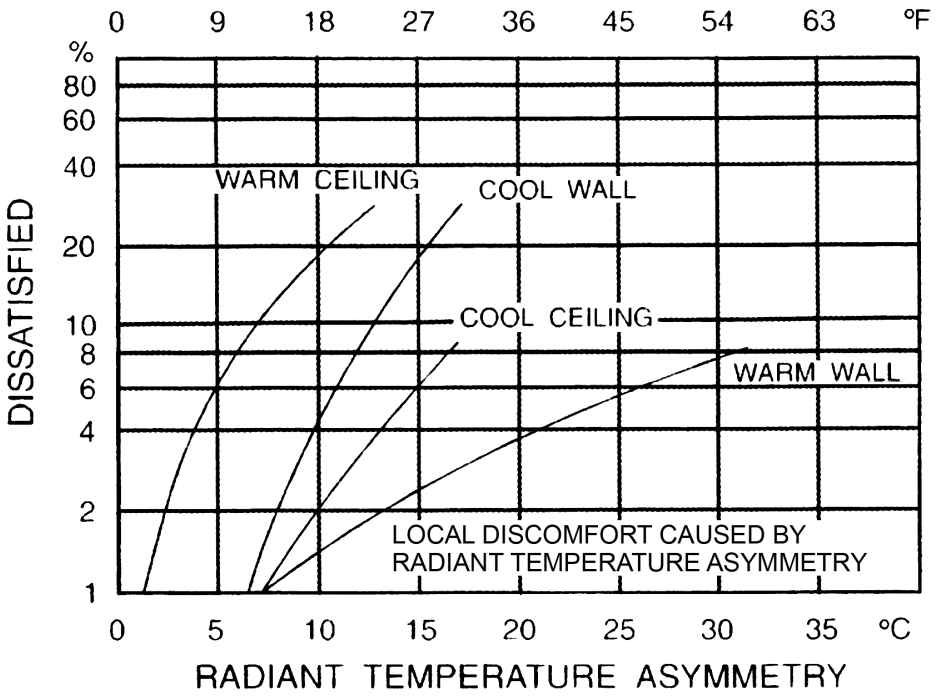

Figure 12-6 *Local Thermal Discomfort Caused by Radiant Asymmetry*
Source: ANSI/ASHRAE Standard 55-2010.

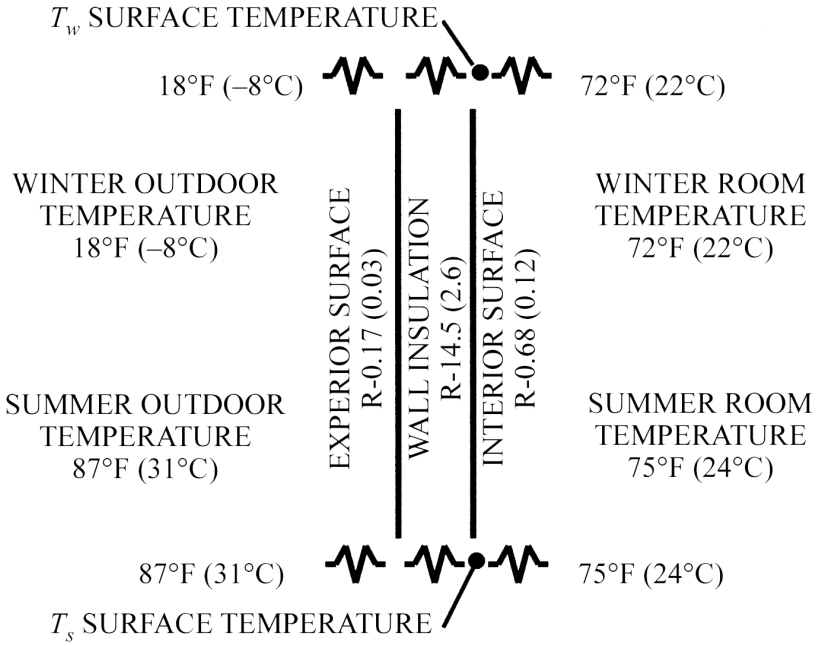

Figure 12-7 *Analysis of Wall Surface Temperatures Relative to Thermal Comfort*

In I-P units:

$$Q_w = (T_1 - T_2)/R_{total} = 54/15.35 = 3.518$$

$$3.518 = (72 - T_w)/0.68$$

$$T_w = 66.8°F$$

$$Q_s = (T_1 - T_2)/R_{total} = 12/15.35 = 0.782$$

$$0.782 = (75 - T_s)/0.68$$

$$T_s = 74.5°F$$

In SI units:

$$Q_w = (T_1 - T_2)/R_{total} = 30/2.75 = 10.91$$

$$10.91 = (22 - T_w)/0.12$$

$$T_w = 19.3°C$$

$$Q_s = (T_1 - T_2)/R_{total} = 7/2.75 = 2.55$$

$$2.55 = (24 - T_s)/0.12$$

$$T_s = 23.6°C$$

The next discomfort concern is vertical air temperature difference. Based on generic project conditions, less than a 5°F [2.4°C] temperature difference is expected between the head and the feet of occupants, and therefore less than 5% PD is expected, based on Figure 12-8. This vertical temperature difference analysis assumed a maximum ceiling temperature, minimum floor temperature, and changes in wall temperatures, and was based on the diffuser layout and air change rates with selected VAV minimums and supply air temperature.

Adjustable vanes (as in Figure 12-9) in a standard supply diffuser or adjustable deflection in other diffusers may allow occupants to manipulate the velocity of air in specific areas of the space (Figure 12-10) so turbulence can be created to mix room air.

The effect of floor surface temperature on discomfort must also be considered. For example, using steady-state analysis under assumed worst-case winter design conditions leads to the results shown in Figure 12-11. This winter worst-case scenario shows the floor with less than a 2°F [0.9°C] difference from the space temperature, leading to less than 10% PD, based on Figure 12-12 (valid for a range of floor surface temperatures between 66.2°F and 84.2°F [19°C and 29°C]).

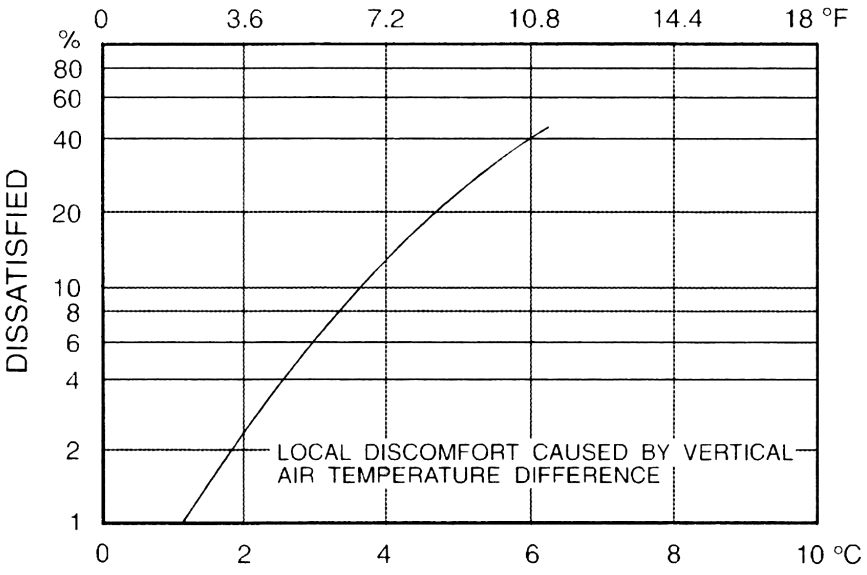

Figure 12-8 *Local Thermal Discomfort Cased by Vertical Temperature Differences*

Source: ANSI/ASHRAE Standard 55-2010.

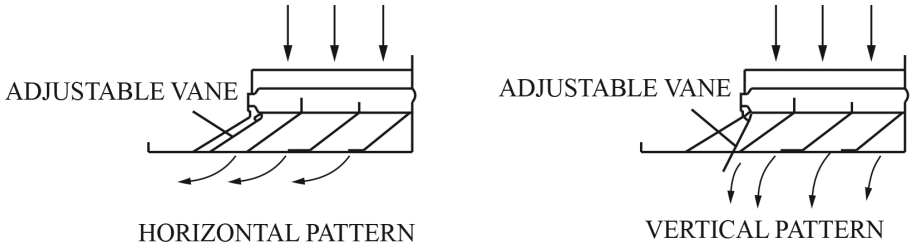

Figure 12-9 *Adjustable Supply Air Diffuser*

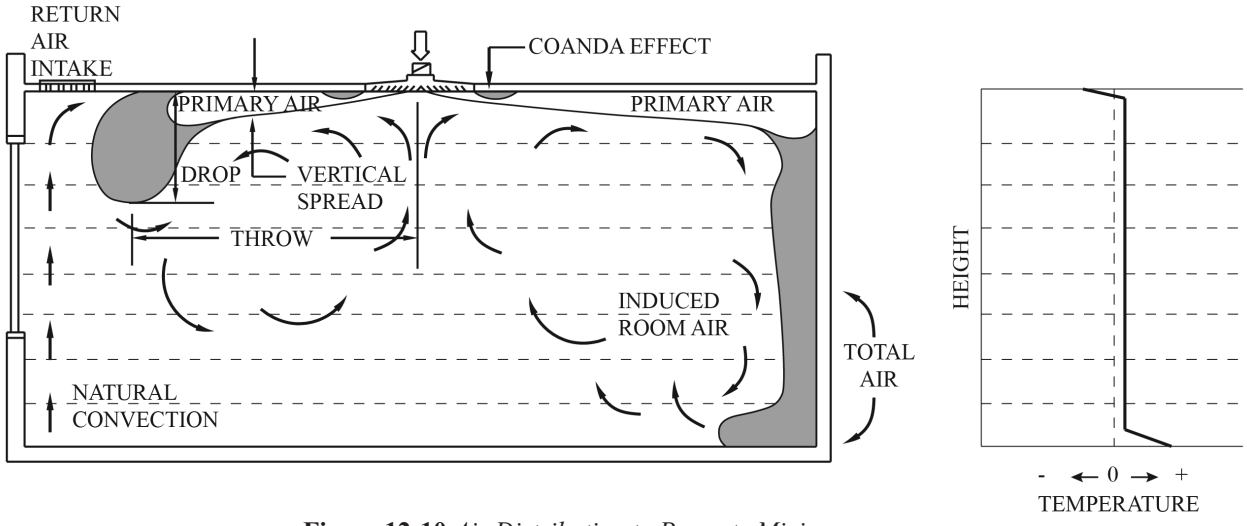

Figure 12-10 *Air Distribution to Promote Mixing*

In I-P units:

$$Q = (T_1 - T_2)/R_{total} = 54/31.17 = 1.732$$

$$1.732 = (72 - X)/0.92$$

$$X = 70.4°F$$

In SI units:

$$Q = (T_1 - T_2)/R_{total} = 54/31.17 = 1.732$$

$$1.732 = (72 - X)/0.92$$

$$X = 70.4°F$$

The final discomfort consideration is drafts, which can be evaluated using the following calculations (see Figure 12-13):

$$PD = [(93.2 - t_a) \times (v - 10)^{0.62}] \times (0.00004 \times v \times Tu + 0.066)$$

where

PD = predicted percentage of occupants dissatisfied because of draft, %
t_a = local air temperature, °F [°C]
v = local mean air speed based on *va,* the mean velocity, fpm [m/s]
Tu = local turbulence intensity, %

In summer:

(I-P units)

$$[(93.2 - 75.0) \times (40 - 10)^{0.62}] \times (0.00004 \times 40 \times 0.35 + 0.066) = 10\%$$

(SI units)

$$[(34.0 - 23.9) \times (0.2 - 0.05)^{0.62}] \times (0.37 \times 0.2 \times 0.35 + 3.14) = 10\%$$

In winter:

(I-P units)

$$[(93.2 - 72.0) \times (40 - 10)^{0.62}] \times (0.00004 \times 40 \times 0.35 + 0.066) = 11.6\%$$

(SI units)

$$[(34.0 - 22.2) \times (0.2 - 0.05)^{0.62}] \times (0.37 \times 0.2 \times 0.35 + 3.14) = 11.6\%$$

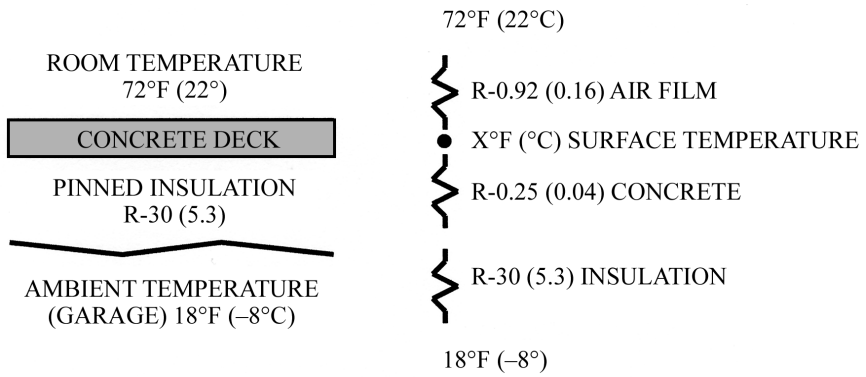

Figure 12-11 *Analysis of Floor Surface Temperatures Relative to Thermal Comfort*

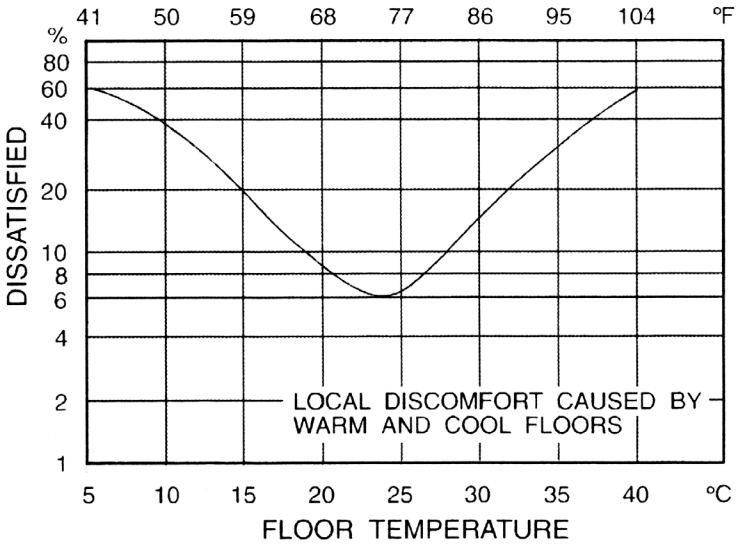

Figure 12-12 *Local Thermal Discomfort Caused by Warm and Cool Floors*

Source: ANSI/ASHRAE Standard 55-2010.

Expected velocities are 40 fpm [0.2 m/s] or less in the region of the occupant's head. Velocities of 40 fpm [0.2 m/s] lead to less than 12% PD based on Figure 12-13. Diffusers with adjustable deflection are often used to allow occupants to manipulate the velocity of air in specific areas of a space. Diffusers flush-mounted on the ceiling can help to effectively spread cool air into the space without draft.

12.8.3 Acoustic Design in Health Care

Acoustical conditions in health care facilities are getting more attention as a result of evidence-based design research that connects sound and speech privacy to patient safety and healing, as well as a lowering of staff fatigue. Those findings have resulted in regulations and codes that are setting sound level requirements aimed at improving the acoustical environment in health care facilities. There are numerous accounts and evidence-based design studies showing how sound and speech intelligibility support positive patient and staff outcomes. A good bibliography on the subject can be found in CISCA (2010).

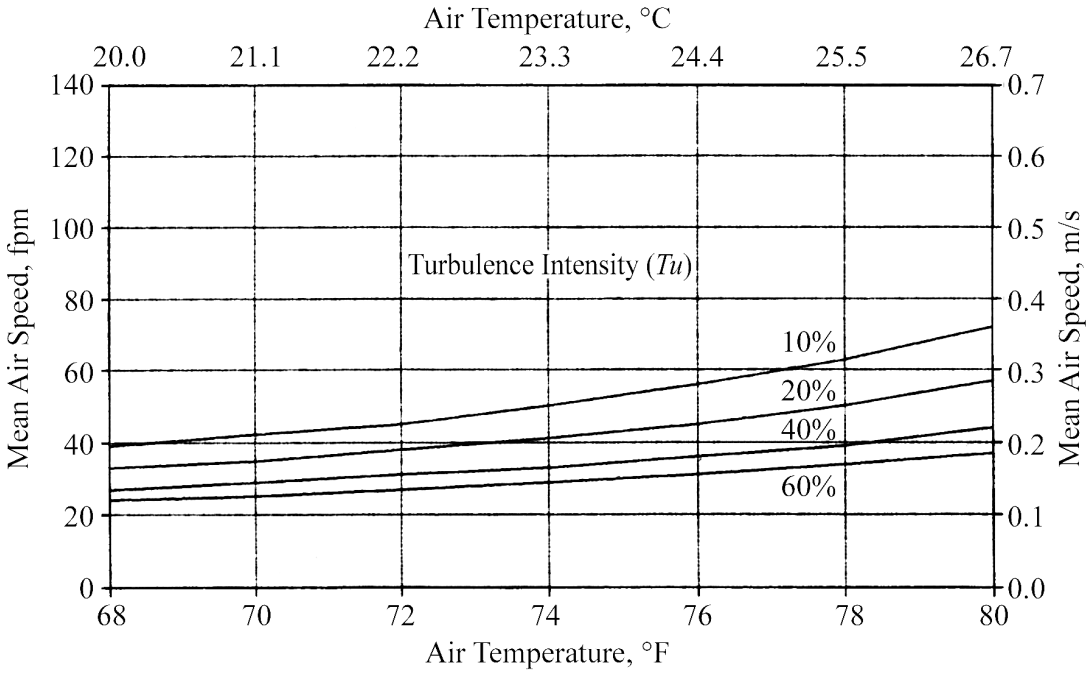

Figure 12-13 *Allowable Mean Air Speed as Function of Air Temperature and Turbulence Intensity*

HVAC designers also need to be familiar with the regulatory requirements included in the Health Insurance Portability and Accountability Act (HIPAA), initiated by the U.S. Department of Health and Human Services (DHHS). HIPAA requires that health care providers in the United States provide privacy for patient health information (e.g., medication, symptoms, health conditions) in electronic, written, and oral formats. The purpose is to prevent intentional or unintentional privacy breaches. HIPAA privacy standards apply to both new construction and renovations for all types of health care organizations, including pharmacies, physicians' offices, and hospitals.

In 2005, the Facility Guidelines Institute (FGI) commissioned the Health Care Acoustics Working Group, Acoustics Research Council (ARC), to develop a set of minimum design recommendations to help achieve acceptable acoustical environments and privacy conditions in health care facilities. That effort resulted in the 2010 publication of *Sound & Vibration: Design Guidelines for Health Care Facilities* (ARC 2010). This is the support document for the acoustic and vibration requirements in the 2010 FGI *Guidelines* (FGI 2010). The 2010 FGI *Guidelines* include requirements for both interior and exterior sound, as well as vibration. Acoustical conditions are generally found to be acceptable when all of the sounds are compatible with the intended uses of a space. Acceptable acoustics can be achieved in a number of ways: using sound-absorbing room finishes; exterior and interior wall/floor/ceiling constructions that block sound transmission; and by controlling mechanical equipment sound and vibration. The most

Table 12-9 *FGI Limits for Background Noise*

Room Type	NC/RC(N)	dBA
Patient rooms	30 to 40	35 to 45
Multiple occupant patient care areas	35 to 45	40 to 50
NICU	25 to 35	30 to 40
Operating rooms	35 to 45	40 to 50
Corridors and public spaces	35 to 45	40 to 50
Testing/research lab, minimal speech	45 to 55	50 to 60
Research lab, extensive speech	40 to 50	45 to 55
Group teaching lab	35 to 45	40 to 50
Doctor's offices, exam rooms	30 to 40	35 to 45
Conference rooms	25 to 35	30 to 40
Teleconferencing rooms	25 (max)	30
Auditoriums, large lecture rooms	25 to 30	30 to 35

Source: FGI (2010). NC = noise criterion RC(N) = room criterion

practical means of controlling mechanical sound will generally include a combination of approaches: selecting equipment with specific sound-generation criteria; providing sound and vibration isolation; and using sound-absorbing/blocking supports and/or enclosures. Sound masking is also considered a reasonable approach to speech privacy and acoustical comfort.

The FGI requirements are new and will impact the design of many common architectural wall, floor, and ceiling assemblies as well as the selection and installation of mechanical equipment. Project budgets may likely need to be increased to achieve these requirements. Designers will be challenged to meet the requirements in the most cost-effective ways because of national and industry-wide pressure to reduce health care costs. "Acceptable" acoustics is a complicated phenomenon, because it involves human subjectivity and variability. Acoustical acceptance is as variable as thermal comfort, because sound quality involves so many different elements. Designers should not have the expectation that all occupants will find room noise acceptable even if these guideline requirements are met. On the other hand, there will likely be rooms that fail to meet the requirements but generate no complaints. This has been an issue with sound performance metrics up to this point.

The HVAC designer will likely need to lead the project team in achieving the FGI *Guidelines* room noise level requirements. Background noise level, assuming no occupants and without medical equipment operating, is to comply with the levels in Table 12-9. The range of values represents the *minimum* and *maximum* recommended NC (noise criterion) or RC (room criterion) levels.

An appendix in FGI *Guidelines* calls for operating rooms to be NC/RC(N)/RNC 35 to 45 (40 to 50 dBA) and states that dealing with the noise from the required ventilation airflow may require "extraordinary" system design. The *Guidelines* state that sound levels are to be measured using ANSI standards and that one rating approach (NC, RC(N), RNC, or dBA) be chosen and used consistently. Refer to *Sound & Vibration: Design Guidelines for Health Care Facilities* for details regarding acoustics in NICU areas. Also be aware of site exterior noise requirements in the FGI *Guidelines* that a chiller or other HVAC equipment may need to meet.

Design professionals will need to work with facility owners and health care staff to understand these complex acoustical considerations and balance expectations with costs for the various means of acoustical control. Set realistic expectations and understand that meeting these guidelines will not necessarily make all spaces acceptable to all occupants. Also determine the responsibility of the design and construction team for spaces that do not meet these requirements but that occupants find acceptable.

Design Considerations for Indoor Air Quality

Designing to provide indoor air quality in health care facilities includes meeting code minimums for air filtration and the amount of outdoor air to be provided in the occupied areas. Typically a facility will be required to follow either ANSI/ASHRAE Standard 62.1-2010 (ASHRAE 2010b) or ANSI/ASHRAE/ASHE Standard 170-2008 (ASHRAE 2008). In some states, the health department will have its own specific requirements. The applicable standard depends upon the type of facility. Hospitals and outpatient surgery will typically be required follow ANSI/ASHRAE/ASHE Standard 170-2008, whereas many medical office buildings and other ambulatory facilities will follow ANSI/ASHRAE Standard 62.1-2010. Work with the building owner and AHJ to determine minimum requirements and consider exceeding the minimums for improved air quality.

Project teams considering exceeding code requirements should evaluate continually evolving new filter technologies, such as ultraviolet (UV) and filters that use a combination of electrical/ ion/ mechanical media. There is often no independent performance rating or certification for new technology; therefore, it typically cannot be used as a replacement for code-required mechanical filtration. This makes evaluating new technology a challenge for project teams and building owners.

A commonly accepted indoor air quality practice involves directly measuring and monitoring outdoor airflows. Measuring and monitoring to provide the proper amount of outdoor air is a critical component in maintaining good air quality year-after-year. Unfortunately, reducing outdoor airflow (or even closing the outdoor air intake completely) has been commonly seen in attempts to solve non-outdoor-related temperature or humidity complaints. Also, mechanical components associated

with outdoor air delivery will eventually fail. Monitoring of airflows is the key to maintaining good air quality.

Designers should consider common health-care-specific outdoor air contamination sources, such as a helipad, delivery trucks, emergency generators, and parking garages. For large, urban hospital facilities, airflow modeling for outdoor air intakes and potential contaminant sources could be an important design tool. Project teams can consider either CFD modeling or wind tunnel simulations. Indoor contaminant sources to consider for containment are medical and housekeeping chemicals (both use and storage), and biological/radioactive chemicals.

12.8.4 Construction Practices to Improve Indoor Air Quality

The following information is in addition to the requirements for an infection control risk assessment. Improving air quality during construction can help provide a higher level of air quality for permanent occupants and helps in reducing health risks for construction workers. During construction, the indoor environment will need to be cooled and dehumidified to provide a suitable environment for interior finishes. The permanent HVAC system, however, must be clean at the completion of construction so as not to contaminate air that will be supplied to future occupants. The preferred approach is to minimize and manage airborne construction contaminants and to prevent dust and particulates from depositing/collecting inside any of the air distribution systems during construction. The project team should consider developing an IAQ plan for the construction phase that would include (1) HVAC system protection, (2) source control, (3) pathway interruption, (4) housekeeping and moisture management, and (5) scheduling (SMACNA 2007). The cost, manpower, and schedule impacts of actions in each of these categories, discussed in the following, should be evaluated to determine the best approach for the construction project:

HVAC System Protection

Project teams and building owners dealing with hospitals and sensitive outpatient facilities may chose to not use permanent HVAC equipment during construction. Even if permanent equipment is not being used, it needs to be protected from dust and contaminants. If permanent equipment is to be used during construction, special procedures should be enacted, such as the following.

- Inspection and sign-off from the building owner's representative that the air systems are clean before substantial completion, regardless of the method of providing construction cooling/heating. Components that are dusty and/or contaminated must be cleaned, including the interior of all ductwork and equipment.
- Provide clean and dry storage for all air distribution components, such as supply and return ductwork, air handlers, rooftop units, coils, air terminal units, filters, diffuser, grilles, and duct wrap.
- Meet or exceed the project duct cleanliness specifications.

The project team should consider implementing similar steps if the permanent HVAC equipment is going to be used during construction:

- All rooftop or air-handling systems should have operational safeties in place to avoid premature duct damage.
- If permanent cooling systems are to be used, confirm whether permanent power is needed.
- Rooftop units and air handlers should operate in 100% outdoor air mode to provide temporary cooling and dehumidification (with no return air); this will place the building under positive pressure and require some means for air to escape, either through doors, windows, or some form of temporary opening.
- Determine whether cooling is needed 24 h/day, 7 days/week or only during construction hours. Ensure that relief openings are provided whenever the units are operating. Temporary filter media should cover outdoor air intakes to protect them from site/exterior work dust.
- All return air systems should be disabled and sealed off.
- Air filters used during construction should meet (as a minimum) the efficiencies intended for the final operation of the equipment.
- The supply fan variable-frequency drive (VFD) on any rooftop unit or air handler being used during construction should be operational and controlling to a static pressure. All controls and safeties should be operational and verified before operation of the HVAC system.
- Determine whether the heating system will need to provide reheat at the VAV units and plan accordingly.
- No final testing, adjusting, and balancing (TAB) should be performed until all supply, return, and exhaust systems are complete, readjusted to their permanent settings, and connected to permanent power.
- Replace filter media in rooftop units or air handlers used during construction just before TAB work.
- Consider having a qualified technician review and monitor temporary operations for several days following initial commencement. Also perform periodic system inspections.
- When air-handling systems are off, seal all supply ductwork, equipment, and openings with plastic to provide further protection.

Source Control

Project teams and building owners should consider using low-emitting products that meet or exceed industry standards. The *LEED 2009 Reference Guide for Green Building Design and Construction* (USGBC 2010) cites common low-volatile-organic-compound (VOC) industry standards for adhesives, sealants, paints, coatings, and other common products. Additional source-control construction practices to consider are as follows:

- Use electrically powered equipment within the building envelope, such as fork lifts, saws, and man-lifts, when feasible.
- If necessary, exhaust pollution sources to the outdoors through an exhaust system or portable fan. If an exhaust fan is not feasible, a portable air cleaner may be effective.
- Keep lids on wet-product or waste material containers.
- Surfaces that are a persistent odor source should be controlled by applying a sealer.
- Recover, isolate, and ventilate containers housing toxic materials.
- Store pollutant sources outside of occupied areas.
- Implement a nonsmoking policy within the building once it is enclosed or final finishes are in place.

Pathway Interruption

Consider the following ideas to assist in mitigation of construction-related particulates:

- Belt sanders for drywall sanding should have HEPA-filter exhaust bags to reduce airborne pollutant production.
- Erect barriers to contain drywall dust to prevent it from contaminating occupied or newly finished areas; barriers can range from dust curtains to a plastic seal around the work site and should be selected based on the materials involved and the implications of the dust or odor escaping from the site.
- Use fans to depressurize areas to contain dust and construction contaminants.

Housekeeping and Moisture Management

Consider controlling dust with wetting agents or sweeping compounds and use efficient dust-control methods that include the following:

- Increase the cleaning frequency to provide daily sweeping of contaminated floors after drywall sanding.
- Protect porous building materials from exposure to moisture and store them in a clean area before installation.
- Keep all surfaces clean (including high ledges and the insides of mechanical equipment).
- Remove spills or excessive applications of solvent-containing products as soon as possible.
- Use a HEPA filter in vacuums to prevent the aerolization of settled dust.
- Keep the site as dry as possible and remove accumulated water.

Phasing

Consider phasing of installation steps to improve indoor air quality. As an example, install carpet as one of the last finish items to avoid contamination of absorptive materials. Protect absorptive materials that are stored on-site from moisture damage by staging them in a designated laydown area. On completion of construction, replace all filtration media immediately before occupancy. Install materials with a high potential for pollution production during off hours to allow time for the materials to air out.

Preoccupancy Purge/Dilution

After final finishes are applied, and just before occupancy, consider flushing out VOCs and contaminants by supplying high volumes of outdoor air. LEED For Healthcare™ requires 14,000 ft^3 of outdoor air per square foot of floor area [4268 m^3/m^2] while maintaining at least 60°F [15.6°C] and no higher than 60% relative humidity. LEED also has an option that allows for occupancy to occur at a particular point in the flush-out phase. It is suggested that new filtration media be installed before performing the flush.

12.9 WATER USE EFFICIENCY

Hospitals are significant water consumers. The EPA reports water consumption that ranges widely, from 40 gal/day [150 L/day] to 350 gal/day [1325 L/day] per capita. Water use varies with factors such as size, age, and type of building, water use equipment, and water use practices. The mean water use in *Operations and Maintenance Benchmarks for Health Care Facilities Report* (IFMA 2010) was 51 gal per gross ft^2 [2078 L/m^2]. A study of Massachusetts hospitals (MWRA 2012) found the potential to reduce water use by nearly 20%.

As with energy, consider developing a water management program. The first step is determining where water use is occurring so that the efforts can be focused on the biggest opportunities that are affordable. An organization will have to assess its goals and motivation for implementing such a plan. As part of that effort, clarify what level of investment of resources will be available; this will help determine the types of water saving strategies that can be considered and how aggressive the strategies can be. Consider involving the local utility resource providers and also engage important stakeholders both inside and outside of the health care organization. The U.S. Department of Energy (DOE 2012) and Practice Greenhealth (2012) are good water efficiency resources. Practice Greenhealth lays out a water management plan that includes the following:

- Benchmark the water use
  - Determine if water meters need to be installed at key locations
  - Analyze water data on an appropriate frequency
- Identify opportunities
  - Fix leaks and unnecessary use
  - Review practices in cleaning, kitchen, and laundry
  - Investigate equipment and engineered solutions involving toilets, sterilizers, boilers, chillers, cooling towers
- Determine cost/benefit opportunities
- Prioritize opportunities
- Develop phasing and capitalization plan
- Measure/monitor and use a continuous-improvement plan

Potential areas to consider when looking for water-saving opportunities include the following:

- Domestic water use: there are lower-water-use water closets, urinals, and faucets; the key is to find ones that the organization will accept in terms of performance; third party testing may be required.
- Outdoor water use: evaluate water-saving techniques, such as changing to landscaping that requires less irrigation; use wet-weather shutoffs or soil-moisture controllers; investigate used-water options; and rainwater collection systems.
- Process equipment: evaluate air-cooled instead of water-cooled equipment (consider energy impacts as well); avoid or replace water-induced vacuum devices on sterilizers; avoid using continuous-flow-through systems on film processors; reuse water used to cool medical equipment, such as linear accelerators, and/or water rejected from reverse osmosis processes for cooling tower makeup water.
- HVAC equipment: check steam traps regularly; recover condensate from refrigerators, freezers, ice makers, and cooling coils; evaluate water-saving strategies for cooling tower blowdown and treatment methods.

EPA (2007) describes several case studies of water-saving strategies. One case study involved reusing condensate from air-handling units for cooling tower makeup water. The study reported a savings of 900,000 gal [3.4 million L] of water per year with a five-year simple payback. Another study reported on a walk-in refrigerator project that saved over 11 million gal [41.6 million L] per year with a less than a one-year payback.

12.10 SITE SUSTAINABILITY

Site sustainability involves the environmental impacts associated with a building project site. Included are concerns related to landscaping, hardscape, heat island effects, pollution emissions related to building occupants' transportation, and light pollution. Building orientation should take numerous constraints and considerations into account.

There are synergies within this area where the HVAC engineer can provide expertise and input. For example, the HVAC engineer can provide input on the effect of solar heat gain on equipment sizing, and the operational cost impacts of building orientation and proposed glazing options. The engineer can help analyze the cost/benefit of materials that are proposed to reduce the heat island effect.A reflective roof membrane is the most common method of reducing heat island effects. Various energy modeling software tools that include roof reflectance properties and use a full hour-by-hour calculation approach can assist with estimating the energy savings from reflective roofs. Projects in urban areas are likely to be more interested in (and, at times, required, as in Chicago) providing some means to reduce a building's heat island impact. Reflective roof membranes have been used in southern climates for quite some time. It is unclear in how cold a climate it makes sense to use a reflective roof, but it is important to

realize that hospitals and heath care facilities are cooling-dominated buildings. The HVAC engineer can help determine feasibility. A plus for reflective roofs that is not commonly mentioned is the indirect benefit for rooftop electrical/mechanical equipment; unfortunately, there is only anecdotal evidence of this benefit.

Less common than reflective roofs, but gaining in popularity, are green or landscaped roofs. Along with reduced heat island effect, they can provide additional roof insulation and a usable outdoor space. The cost for a green roof is higher, but the benefits go beyond energy savings. A good case study of a green roof in a health care facility can be found in *Advanced Energy Design Guide for Small Hospitals and Healthcare Facilities:* the Cheyenne One Medical Office Building in Webster, Texas (ASHRAE 2010c). Landscaping and its opportunities are often overlooked or not considered in health care facility design.

REFERENCES

ASHE. 2010a. *Health care facilities operations and maintenance benchmarks.* Chicago: American Society for Healthcare Engineering.

ASHE. 2010b. *Health facility commissioning guidelines.* Chicago: American Society for Healthcare Engineering.

ARC. 2010. *Sound & vibration design guidelines for health care facilities.* http://speechprivacy.org/joomla//index.php?option=com_content&task=view&id=33&Itemid=43. Acoustics Research Council.

ASHRAE. 2008.*Ventilation of health care facilities*. ANSI/ASHRAE/ASHE Standard 170-2008. Atlanta: ASHRAE.

ASHRAE. 2010a. *Thermal environmental conditions for human occupancy.* ANSI/ASHRAE Standard 55-2010. Atlanta: ASHRAE.

ASHRAE. 2010b. *Ventilation for acceptable indoor air quality*. ANSI/ASHRAE Standard 62.1-2010. Atlanta: ASHRAE.

ASHRAE. 2010c. *Advanced energy design guide for small hospitals and healthcare facilities.* Atlanta: ASHRAE.

ASHRAE. 2010d. *ASHRAE greenguide*, 3rd edition. Atlanta: ASHRAE.

ASHRAE. 2012. *Advanced energy design guide for large hospitals.* Atlanta: ASHRAE.

BetterBricks. 2012. SEMP template and workplan. http://www.betterbricks.com/healthcare/tools/semp-tools-resources. Portland, OR: Northwest Energy Efficiency Alliance.

CISCA. 2010. *Acoustics in healthcare environments.* St. Charles, IL: Ceilings & Interior Systems Construction Association.

DOE. 2012. Best management practice: Water management planning. http://www1.eere.energy.gov/femp/program/waterefficiency_bmp1.html. Washington, DC: U.S. Department of Energy.

DSIRE™. 2012. Database of state incentives for renewables & efficiency. http://www.dsireusa.org/. Raleigh: North Carolina Solar Center, North Carolina State University, and the Interstate Renewable Energy Council (IREC).

EPA. 2007. Process Water Efficiency. Publication 909-F-07-001. http://www.epa.gov/region9/waste/p2/pdf/water-final-071126.pdf. Washington, DC: U.S. Environmental Protection Agency.

EPA. 2013. ENERGY STAR® program. http://www.energystar.gov. Washington, DC: U.S. Environmental Protection Agency.

FGI. 2010. *Guidelines for design and construction of health care facilities.* Dallas, TX: Facility Guidelines Institute.

IDL. 2011. *Legacy Salmon Creek Medical Center energy use and model calibration study.* http://idlseattle.com/Health/study_hospital.html. Seattle: Integrated Design Lab, University of Washington.

IFMA. 2010. *Operations and maintenance benchmarks for health care facilities report.* Houston, TX: International Facility Management Association.

LBNL. 2009. *Hospital energy benchmarking guidance–Version 1.0*. LBNL-2738E. Berkeley, CA: Lawrence Berkeley National Laboratory.

MWRA. 2012. Water use case study: Norwood Hospital. http://www.mwra.state.ma.us/04water/html/bullet1.htm. Boston: Massachusetts Water Resources Authority.

NEMA. 2012. About the provisions: Frequently asked questions. http://www.efficientbuildings.org/. Rosslyn, VA: Commercial Building Tax Deduction Coalition, National Electrical Manufacturers Association.

NREL. 2010. *50% energy savings design for large hospital buildings: Technical support document.* TP-550-47867. Golden, CO: National Renewable Energy Laboratory.

Practice Greenhealth. 2012. http://practicegreenhealth.org/. Reston, VA: Practice Greenhealth.

SMACNA. 2007. *IAQ guidelines for occupied buildings under construction*, 2nd ed. Chantilly, VA: Sheet Metal and Air Conditioning Contractors' National Association.

TIAP. 2012. The Tax Incentives Assistance Project. http://www.energytaxincentives.org/

USGBC. 2010. *LEED 2009 reference guide for green building design and construction.* Washington, DC: U.S. Green Building Council.

CHAPTER 13

SEISMIC RESTRAINTS IN HEALTH CARE HVAC DESIGN

13.1 INTRODUCTION

The reason for including a chapter on seismic restraint in this manual is to address widespread changes in the codes that, for the first time, have resulted in seismic design and restraints being required in hospitals across the U.S. For example, some hospitals in Illinois and Wisconsin are now required by code to have seismic restraints for HVAC systems. To a lesser degree, these changes have also impacted those locations where clinics and other health care facilities will require seismic restraints. The information and terminology presented in this chapter is based on the *International Building Code® (IBC®)* (ICC 2012a) and ASCE/SEI Standard 7-10, *Minimum Design Loads for Buildings and Other Structures* (ASCE 2010). These are not necessarily the code requirements in all states or local jurisdictions; be sure to confirm the code requirements for each specific project. This information is provided to assist designers and is not intended to be a substitute for the code or the standard. The chapter limits its focus to HVAC components. Project teams will also need to consider seismic restraints for architectural, plumbing, electrical, and medical equipment components. As discussed in the following sections, seismic design involves interaction and coordination between the design professionals, the building owner, and the authority having jurisdiction (AHJ).

Since IBC 2003, significant changes have been made to the code requirements involving seismic restraints; these apply to both inpatient and outpatient facilities. The requirements depend upon many variables such as: probability of a seismic event and its probable strength; soil characteristics relative to an ability to withstand seismic forces; the building type and the importance of it operating after an event and/or the potential hazard it may pose to a community and occupants during

an event. This chapter will introduce the seismic requirements and suggest some possible means and methods of dealing with mechanical components. In addition to seismic restraints, the chapter will also cover the special inspections required by the IBC.

13.2 SEISMIC RESTRAINTS FOR NONSTRUCTURAL COMPONENTS

The IBC's Chapter 16 deals with seismic forces and restraint requirements and refers to ASCE/SEI Standard 7-10 for determination of the specific seismic restraint requirements. ASCE 7's Chapter 13 is devoted to seismic design requirements for nonstructural building components—including the HVAC equipment and components. Table 13-1 shows the relationship between the various versions of these two references. There are significant changes in ASCE/SEI 7-10, some of which are pointed out in this chapter.

13.3 SEISMIC DESIGN AND RISK CATEGORIES

A first step in determining applicable requirements is to know the building's seismic design category (SDC) and the risk category (I, II, III, or IV). A building's seismic design category is represented by the letters A, B, C, D, E, or F, with seismic intensity increasing with each letter. The SDC and risk categories are typically determined by the project's structural engineer. The SDC of the building is also the SDC for the nonstructural components. Early in the design process, the seismic design category may be assumed until soil borings from the actual site are analyzed. Determine whether this is the case, and ensure that confirmation of category is provided prior to design. It is critical to obtain the AHJ's confirmation for both of these classifications. In some locations, the AHJ may not be fully familiar with these requirements, especially in areas that, until 2003, did not require seismic restraints.

IBC Chapter 16 defines a key seismic design parameter called risk category. It is based on the nature of the occupancy and function of the activity or service being performed in the building or by the occupants housed in the building. Health care facilities fall into Risk Category II, III, or IV (per Table 1604.5 of ICC 2012a). Hospitals (IBC Group I-2) with surgery or emergency departments are listed as Risk Category IV. Other types of health care facilities would likely be either Risk Category II or III. Before IBC 2009, risk category was called occupancy category. IBC 2012, Table 1604.5, has clarified many descriptions categorizing health care facilities compared to earlier code versions. If a project falls under an earlier version of the code and ASCE standard, the project team and AHJ may want to consider using IBC 2012 to determine the occupancy category.

Table 13-1 *ASCE 7 Versions versus IBC Versions*

IBC Date	ASCE 7 Date
2006	2005
2009	2005
2012	2010

Risk Category IV buildings are designated as *essential facilities*. IBC defines essential facilities as buildings "that are intended to remain operational in the event of extreme environmental loading from flood, wind, snow or earthquakes." Because the IBC risk category table uses the phrase "including but not limited to," project teams should obtain a determination for risk category from the AHJ early in the design process. This will help to align budgets and project scope at project initiation. In many locales, it is unclear who makes the determination that a facility is essential. A project team can check with the AHJ in charge of the building code, the fire marshal, and local or state agencies that develop emergency response plans or policy. Risk Category IV has a significant impact on the scope and cost of required HVAC system seismic restraints.

Consider, for example, an outpatient ambulatory-surgery facility. Under IBC 2003 and IBC 2006, this facility type seems to fit the Risk Category IV definition, despite the fact that many of these facilities are not considered essential facilities. Under IBC 2012, it is clear that they are not typically considered Risk Category IV.

13.4 COMPONENT IMPORTANCE FACTOR

IBC and ASCE use component importance factor I_p to account for the potential harm a component can cause and/or if it must be functional after a seismic event. ASCE 7 (Chapter 13, Section 13.1.3) defines the component importance factor. It is used in the seismic-force calculation and is also referenced in seismic-restraint exceptions in combination with the SDC. The definition of I_p was modified in the 2010 version of ASCE-7. The importance factor is either equal to 1.0 or 1.5. The higher value represents a greater need for restraint. Components have $I_p = 1.5$ if they:

- are required to function, after an earthquake, for life safety purposes, such as fire suppression and fire alarm systems and egress stairways;
- convey or contain toxic, highly toxic, or explosive substances in a quantity that exceeds the AHJ's threshold and is sufficient to pose a threat to the public;
- are in a Risk Category IV facility and are required for the facility to continue operation; or
- convey or contain hazardous substances.

ASCE 7's Chapter 13 does not provide definitions for "toxic," "explosive," or "hazardous." Definitions are scattered throughout the standard, but it is not clear that they are to be applied to that chapter. The project team should consider obtaining a clarification from the AHJ. IBC's Chapter 2 references the definition for "hazardous" from the *International Fire Code® (IFC®)* (ICC 2012b). The IFC definition includes chemicals and materials that pose either a health or physical hazard. Health hazards include chemicals that are toxic, highly toxic, and corrosive. Physical hazards include the following chemicals or materials:

- Combustible liquids
- Cryogenic fluids
- Explosives
- Flammable solids, liquids, and gases
- Organic peroxide
- Oxidizers
- Oxidizing gases
- Pyrophorics
- Unstable reactives
- Water reactives

Also consider confirming if steam (low- and high-pressure) or hot-water (above a certain temperature) systems are to have an importance factor of 1.5. They certainly could pose a threat to the public if a pipe in a clinic is broken during an earthquake.

All other components have $I_p = 1.0$.

For projects in seismic design categories C thru F, the designer should work with the AHJ and building owner to understand which components are defined as life safety, toxic, explosive, and hazardous. Examples of mechanical components that would likely be considered part of a life safety system regardless of the facility type are

- fire suppression systems
  (piping systems, fire pumps, control panels and wiring);
- smoke management systems
  (fans, control panels and wiring, ductwork);
- stairwell pressurization systems
  (fans, control panels and wiring, ductwork);
- components of medical gas systems; and
- machine room ventilation components.

Depending on the facility type, there are many other systems that might be considered important to life safety following an earthquake. For example, in a facility in the lower risk categories (I, II, or III), such as a rehabilitation hospital (Risk Category III), the service and potable water components might be considered systems that need to be functioning for life safety, considering the difficulties and limited choices associated with relocating the patients or providing supporting functions such as food refrigeration or (in some cases) heating and cooling. These systems in a medical office building, however, are not likely to be considered life safety related following an earthquake, because the patients and staff are going to leave the facility after the earthquake.

A building owner or heath care organization with a facility in the lower risk categories (II or III) may want to add components or systems to the list of I_p = 1.5 factors in seismic design categories C to F based upon considerations other than those listed. For example, an owner may want the pharmaceutical environment control systems to remain operational after a seismic event because of the cost of the inventory. The data center systems, including air conditioning, might be important if loss of data is a risk. Table 13-2 shows a sample of HVAC components that are likely to have I_p = 1.5 for risk categories I, II, or III.

Hospitals would likely be a Risk Category IV, and all HVAC systems would be needed for continued operation; therefore, they would have I_p = 1.5 and would likely be a designated seismic system.

13.5 SEISMIC DESIGN REQUIREMENTS

Numerous considerations and variables must be taken into account when dealing with seismic activity and the impact it has on buildings and their systems and components. ASCE/SEI Standard 7-10 takes into account the following:

- Seismic forces, both horizontal and vertical
- Relative displacement of different components and systems
- Effect or impact of nonessential components on essential components
- Component anchorage and support design
- Component strength and flexibility considerations
- Requirements for manufactured components

Table 13-2 *Sample HVAC Component Importance Factors in Risk Categories I, II, or III*

HVAC Component	Life Safety Systems	Hazardous Materials	Ip	Comments
MRI cryogenic piping		Yes	1.5	Hazardous gas
Steam piping		?		
Hot water piping		?		
Boilers and pressure vessels		Yes	1.5	Flammable gas
Gas/propane-fired equipment and piping		Yes	1.5	Flammable gas
Ductwork (hazardous)		Yes	1.5	Example: isolation room exhaust duct
Gas-fired kitchen equipment		Yes	1.5	Flammable gas
Gas-fired laundry dryers		Yes	1.5	Flammable gas
Housekeeping pads			1.5	If component on pad I_p = 1.5
Smoke control systems	Yes		1.5	
Machine room refrigerant exhaust systems	Yes		1.5	

ASCE 7 identifies when mechanical components are exempt from seismic design considerations (as summarized in Table 13-3 of this manual). These general exemptions are based on the building's seismic design category and the component importance factor I_p.

For HVAC systems, no seismic restraints are required in Seismic Design Category A or B. Although SDC-A is not specifically stated, it is assumed to be an exception, because SDC-A is a lesser seismic category than B. ASCE 7-10 has clarified some of the language in its Section 13.1.4; especially critical is the wording regarding the flexible connection exemption. Section 13.1.4(4) in the 2005 version states that any component in SDC D, E, or F with $I_p = 1.0$ is exempt if flexible connections are applied. This is commonly interpreted as meaning if the component is less than 400 lb [180 kg] and less than 4 ft [1.2 m] off the floor *and* has flexible connections. If a project falls under ASCE 7-05, work with the AHJ for a clarification before design.

13.5.1 General Design Requirements

Project-specific seismic-restraint design and documentation must be approved by a registered design professional and by the AHJ. For manufactured equipment items that are not exempt, a certification from the manufacturer is required for approval to verify that the equipment is seismically qualified. Seismically qualified can be demonstrated in three ways:

- Analysis
- Testing based on a nationally recognized procedure acceptable to the AHJ
- Experience data from the manufacturer that is acceptable to the AHJ

If components have $I_p = 1.5$, IBC and ASCE refer to this as a designated seismic system. Designated seismic systems in seismic design categories C to F have additional testing and inspection requirements. The intention is that they remain functional following a

Table 13-3 *Nonstructural Components Exemptions*

ASCE 7-10 Section	General Exemptions	Seismic Design Category
13.1.4(4)	No seismic restraints *Assume that this applies to SDC-A*	B
13.1.4(5)	No seismic restraints if $I_p = 1.0$	C
13.1.4(6)	No seismic restraints if $I_p = 1.0$ *and* component is positively attached to structure *and* there are flexible connections between components *and* either (1) components weigh less than 400 lb [180 kg] *and* center of mass is located 4 ft [1.2 m] or less from floor; *or* (2) components < 20 lb [9 kg] or distribution systems < 5 lb/ft [7.4 kg/m]	D, E, F

design level earthquake. For manufactured equipment that is part of a designated seismic system, the manufacturer's certification must be based on either approved shake table testing, experience data, or proof that it is inherently rugged by comparison with similarly qualified equipment. All certification methods require approval by the AHJ.

Seismic restraint design for nonstructural components must account for the interrelationship between components and their supports. The designer should ensure that a failure of one system, whether essential or nonessential, doesn't cause the failure of an essential system.

ASCE 7 allows the use of reference publications or documents for the seismic-restraint design of a particular type of component provided that

- the AHJ approves;
- earthquake forces are not less than those determined in ASCE 7, Section 13.3.1;
- relative displacement and drift are accounted for per the ASCE 7 reference; and
- anchorage requirements are not less than those specified in ASCE 7.

An example of this approach would be use of the 2008 *SMACNA Seismic Restraint Manual: Guidelines for Mechanical Systems* (SMACNA 2008). The SMACNA manual, however, conforms to the IBC 2006 and IBC 2009 requirements, which reference ASCE 7-05. If a project falls under ASCE 7-10, care should be taken in application and AHJ approval obtained before use.

13.5.2 Seismic Design Force/Relative Displacement/Component Anchorage

Whichever code or standard a project falls under, those requirements provide the method for determining seismic forces, displacement distances, and support and anchorage requirements. Typically, seismic force is related to component weight, the acceleration of the ground, amplification and response factors, the support, and building height.

There are specific anchor requirements and restrictions. Be sure to understand these requirements, because common attachment methods are not allowed in seismically active areas unless they have been seismically tested and approved. Also, because seismic forces are both horizontal and vertical in nature, friction anchors have limitations. Seismic and support calculations and detailing are often done by the project's licensed structural engineer with the mechanical designer's input regarding the HVAC components. There are also companies that provide seismic-restraint design and installation services using proprietary restraints.

13.5.3 HVAC Design Requirements

If HVAC systems are not exempt from seismic restraints, then more detailed requirements and additional exceptions that apply can be found in ASCE 7-10, Section 13.6. A system I_p of 1.5 brings additional

requirements to account for: (1) potential impact of other components, (2) loads from attached service or utility lines because of differential movement, and (3) ductwork and piping attached to structures that could displace from one another. There are a significant number of exceptions for HVAC component seismic restraints in the specific conditions outlined in Table 13-4. It is important to point out that the exceptions are quite different between ASCE 7-05 and ASCE 7-10 for components with $I_p = 1.5$. ASCE 7-10 maintains many of the ductwork and piping exceptions, regardless of importance factor. Project teams working under ASCE 7-05 may want to consider requesting that the AHJ allow the requirements in the more recent version.

Any mechanical equipment that is being placed on a nonbuilding structure, such as a cooling tower placed on an I-beam frame, must be designed per ASCE 7, Chapter 15, which covers tanks and vessels.

Equipment mounted on springs involves special considerations, because earthquake movements can be amplified by the springs. Review the code and standards closely for additional testing and inspections.

13.6 SEISMIC RESTRAINT SPECIAL INSPECTIONS AND TESTS

Building projects with IBC mechanical seismic design requirements will also have *special inspections for seismic restraints,* as outlined in IBC Chapter 17. HVAC system inspections are required in seismic design categories C to F for piping, ductwork, and associated mechanical units that are designed to carry hazardous materials. These inspections are to be performed during the installation and anchorage. Refer to the "hazardous material" definition in IBC Chapter 2, which includes chemicals and materials that present a health or physical hazard, such as toxic, flammable, combustible, cryogenic, oxidizer, and other materials. Vibration isolation systems must also be inspected during installation if there is a 0.25 in. [6.4 mm] or less clearance between the equipment support frame and the restraint. The testing requirements of Section 13.2.1(2), ASCE 7-10, apply to manufactured HVAC equipment in seismic design category C if $I_p = 1.5$, and also in SDCs D to F. IBC Chapter 17 requires that the seismic certification requirements are specified on the construction drawings.

Inspections must be performed by a qualified agent, who must be approved by the AHJ and must disclose any conflict of interest. Special Inspectors are required to keep records of inspections and furnish reports to the AHJ and to the registered design professional. Work reported as not in compliance must be brought to the contractor's immediate attention. If not corrected, the inspector is to notify the AHJ and design professional before that phase of work is completed. Inspectors are to provide a final report documenting inspections and corrections.

Whenever special inspections are required, the design-professional-in-responsible-charge is required to prepare a Statement of Special Inspections. The required contents are outlined in IBC Section 1704.3.

Table 13-4 *HVAC Components Seismic Design Exceptions*

ASCE 7-10 Section	Nonstructural Component	Exception Requirements
13.6.7	HVAC ductwork *Exceptions do not apply to:* • *ductwork carrying toxic or flammable gases, or used for smoke control* • *ductwork with I_p = 1.5 that crosses seismic joints*	No design for seismic forces or relative displacement is required if: (a) trapeze assemblies are used and total weight is less than 10 lb/ft [14.9 kg/m]; **or** (b) all hangers in duct run are 12 in. [305 mm] or less in length from duct support point to structure; where rod hangers are used, equip with swivels to prevent inelastic bending in rod. No design for seismic forces or relative displacement is required if: (a) provisions are made to avoid impact with larger ducts or equipment or to protect ductwork in the event of such an impact; **and** (b) ducts area is smaller than 6 ft^2 [0.56 m^2] or weight less than 17 lb/ft [25.3 kg/m] *Alternative methods are allowed if installed in accordance with standards approved by AHJ.* Equipment installed in ductwork > 75 lb [34 kg] must be supported and braced independently. Dampers, louvers, diffusers must be positively attached and have adequate flexibility for differential displacement.
13.6.6	Utility and service lines	Provide adequate flexibility to accommodate differential movement. Differential displacement calculations shall be per Section 13.3.2 of ASCE 7.
13.6.8 ASME pressure piping (13.6.8.1 of ASCE 7)	Piping systems *Piping exceptions listed here do not apply to elevator piping.*	No seismic supports if one of the following applies: (1) Trapeze assemblies are used and no single pipe exceeds limits set forth in 3a, 3b, or 3c below and total weight is less than 10 lb/ft [14.9 kg/m]. (2) Each hanger in piping run is 12 in. [305 mm] or less in length. Where pipes are support by trapeze, the hangers are 12 in. [305 mm] or less. Where rod hangers are used, they have swivels, eye nuts, or other device to prevent bending the rod. (3) Piping in Table 13.6-1 of ASCE 7 with component response modification factor R_p = 4.5 or greater and provisions are made to avoid impact with other elements and where the size requirements are met: a. SDC=C; I_p = 1.5; pipes 2 in. [50 mm] or less b. SDC=D,E,F; I_p = 1.5; pipes 1 in. [25 mm] or less c. SDC=D,E,F; I_p = 1.0; pipes 3 in. [76 mm] or less
13.6.8.2 13.6.8.3	Fire protection sprinkler systems	No seismic supports required *if* SDC = C and system is designed and constructed to NFPA 13. For SDC = D, E, F, see criteria listed in 13.6.8.3 of ASCE 7.
13.6.9	Boilers and pressure vessels	If designed in accordance with ASME *Boiler and Pressure Vessel Code* (BPVC), they comply with 13.3.1 and 13.3.2; otherwise, follow 13.3.1 and 13.3.2. Other boilers and pressure vessels where I_p = 1.5 that do not comply with ASME BPVC shall comply with 13.6.11 of ASCE 7.

This report is a required condition for issuing a permit. It is interesting to note that contractors responsible for seismic-resisting systems requiring special inspections must also submit a statement of responsibility to the AHJ for approval before any work is performed on those systems or components. Contractors need to acknowledge the special seismic requirements.

Design professionals should also realize that the project's construction management is required to appoint a Special Inspection (SI) Coordinator. The SI Coordinator will keep records of all inspections and will furnish interim inspection reports to the Building Official and the registered design professional. The SI Coordinator will ensure that the design professional, inspector, and contractor resolve all noted discrepancies. The SI Coordinator will also compile information and signatures for the Final Report of Special Inspections. Acceptance of the Final Report is typically a condition for issuance of a Certificate of Use and Occupancy.

REFERENCES

ASCE. 2010. *Minimum design loads for buildings and other structures*. ASCE/SEI 7-10. Reston, VA: American Society of Civil Engineers.

ICC. 2012a. *International building code®(IBC®).* Washington, DC: International Code Council.

ICC. 2012b. *International fire code® (IFC®).* Washington, DC: International Code Council.

SMACNA. 2008. *Seismic restraint manual: Guidelines for mechanical systems*, 3rd ed. ANSI/SMACNA 001-2008. Chantilly, VA: Sheet Metal and Air Conditioning Contractors' National Association.

ACRONYMS

AAMC	Association of American Medical Colleges
ACH	air change per hour
ACHC	Accreditation Commission for Health Care
ACO	accountable care organizations
AEDG	Advanced Energy Design Guide
AHA	American Hospital Association
AHJ	authority having jurisdiction
AHRQ	Agency for Healthcare Research and Quality
AII	airborne infection isolation
ASC	ambulatory surgery center
ASHE	American Society for Healthcare Engineering
ARRA	American Recovery and Reinvestment Act
AVM	air volume migration
BIM	building information modeling
CAFM	computer-aided facility management system
CAV	constant air volume
CBO	Congressional Budget Office
CCRC	continuing care retirement community
CDC	Centers for Disease Control and Prevention
CEO	Chief Executive Officer
CFD	computational fluid dynamics
CHC	Certified Healthcare Constructor
CHD	The Center for Health Design
CMMS	computerized maintenance management system
CMS	Centers for Medicare & Medicaid Services
CON	Certificate of Need
CT	computer tomography
DEOP	disaster emergency operations plan
DOE	U.S. Department of Energy
DRG	diagnosis-related groups
DSIRE™	Database of State Incentives for Renewables and Efficiency
DV	displacement ventilation
EBD	evidence-based design
EDAC	evidence-based design accreditation and certification
EMR	electronic medical record
EOC	environment of care
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
EPS	emergency power system
EUI	energy use index
FA	facility assessment
FACT	Foundation for the Accreditation of Cellular Therapy
FDA	U.S. Food and Drug Administration
FEMA	U.S. Federal Emergency Management Agency
FGI	Facility Guidelines Institute
GDP	gross domestic product
HC	health care
HEPA	high-efficiency particulate air (filter)
HIPAA	Health Insurance Portability and Accountability Act
HSS	U.S. Department of Health and Human Services
HVAC	heating, ventilating, and air conditioning
IAQ	indoor air quality
ICU	intensive care unit
IEQ	indoor environmental quality
ILSM	interim life safety measures
IMG	international medical group
IT	information technology
JCAHO	Joint Commission on Accreditation of Healthcare Organizations
LED	light-emitting diode
LEED®	Leadership in Energy and Environmental Design
MERV	minimum efficiency reporting value
MET	metabolic equivalent of task

MGMA	Medical Group Management Association
MOB	medical office building
MRI	magnetic resonance imaging
MSA	metropolitan statistical area
MWB	mean wet-bulb (temperature)
NADCA	National Air Duct Cleaners Association
NAFA	National Air Filtration Association
NC	noise criterion (curve)
NCQA	National Committee for Quality Assurance
NFPA	National Fire Protection Association
OSHA	U.S. Occupational Safety and Health Administration
PACU	postanesthesia care unit
PET	positron emission tomography
PPACA	Patient Protection and Affordable Care Act
RC	room criterion (curve)
RF	radio frequency
SARS	severe acute respiratory syndrome
SGR	sustainable growth rate
SMACNA	Sheet Metal and Air Conditioning Contractors' National Association
SOC	statement of conditions
STC	sound transmission class
TJC	The Joint Commission
UL	Underwriters Laboratory
USGBC	U.S. Green Building Council
UV	ultraviolet
UVGI	ultraviolet germicidal irradiation
VA	U.S. Department of Veterans Affairs
VAV	variable air volume
VAVTR	variable air volume with terminal reheat
WAGD	waste anesthesia gas disposal

GLOSSARY

airborne droplet nuclei
particles are released when an infected host coughs or sneezes; droplet nuclei are formed when mucus coating these particles evaporates and the virus becomes airborne. Also known as *quanta*.

airborne infection isolation (AII) room
rooms in which care is administered to patients who have, or are suspected of having, an infectious disease. AII rooms are used to protect the population of a health care facility by placing potentially infectious patients in quarantine.

ambulatory care
outpatient treatment, consultation, or intervention that is performed on the same calendar day as registration and discharge.

ambulatory surgery center
stand-alone building where outpatient surgeries are performed.

ambulatory treatment facility
stand-alone building where outpatient treatment is administered.

anesthetizing gas
nitrous oxide (N_2O).

anteroom
room that is strategically used to help create and maintain required pressure offsets for isolation (PE or AII) rooms. When the isolation room is occupied, staff should travel from the corridor to the anteroom and then into the isolation room.

asepsis
state of being free from microbes, viruses, fungi, bacteria, parasites, or infection. An aseptic environment is also known as a sterile environment.

Aspergillus
genus that includes several hundred species of mold. Some species can cause paranasal sinus infections or Aspergillosis. *Aspergillus* is of particular concern in health care facilities, because many patients already have compromised immune systems. If HVAC systems are not properly maintained or designed, mold growth may be likely.

bioaerosol
biological matter suspended in the air in the form of droplets or particles. Examples include fungal spores, plant pollen, bacteria, and viruses.

biological safety cabinet
mechanically ventilated enclosure that draws air inward and with HEPA filtration of all air exhausted from the cabinet. This device is used to protect the user, the product, and the environment. Used commonly in sterile-compounding procedures, its specific air change, exhaust, filtration, and recirculation requirements are based on the types of chemicals being mixed.

blanket warmer
cabinet for heating of blankets. Often found in pre-op and recovery areas. Heated blankets are used to better control temperature and metabolic rate, for increased comfort, or in the treatment of a patient.

burn unit
area of a health care facility dedicated to the treatment of burn victims. These areas often have very stringent HVAC requirements, including higher-than-normal air temperatures.

clean steam
steam generated in a system without chemical additives.

community-acquired infection
infection obtained before admission or entrance to a health care facility. Also known as *occupationally acquired infection*.

cough-inducement booth
closed booth with a seat for a patient; used to administer aerosol treatments. Patient isolation is important, both to administer the treatment and to isolate the infirmed patient from others. The booth draws air in through a prefilter and exhausts air through a HEPA filter.

decontamination
location in a health care facility where soiled instruments are sterilized. These rooms are exhausted.

emergency department (ED)
location where emergency services are administered. Patients are kept in the emergency department (ED) for observation and testing for up to eight hours.

emergency services
treatment or examination of injuries or ailments that require immediate response.

emergency ventilation
capability, as required in some facilities or rooms, for smoke removal (also called *smoke evacuation*). Generally requires (as a minimum) additional detail in the HVAC control sequence.

exam room
room where a patient is interviewed and receives a prognosis of treatment or is admitted to the facility for further treatment and observation.

fluoroscope
medical equipment used in a fluoroscopy procedure that allows a physician to see moving real-time images of a patient's internal structure. Consists of a fluorescent screen and an x-ray source; the patient is placed between these two elements for imaging.

fume hood
mechanically ventilated enclosure that draws air inward, to protect the user, the product, and the environment.

gamma knife
apparatus used in radiosurgery on the brain, in which high-intensity gamma rays are targeted to destroy tumors and cancer cells.

HEPA filter
filter with removal efficiencies of 99.97% or higher for a mass median particulate size of 0.30 μm (microns).

inpatient
patient admitted to a facility for overnight stay of an indeterminate length.

isolation room
see *airborne infection isolation (AII) room*.

laminar flow bench
apparatus used to prevent contamination of biological samples; laminar airflow is drawn through a HEPA filter, across the sample, and toward the user.

laser plume
smoke produced during laser surgery.

Legionella
bacterium that can cause the potentially fatal infectious disease legionellosis (Legionnaires' disease). *Legionella* transmission occurs through aerosolized water droplets, common in many cooling systems, that contain the bacteria.

linear accelerator
apparatus that administers radiation treatment to cancer patients.

Medicaid
health program in the United States through which services are provided to persons and families with low incomes and limited resources. The program is funded by the federal and state governments and is administered at the state level.

medical gas container
container that is inserted into a manifold for distribution of its contents.

medical gas manifold
used to distribute medical gases throughout a facility, a manifold has one fully redundant set of containers and is connected to the master alarm panel of the facility.

medical office building
facility that includes examination rooms, imaging, and spaces other than surgery. These buildings are built as a business-type occupancy.

Medicare
social insurance program in the United States for persons age 65 and older; administered by the federal government.

minimum efficiency reporting value (MERV)
value of filter fractional-particle-size efficiency for air cleaners tested per ANSI/ASHRAE Standard 52.2-2007.

nosocomial infection
infection obtained during a patient's stay in the hospital. Also known as a *hospital-acquired infection (HAI)*.

nuclear medicine laboratory (hot lab)
laboratory in which radioactive pharmaceuticals are prepared for administration to patients.

OBs unit
location in a health care facility where patients are taken when they require testing and observation in excess of eight hours.

oncology
branch of medicine dealing with cancer.

operating room
room used for surgeries requiring the administration of anesthetic gases that render the patient incapable of self-preservation in the case of an emergency. These rooms have stringent air change, temperature and humidity, air distribution, lighting, medical gas, and emergency requirements compared to other spaces in a health care facility.

outpatient clinic
facility that offers treatment, but does not admit patients for overnight stays.

parking deck
vehicle-parking facility, often spatially contiguous to a health care building, that is often the point of entrance for nonemergency patients and facility staff.

pathogenic
infectious; capable of causing disease.

protective isolation room
room for patients with immunodeficiency. Has special requirements to ensure that the patient receives only clean air. Also known as a *protective environment (PE) room*.

radioisotope hood
mechanically ventilated enclosure that draws air inward, to protect the user, the product, and the environment. HEPA or charcoal filter in the exhaust provides extra protection to the environment.

staph
short for *Staphylococcus*, a bacterium that can cause several different diseases in humans, including food poisoning.

sterile environment
necessary level of air cleanliness within a space in a health care facility. The HVAC system achieves a sterile environment through filtration, air distribution layout, and pressure relationships between adjacent spaces.

sterile field
designated volume of space that encapsulates the patient; is impinged upon by medical personnel during a surgery, and must be properly conditioned to prevent infection.

sterilizer
apparatus used to clean (sterilize) medical instruments with steam. Similar to an autoclave.

trauma
sudden physical injury, typically related to violence or an accident, that causes a subsequent wound or shock.

trauma level
levels of care, numbered I to V, from highest level of care to lowest. A Level I facility has a full range of specialists available 24 h/day and a research program on site. A Level II facility has the same capability as a Level I facility, but no research program. Level III has full availability of emergency resuscitation, surgery, and recovery areas. Levels IV and V provide diagnostic, stabilization, and evaluation services. Level IV may provide surgery and critical-care services. Transfer agreements with higher-level facilities are required for Levels III to V.

ultrasound
technology that uses electromagnetic waves just above the human audible range to create internal images; typically used with pregnant patients.

waiting room
typically open area where patients and guests wait to be seen. These areas often have high air-change requirements based on occupancy.

waste anesthesia evacuation system
system dedicated to catching waste anesthetic gas (gas that is not taken in by the patient). This function is vital because these fumes are flammable and can affect others. The system has two dedicated compressors. Related to *waste anesthesia gas disposal (WAGD)*.

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