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Air-Conditioning for the Environment of Care

According to the U.S. Environmental Protection Agency (EPA), Indoor Air Quality (IAQ) is one of the most important environmental health problems facing Americans today. Nowhere is this problem more of a concern than in healthcare settings where a significant population of the building occupants may be either sick, immunosuppressed, or both. These individuals spend the majority of their time within the hospital, vulnerable not only to building-related health concerns through exposure to airborne pollutants such as microorganisms, but additional factors such as building temperature, humidity, particle-count, pressurization, air-distribution and ventilation may also impact them negatively.

Many rooms in hospitals require special design considerations because of intensified infection concerns, high air change rates, special equipment, unique procedures, high internal loads and the presence of immunocompromised patients, but in no other healthcare space does the design of the HVAC system take on more importance than in an operating room (OR), where its sole purpose is to minimize infection, maintain staff comfort and contribute to an environment of patient care. While this engineering newsletter will discuss various aspects of HVAC system and ventilation design applicable to a hospital in general, its main focus will be on the design and control requirements specific to an OR setting.

Code and Standards Requirements

ANSI/ASHRAE/ASHE Standard 170, Ventilation of Health Care Facilities is considered the backbone of healthcare ventilation design. While the intent of the standard was never as a design guide, it does comprise a set of minimum requirements that define ventilation system design which helps provide environmental control for comfort, asepsis, and odor in health care facilities. It can also be (and is) adopted by code-enforcing agencies.

The standard defines minimum design requirements only, and due to the wide diversity of patient population and variations in their vulnerability and sensitivity, these standards do not guarantee an environment that will satisfactorily provide comfort and control of airborne contagions and other elements of concern. More comprehensive design assistance and best practices are available in other publications available from ASHRAE, such as ASHRAE Handbooks – HVAC Applications as well as the ASHRAE HVAC Design Manual for Hospitals and Clinics. Compliance with the standards should include HVAC systems designed for new or existing buildings, additions/alterations to existing buildings and HVAC system alterations.

Spaces within healthcare facilities vary widely by type of injury or illness presented by a patient and the scope of the various treatments and services which must be provided. The Standard includes three tables which define the design parameters for healthcare ventilation systems based on various occupancy classifications. Table 7.1 details the requirements for Hospital Spaces (see Fig. 1), Table 8.1 defines Outpatient Spaces, and Table 9.1 covers Nursing Home Spaces. Along with providing guidance on ventilating different space classifications, requirements for space pressurization and temperature are also included.

According to the World Health Organization[1], of every 100 hospitalized patients at any given time, seven in developed and 10 in developing countries will acquire at least one health care-associated infection.

[1] World Health Organization, *Health Care-Associated Infections Fact Sheet, http://www.who.int/gpsc/country_work/gpsc_ccisc_fact_sheet_en.pdf*

Figure 1 – Excerpt from ASHRAE Standard 170

Section 7 Space Ventilation — Hospital Spaces

7.1 General Requirements. Spaces shall be ventilated according to Table 7.1.

Table 7.1 Design Parameters – Hospital Spaces

Function of Space	Pressure Relationship to Adjacent Areas (n)	Minimum Outdoor ach	Minimum Total ach	All Room Air Exhausted Directly to Outdoors (j)	Air Recirculated by Means of Room Units (a)	Design Relative Humidity (k), %	Design Temperature (l), °F/°C
SURGERY AND CRITICAL CARE							
Critical and intensive care	NR	2	6	NR	No	30–60	70–75/21–24
Delivery room (Caesarean) (m), (o)	Positive	4	20	NR	No	20–60	68–75/20–24
Emergency department decontamination	Negative	2	12	Yes	No	NR	NR
Emergency department exam/treatment room (p)	NR	2	6	NR	NR	Max 60	70–75/21–24
Emergency department public waiting area	Negative	2	12	Yes (q)	NR	Max 65	70–75/21–24
Intermediate care (s)	NR	2	6	NR	NR	Max 60	70–75/21–24
Laser eye room	Positive	3	15	NR	No	20–60	70–75/21–24
Medical/anesthesia gas storage (r)	Negative	NR	8	Yes	NR	NR	NR
Newborn intensive care	Positive	2	6	NR	No	30–60	72–78/22–26
Operating room (m), (o)	Positive	4	20	NR	No	20–60	68–75/20–24
Operating/surgical cystoscopic rooms (m), (o)	Positive	4	20	NR	No	20–60	68–75/20–24
Procedure room (o), (d)	Positive	3	15	NR	No	20–60	70–75/21–24
Radiology waiting rooms	Negative	2	12	Yes (q), (w)	NR	Max 60	70–75/21–24
Recovery room	NR	2	6	NR	No	20–60	70–75/21–24
Substerile service area	NR	2	6	NR	No	NR	NR
Trauma room (crisis or shock) (c)	Positive	3	15	NR	No	20–60	70–75/21–24
Treatment room (p)	NR	2	6	NR	NR	20–60	70–75/21–24
Triage	Negative	2	12	Yes (q)	NR	Max 60	70–75/21–24
Wound intensive care (burn unit)	NR	2	6	NR	No	40–60	70–75/21–24
INPATIENT NURSING							
All anteroom (u)	(e)	NR	10	Yes	No	NR	NR
All room (u)	Negative	2	12	Yes	No	Max 60	70–75/21–24
Combination All/PE anteroom	(e)	NR	10	Yes	No	NR	NR
Combination All/PE room	Positive	2	12	Yes	No	Max 60	70-75/21-24

Note: NR = no requirement

Space Requirements

When designing a system within a healthcare facility, a variety of space requirements must be incorporated. Engineers should be sure to consider the following; Pressure Relationship to Adjacent Areas, Minimum Outdoor Air-Change Per Hour (ACH), Minimum Total ACH, Room Air Exhaust, Recirculated Air, Design Relative Humidity (RH), and Design Temperature.

Temperature

The purpose of the HVAC system serving an OR is to ensure staff and patient comfort while helping minimize infection. Therefore, one of the first determinations to make during the initial design phase is the environmental space temperature and humidity. These requirements should be considered a fundamental prerequisite in helping to promote overall occupant satisfaction and well-being. As shown in Figure 1, Standard 170 requires temperatures ranging from 68-75°F dry bulb (db) (20-24°C). It is important to note that these recommendations are considered minimum design values. The ASHRAE HVAC Design Manual for Hospitals and Clinics states that 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 HVAC system. A sick or immunocompromised patient residing in an uncomfortable environment may experience stress which could hinder their ability to better tolerate and recover from invasive surgery. Additional concern must revolve around the comfort of the surgeon and staff. A number of factors will go into the determination of the desired OR temperature, but many times the final decision is made by the surgeon-in-charge.

The ASHRAE Design Manual points out that the inability to maintain low OR temperature is probably the number one complaint by surgeons to facility engineers. To help mitigate this concern, OR design conditions should be developed in consultation with surgeons, anesthesiologists, infection control and nursing staff based on the classification of the surgery and any specific requirements that may result. The classifications and their characteristics are defined in Figure 2.

Figure 3 shows the range of various temperatures which are typically asked for in different OR settings. For example, orthopedic and cardiac operating room surgeons may request low temperatures, often as low as 60°F (15.5°C). While the standard contains specific requirements for continuous monitoring, those authorities having jurisdiction (AHJs) may request or require monitoring of temperature, relative humidity (RH), and dew point in ORs.

Figure 2 – Excerpt from ASHRAE Standard 170

Section 8 Space Ventilation — Outpatient Spaces
Table 8-2 — Classification of Surgeries from the *ASHRAE HVAC Design Manual for Hospitals and Clinics*

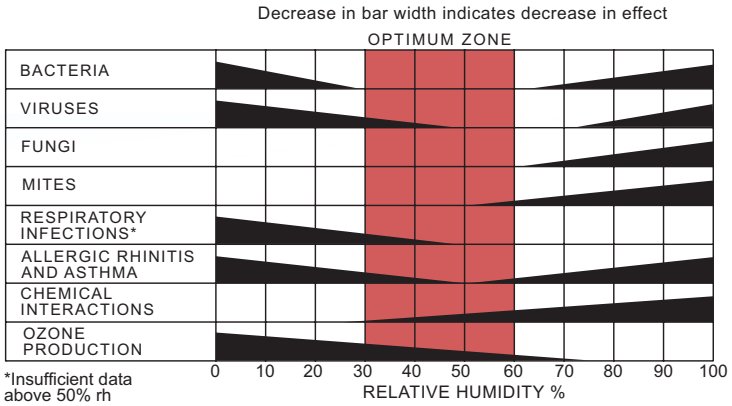
Class	Characteristics
Class A surgery	Provides minor surgical procedures performed under tropical, local, or regional anesthesia without preoperative sedation; excluded are intravenous, spinal, and epidural procedures, which are Class B or C surgeries.
Class B surgery	Provides minor or major surgical 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.

Figure 3 – Excerpt from ASHRAE Standard 170

Section 8 Space Ventilation — Outpatient Spaces
Table 8-4 – Typical Operating Room (OR) Requirements from the *ASHRAE HVAC Design Manual for Hospitals and Clinics*

OR Room Type	Requirements
Heat	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 4 – Excerpt from ASHRAE HVAC Systems and Equipment Handbook — Ch. 22



2016 ASHRAE HVAC Systems and Equipment Handbook — Ch 22

Relative Humidity

Just as critical as temperature, relative humidity (RH) plays a key role in maintaining a comfortable and healthy OR environment. The excerpt from Figure 1 shows Standard 170 requiring RH to be maintained in a range from 20-60%. Too much humidity can decrease the perspiration rate from a person's skin, resulting in an environment that feels relatively warmer than it actually is. It can also lead to a potential for mold and mildew growth within the built environment. On the other hand, dry air can affect people with respiratory problems, and also cause dry skin which can result in discomfort.

The Sterling Chart (Figure 4) was first published in 1985 with its focus being allergens, pathogens, chemicals and ozone with their increasing or decreasing effect on humans with changes in RH. Updated by ASHRAE, this chart has become a common reference for building design criteria, indicating that mid-range humidities between 30 and 60% RH are optimal for occupancy health and well-being.

While ORs have an upper humidity limit of 60% RH, it must be remembered that this value is relative to temperature and in some cases may be too high for the comfort of surgeons and staff who typically are garbed in various layers of protective gowning which impedes their body's ability to reject heat and perspiration into the atmosphere. In this case, lower RH values may be necessary in order to create an environment which can absorb perspiration and remove heat through multiple layers of clothing and into the surrounding dry air. Certain surgery classifications may require lower RH levels to help cure orthopedic cements and adhesives or to keep the space, equipment and medical devices free from moisture condensation on surfaces. As with temperature, RH may end up being a metric which will simply be asked for by the surgeon or staff at the time of the procedure. It should be noted that many times surgeons will ask for the OR to be made "colder" when in fact what they really want is a space that is relatively drier.

Regardless of what space conditions are deemed acceptable, it's important that the HVAC system be capable of delivering the supply air conditions necessary to maintain the combined OR temperature and RH. As an example of how environmental temperature and humidity requirements impact the HVAC system (and how the system can impact the resulting space condition), consider that a chiller supplying chilled water at 42°F will not be able to provide conditioned supply air (to the space) at a dew point temperature below about 47°F. Assuming traditional OR cooling loads, the lowest space dry bulb temperature that can be achieved in an OR designed for 50% relative humidity is approximately 68°F.

Table 1 – Chilled Water (CW) Temperature Required to Meet Space Dew Point Requirement

OR Space Conditions	Space Dew Point	CW Temp
60°F db at 50% rh	41°F	34°F
60°F db at 60% rh	46°F	39°F
64°F db at 50% rh	45°F	38°F
64°F db at 60% rh	50°F	43°F
68°F db at 50% rh	49°F	42°F
68°F db at 60% rh	54°F	47°F
72°F db at 50% rh	52°F	45°F
72°F db at 60% rh	57°F	50°F

Table 1 above lists the approximate chilled water temperatures that must be supplied in order to maintain various combinations of OR temperature and humidity. It is apparent that these space requirements have a direct impact on both sizing and selecting HVAC system components as well as what type of system can be utilized (chilled water, glycol or desiccant). It may be prudent for engineers to consider the possibility for future demands that will necessitate more extreme operational conditions, and discuss this with the "owner" during the initial design phase of the project.

LOAD ANALYSIS

In dealing with OR design where the mandate is for an environment that is both cool and dry, it is imperative to perform a comprehensive load analysis which includes all loads associated with the outdoor ambient condition, desired indoor space conditions (both temperature and humidity), ventilation air requirements, building heat gain and infiltration, internal heat sources, and any additional factors that will influence air-conditioning unit sizing.

Achieving the desired environmental conditions require simultaneously satisfying both the sensible (temperature) and latent (moisture) load components. An analysis of this magnitude may be outside the scope of traditional load calculation software, requiring additional psychrometric evaluation to ensure the humidity component of the load is properly addressed.

Colds, flu, sore throat, dry eyes, and itchy and cracked skin are usually prevalent in the cold dry months of the winter when the indoor RH is also at its lowest. Standard 170 states that when outdoor humidity and internal moisture sources are not sufficient to meet the minimum requirements of Tables 7.1, 8.1 or 9.1, humidification shall be provided by means of the facility air-handling systems. It also specifies the use of steam or adiabatic high-pressure water-atomizing humidifiers. Steam humidifiers are by far the most widely used means for achieving these requirements. In areas with hygienic constraints, the quality of steam provided to the environment is of great concern. The immersion-electrode steam humidifier (for example) uses “potable-water” in order to produce aseptic-steam that is breathable and considered free from contamination caused by bacteria and other harmful organisms.

Figure 5 – Excerpt from ASHRAE Standard 170

Section 6 – Systems and Equipment

6.4 Filtration. Filter banks shall be provided in accordance with Table 6.4.

Table 6.4 — Minimum Filter Efficiencies

Space Designation (According to Function)	Filter Bank No. 1 (MERV)[a]	Filter Bank No. 2 (MERV)[a]
Operating rooms (ORs); 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 (PE) rooms	7	HEPA[c,d]
Laboratory work areas, procedure rooms, and associated semirestricted spaces	13[b]	NR
Administrative; bulk storage; soiled holding spaces; food preparation spaces; and laundries	7	NR
All other outpatient spaces	7	NR
Nursing facilities	13	NR
Psychiatric hospitals	7	NR
Resident care, treatment, and support areas in inpatient hospice facilities	13	NR
Resident care, treatment, and support areas in assisted living facilities	7	NR

NR = not required

a. ***Informative Note:*** The minimum efficiency reporting value (MERV) is based on the method of testing described in ANSI/ASHRAE Standard 52.2 (ASHRAE [2017a]).

b. Additional prefilters may be used to reduce maintenance for filters with efficiencies higher than MERV 7.

c. As an alternative, MERV-14 rated filters may be used in Filter Bank No. 2 if a tertiary terminal HEPA filter is provided for these spaces.

d. ***Informative Note:*** High-efficiency particulate air (HEPA) filters are those filters that remove at least 99.97% of 0.3 micron-sized particles at the rated flow in accordance with the testing methods of IEST RP-CC001.6 (IEST [2016]).

Filtration

Standard 170 states that filter banks shall be provided in accordance with Figure 5, and that all of the air provided to a space shall be filtered in accordance with the data shown in this table unless otherwise indicated for spaces which allow recirculating HVAC room units.

Figure 5 specifies the number of filter banks required, and their location, as well as the minimum efficiency reporting value (MERV) of all filters. In HVAC systems requiring only one filter bank, it is to be located upstream of the heating and cooling coils so as to filter all of the mixed air flowing through the unit. When a second filter bank is required, it should be located downstream of all wet-air cooling coils and the supply air fan. When final filters are located downstream of any wet-air cooling coils, humidification devices or the supply air fan, particular attention by the HVAC design team is required as these filters have a tendency to become wet during air-conditioning system operation. This situation can create a breeding ground for mold and microbial growth. This is an unacceptable condition for any health care setting. In addition to health concerns, this moisture may reduce filter efficiency and add additional air-side pressure drop which increases fan operational costs.

In cooling systems that operate for many hours a day, considerable amounts of condensation may develop and collect on filters or other internal surfaces within the AHU. If downtime is not enough to allow this moisture to evaporate, filters will remain wet. Most conditions that cause wet filters can be eliminated with proper AHU design, selection and control. Ensuring that cooling coil air velocities are kept low enough to prevent moisture carryover into the airstream and that humidification controls, sensors and valves are installed and functioning properly are key considerations.

When designing an AHU for healthcare, which includes final filters, consider using a “draw-thru” (cooling coil before fan) versus a “blow-thru” (cooling coil after fan) configuration. This allows the residual motor heat from the draw-thru fan to be utilized as a source to heat the airstream leaving the cooling coil, moving its temperature slightly off the saturation point and reducing its relative humidity, usually enough to avoid any moisture development.

Most ORs are located within healthcare facilities in large city centers which often present designers with air quality challenges. Particulates can be controlled; however, gas contaminants emanating from vehicular exhaust, helicopter landing pads, or other outside sources often require additional gas-phase filtration.

Specifically, Section 6.2.1 Outdoor Air Treatment (ASHRAE Standard 62.1) states: If outdoor air is judged to be unacceptable in accordance with Section 4.1 (Regional/ Local Air Quality), each ventilation system that provides outdoor air through a supply fan shall comply with the National Ambient Air Quality Standard (NAAQS), which outlines acceptable levels of airborne contaminants (see Table 2). Gas-phase filtration is often used in a staged approach with particulate filtration, after initial particles have been removed. Particulate matter (PM10 and PM2.5), ozone and other outdoor contaminants that may have a synergistic effect on the air quality are the main concern in order to ensure acceptable IAQ in the OR.

Figure 6 – Hospital Roof, Helicopter Landing Pad Close to O.A. Intakes

Table 2 – National Ambient Air Quality Standards

Pollutant		Primary/Secondary	Averaging Time	Level	Form
Carbon Monoxide (CO)		Primary	8 hours	9 ppm	Not to be exceeded more than once per year
			1 Hour	35 ppm	
Lead (Pb)		Primary and Secondary	Rolling 3 month average	0.15 µg/m	Not to be exceeded
Nitrogen Dioxide (NO_2)		Primary	1 hour	100 ppb	98 percentile of 1-hour daily maximum concentrations, averaged over 3 years
		Primary and Secondary	1 year	53 ppb	Annual Mean
Ozone (O_3)		Primary and Secondary	8 hours	0.070 ppm	Annual fourth-highest daily maximum concentrations, averaged over 3 years
Particle Pollution	$PM_{2,5}$	Primary	1 year	12.0 µg/m	Annual mean, averaged over 3 years
		Secondary	1 year	15.0 µg/m	Annual mean, averaged over 3 years
		Primary and Secondary	24 hours	35 µg/m	98 percentile averaged over 3 years
	PM_{10}	Primary and Secondary	24 hours	150 µg/m	Not to be exceeded more than once per year on average over 3 years
Sulfur Dioxide (SO_2)		Primary	1 hour	75 ppb	99 percentile of 1- hour daily maximum concentrations, averaged over 3 years
		Secondary	3 hours	0.5 ppm	Not to be exceeded more than once per year

Internally generated, airborne biological contaminants are of predominant concern in healthcare when undertaking surgical procedures. Design engineers are often suggesting the use of Ultraviolet Germicidal Irradiation (UVGI) in upper ceiling systems to reduce Colony Forming Units (CFU) which can have an impact on patient care, recovery, and reduce Hospital Acquired Infections (HAI). Current trends in HVAC are also including UVGI in the air handling unit that serves the OR, preventing contaminants from forming on cooling coil surfaces which can curtail the development of CFUs in the wetted drain pan immediately following the cooling coil.

Pressurization

To protect patients and healthcare workers from contracting airborne infections in hospitals, space pressurization control and the creation of isolation rooms are used as a strategy to comply with code. Some rooms within a hospital are designated as Airborne Infectious Isolation (AII) rooms and are used for the care of patients with various airborne-communicable diseases. They are designed for negative pressure and 100 percent exhausted air. The intent is to create an environment that will contain and prevent the potential spread of patient-generated microbes that may be infectious to others within the facility. In addition, some spaces are designed as Protective Environment (PE) rooms and are provided for the care of immune-depressed patients who must be protected from various microbes, even those that may not pose a potential infection risk to a healthy individual. This environment is provided with an excess of supply air in order to support a positive pressure within the space.

Standard 170 states that an operating room (OR) must be designed for a minimum positive pressure differential to surrounding spaces of +0.01 inches of water (in. H_2O). This may require a 200-400 cubic feet per minute (cfm) supply-to-exhaust airflow offset in a typically sized, well-sealed OR. By providing the space with excess supply air, the OR becomes positively pressurized and establishes the exfiltration of outward-leaking air from a “cleaner” environment to its “less-clean” surroundings. This positive pressure differential forces interior air from the OR through cracks and leaks, such as around doors, keeping air movement in the desired direction.

Some ORs may be equipped with a permanently installed pressure monitoring device. These will usually have visual indication and can constantly monitor air pressure in order to ensure proper differential pressure is maintained. Various monitoring technologies are available, ranging from something as simple as a flutter strip or calibrated ball-in-tube device, to more sophisticated electronic monitoring systems. If electronic monitoring is installed, the Standard requires allowances to be made that will prevent the device from tripping nuisance alarms when short term pressure variations are experienced, as may occur when doors are temporarily opened and closed. While the Standard states no specific requirement for continuous monitoring, there is the requirement to have each OR tested for positive pressure on a semi-annual basis, or as part of an effective preventative maintenance program.

The air pressurization relationships of the OR cannot be compromised and must be maintained per the Standards requirements at all times, but when supplied with constant airflow these spaces can consume considerable amounts of energy. Recent energy conservation efforts focused on reducing energy use in hospitals have sparked interest in the concept of OR airflow setback during the unoccupied operational mode. Setback strategies which reduce airflow to the OR, only when unoccupied, have been implemented and found to save on fan, cooling and reheat energy.

Air Distribution

Standard 170 requires that the air distribution system be designed to maintain the pressure relationships while in all modes of operation. Any space with a required pressure relationship must be served with a completely ducted return or exhaust air system.

It is often not enough to adequately filter and pressurize incoming air within an OR. The creation of air curtains and laminar flow over the operation site has proven to be an additional effective means of ensuring success as it pertains to a patient's recovery and postoperative infection rate.

OR SETBACKS

When considering OR setback there are certain complexities that must be taken into consideration. In order to maintain the supply-to-exhaust offset necessary to create and maintain the space differential pressure, both supply and return air control devices must be installed. Many older OR HVAC systems do not include these devices, and retrofitting the installation to add them may be difficult or impractical. In addition, a reliable sequence and control strategy for both setback and setback-override must be developed. If manual override is requested by the staff, it may require an interlock to the space through a light switch, occupancy sensor, or time clock, adding complication to a space already inundated with complex equipment.

When in setback mode, it may be difficult to maintain proper temperature and humidity in the OR due to the lower quantity of supply air being delivered, and should a rapid transition from the unoccupied to occupied mode be required, it may be problematic bringing the space back up to acceptable environmental conditions quickly. When in the setback mode, it must also be ensured that the system is capable of adequately ventilating and removing any fumes that may be emitted during off-hour cleaning procedures.

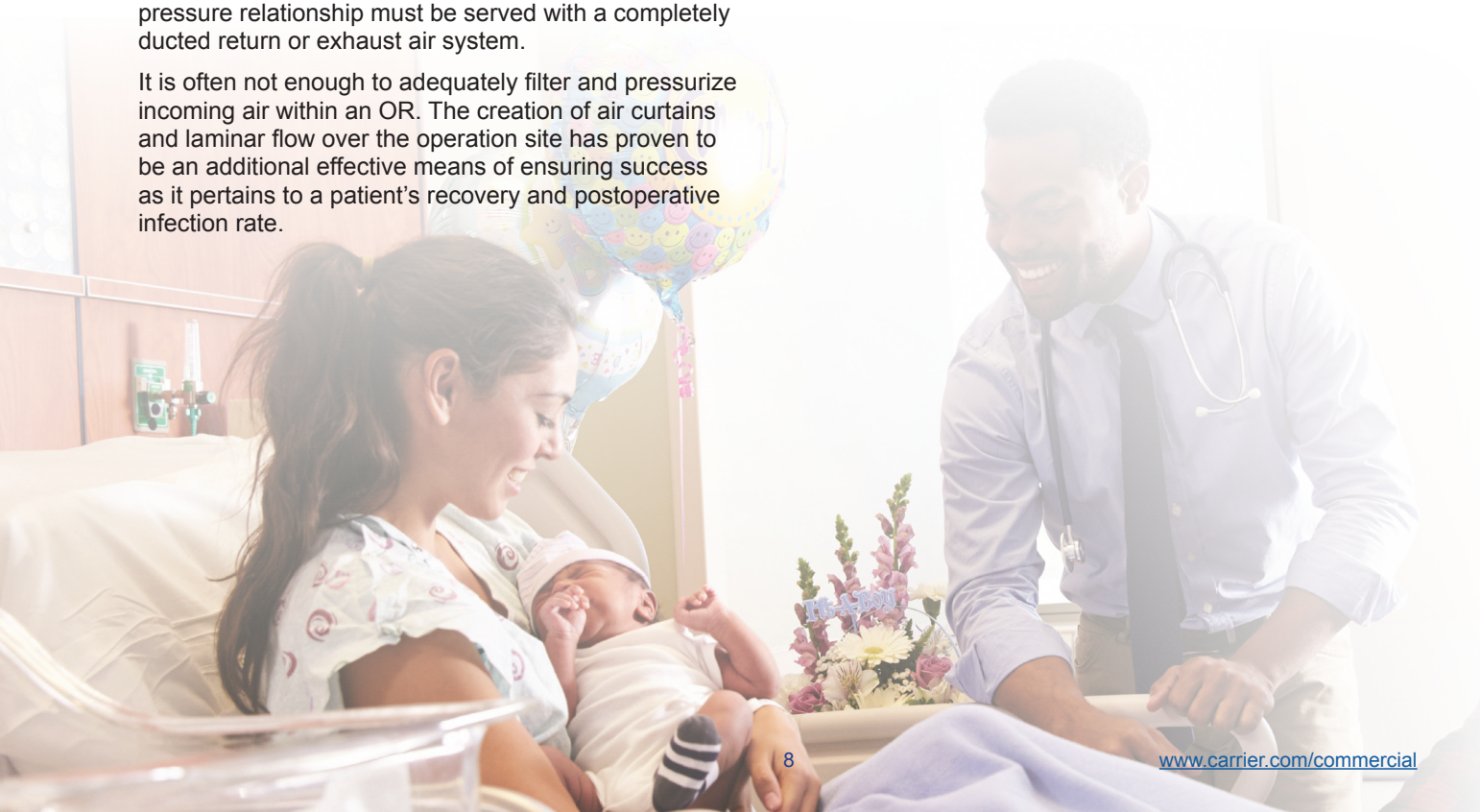


Figure 7 – Excerpt from ASHRAE Standard 170

Section 6 – Systems and Equipment
6.7.2 Air Distribution Devices. Supply air outlets in accordance with Table 6.7.2 shall be used.

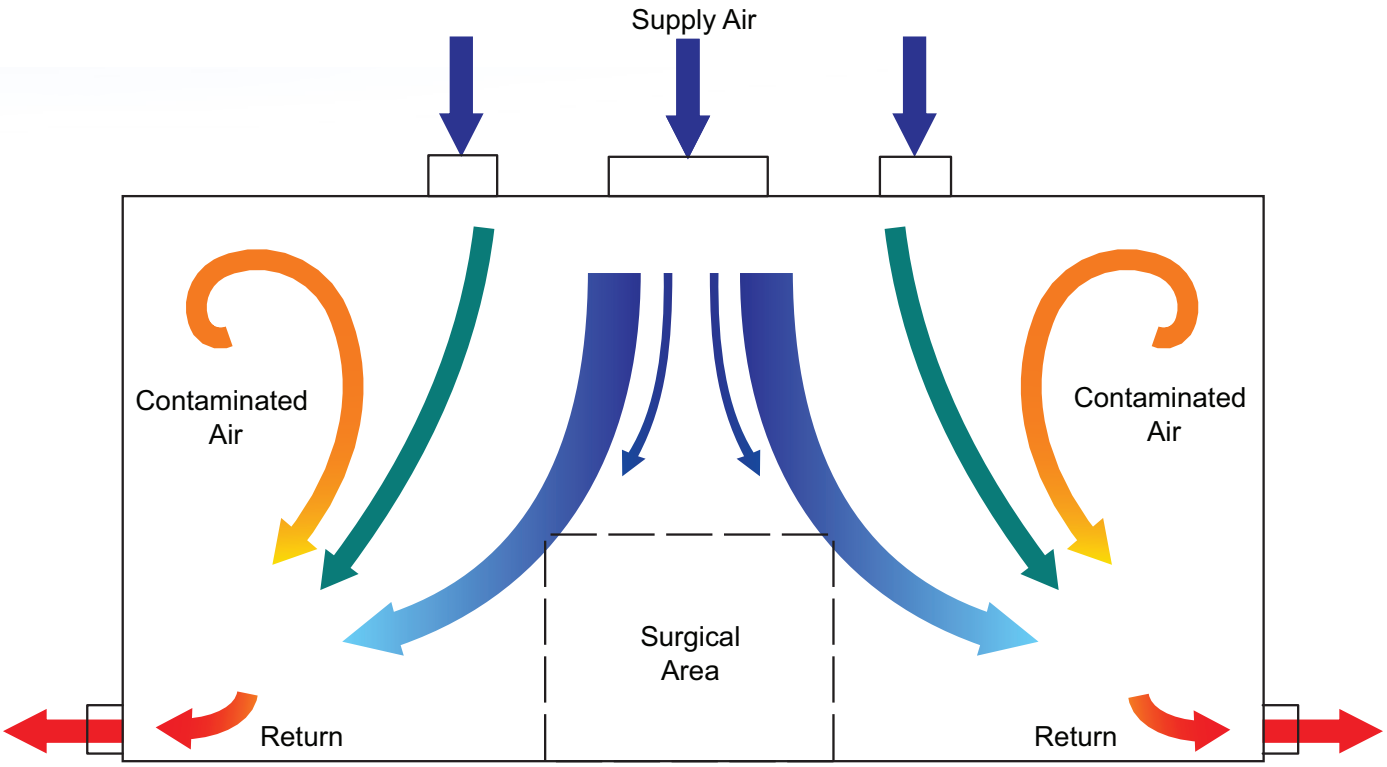
Table 6.7 — Supply Air Outlets

Space Designation (According to Function)	Supply Air Outlet Classification [a]
Operating rooms (ORs) [b], procedure rooms	Supply diffusers within the primary supply diffuser array: Group E, nonaspirating Additional supply diffusers within the room: Group E
Protective environment (PE) rooms	Group E, nonaspirating
Wound intensive care units (burn units)	Group E, nonaspirating
Trauma rooms (crisis or shock)	Group E, nonaspirating
AII rooms	Group A or Group E
Single-bed patient or resident rooms [c]	Group A, Group D, or Group E
All other patient care or resident care spaces	Group A or Group E
All other spaces	No requirement

a. ***Informative Note:*** Refer to the 2017 *ASHRAE Handbook—Fundamentals*, Chapter 20 (ASHRAE [2017c]), for definitions related to outlet classification and performance.
b. Surgeons may require alternate air distribution systems for some specialized surgeries. Such systems shall be considered acceptable if they meet or exceed the requirements of this standard.
c. Air distribution systems using Group D diffusers shall meet the following requirements:
   1. The system shall be designed according to "Design Guidelines" in *System Performance Evaluation and Design Guidelines for Displacement Ventilation*, Chapter 7 [4].
   2. The supply diffuser shall be located where it cannot be permanently blocked (***Informative Note:*** e.g., opposite the foot of the bed).
   3. The room return/exhaust grille shall be located in the ceiling, approximately above the head of the patient bed.
   4. The transfer grille to the toilet room shall be located above the occupied zone.

Air distribution design plays an important role in ensuring a healthy, contaminant free micro-environment around the surgery process. Through properly selected filtration and dilution techniques, the OR steady state concentration of contaminants such as airborne micro-organisms, anesthetic gases, and general odors can be controlled (see Figure 7). The goal is to keep all offending contaminant steady-state concentrations within acceptable limits and ensure that potentially contaminated air is directed away from the patient and the re-introduction of contaminants within the surgery room is minimized.

Figure 8 – Laminar Airflow Over an Operating Table



Source: Carrier

Most air distribution designs used in operating rooms are highly filtered systems commonly known as laminar airflow (LAF) (see Fig. 8). The principles of design are based on Extraction, Dilution, Isolation and Particle Control. In a properly designed and controlled OR ventilation system, air movement is directional with the intent of creating a sterile field around the patient zone.

The dilution air quantity required to be introduced in an LAF ventilation system is typically 15-25 air changes per hour (ACH). In this design, air distribution strategy ensures that the cleaned ventilation air is supplied in a parallel manner through the OR. This is achieved by providing large volumes of air with a uniform flow field over the patient zone. The concept is based on the entrainment of remaining particulates in the primary air, including squames from the OR staff, which are then directed away from the patient zone to perimeter locations where they can be exhausted from the room. Prevention of bacteria-carrying particles (BCPs) from entering the wound area is the primary goal of this ventilation strategy.

Airflow pattern obstacles, including surgical personnel, medical devices, lighting, etc. are considered to be the main factors that influence an OR ventilation system's ability to maintain an infection free site. Since unidirectional-vertical downward airflow patterns can be easily disturbed, particularly when the air is flowing at a low velocity, a secondary ventilation method is often used, namely the Air Curtain. Considering that surgery staff can contribute to site contamination, air curtain design can help ensure that the introduction or re-entrainment of contaminants is minimized by creating an air barrier around the patient zone. With the reduction of post-operative infections as

the primary goal, this dual approach ensures that primary clean air maintains a sterile surgical field, while the air curtain ensures that secondary contamination from the staff or local environment do not enter the operation site. There are specialized air diffusion grills and registers available to the designer that can help achieve the LAF – Air Curtain combination.

Although these fundamental design principles are considered standard in OR design today, surgery room configurations vary and the designer must adapt to continuous changes in OR equipment locations, surgery staff preferences, room sizes and frequency of usage.

Ventilation

Because of heightened infection concerns, ORs have prescribed air change and pressurization requirements. The current recommendation in Facility Guidelines Institute (FGI) *Guidelines for Design and Construction of Hospitals* and *Outpatient Facilities* and Standard 170 (per Table 7-1) is 20 air changes per hour (ACH) supply air including 4 ACH of outdoor air (20% outdoor air).

One important dynamic associated with outdoor air ventilation includes the thermal and energy related influence it has on properly sizing the HVAC system. Outdoor air ventilation requirements can contribute to over 40% of the peak air conditioning load in an OR, so choosing the outdoor ambient conditions to be used in the load analysis, and properly assessing the A/C equipment's capacity requirement are another critical step in determining its total impact.

The ASHRAE Handbook of Fundamentals Chapter 14 provides climatic design information for 6443 locations in the United States, Canada and around the world. This includes summaries of values for dry bulb, wet bulb, and dew point temperature. Warm season temperature and humidity conditions are based on annual percentiles of 0.4, 1.0 and 2.0 (% of 8760 hours). The use of annual percentages ensures that they represent the same probability of occurrence in any climate; so, for example, using the 0.4 percentile would represent a "to-exceed" occurrence at this condition for no more than about 35 hours per year.

When referring to this climatic information, ASHRAE provides five different data sets from which to choose. We will review only two. The first, Cooling db/wb, is considered "Cooling Design Day" data and is traditionally chosen when sizing "less-critical" applications such as commercial office buildings. The second data set, Dehumidification DP (dew point)/HR (humidity ratio)/MCDB (mean coincident dry bulb), is considered "Dehumidification Design Day" data and is traditionally chosen when sizing buildings where there is a "more critical" concern in maintaining the required indoor relative humidity condition at all times, particularly on days of the year that are "wetter" than others, such as a warm mid-summer day when it has just rained. Someone outdoors on a day like this may describe it as feeling like "wearing a wet blanket."

To show the impact in choosing one set of conditions over the other, let's examine weather data compiled for the city of Houston, Texas at the 0.4 percentile:

Cooling Design Day: 97.2°F db / 76.6°F wb = **39.95 Btu/lb.**

Dehumidification Design Day: 78.2°F db / 147.1 HR / 82.9 MCDB = **42.95 Btu/lb.**

This small difference in enthalpy may seem insignificant, but it actually has a major impact on the HVAC system's ability to meet higher latent load requirements when necessary. If attempting to cool 10,000-cfm of outdoor air from Dehumidification Design Day conditions to a supply air temperature of 52°F db/51°F wb, an A/C unit sized using the Cooling Design Day weather data would be undersized by approximately 24 tons of latent cooling capacity and a little over 11-tons in total cooling capacity. This error (particularly in critical care environments) can result in disastrous effects by limiting the ability of the HVAC system to produce proper environmental space conditions. This can contribute to an OR that will rise above acceptable indoor relative humidity levels and possibly result in the formation of condensed moisture (from the air) on interior surfaces. Table 3 shows the same effect this scenario would have on other locations throughout the US.

Table 3 – A/C Capacity Shortage by Various Locations

City	Latent-Tons	Total-Tons
Minneapolis, MN	18.3	11.6
New York City, NY	17.9	7.7
Omaha, NE	17.3	9.5
Charlotte, NC	17.7	5.7
Orlando, FL	17.9	6.2
Atlanta, GA	18.9	7.6
Chicago, IL	17.4	10.4
Los Angeles, CA	26.9	17.9

SUMMARY

Healthcare facility design is a blend of code and standards compliance along with a healthy dose of engineering best practice. There is probably no other industry in the country so heavily governed and regulated. Professionals involved in the design of these complex facilities must keep abreast of ever-changing local, state and federal requirements while taking keen interest in the rapid evolvement of the healthcare process. The HCAHPS (Hospital Consumer Assessment of Healthcare Providers and Systems) survey is the first national, standardized, publicly reported survey of patients' perspectives of hospital care. This creates incentives for hospitals to improve the patient experience, placing new value on the environment of care in which these patients reside. Engineers responsible for the systems which produce the temperature, humidity, air movement, ventilation and filtration within these environments are under increased pressure to assure their designs meet stringent code mandates while also contributing to the complex dynamics of patient wellbeing and outcome.

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