OCTOBER 2019

ASHRAE JOURNAL

THE MAGAZINE OF HVAC&R TECHNOLOGY AND APPLICATIONS ASHRAE.ORG

Hospital ORs: Conditioning For Critical Care

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Conditioning for the Environment of Critical Care

Hospital Operating Rooms

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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 health-care space does the design of the HVAC system take on more importance than in an operating room (OR), where its purpose is to minimize infection, maintain staff comfort and contribute to an environment of patient care.

ANSI/ASHRAE/ASHE Standard 170, *Ventilation of Health Care Facilities,*[1] is considered the backbone of health-care ventilation design. The intent of the standard is to provide comprehensive guidance, comprising a set of minimum requirements that define ventilation system design that 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 OR environment that will satisfactorily provide comfort and control of airborne contagions and other elements of concern. When selecting the temperature and relative humidity combination to be incorporated into the design, these standard minimums as well as the needs and desires of the surgical staff must be taken into consideration. The ASHRAE *HVAC Design Manual for Hospitals and Clinics*[2] 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.

Temperature and Relative Humidity

While this article has an emphasis on areas requiring dehumidification, it is not meant to imply that "very-dry" air is the answer. It's important to remember that a healthy level of indoor air hydration, in balance with the room temperature setpoint, helps promote overall environmental satisfaction and performance. 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

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overall occupant satisfaction and well-being. As shown in *Table 1,* Standard 170 requires temperatures ranging from 68°F to 75°F dry bulb (DB) (20°C to 24°C). It is important to note that these recommendations are considered minimum design values.

TABLE 1 ASHRAE Standard 170-2017, Table 7.1 Design Parameters–Hospital Spaces.

FUNCTION OF SPACE	PRESSURE RELATIONSHIP TO ADJACENT AREA	MINIMUM OUTDOOR ACH	MINIMUM TOTAL ACH	ALL ROOM AIR EXHAUSTED	AIR RECIRCULATED BY ROOM UNITS	DESIGN RELATIVE HUMIDITY %	DESIGN TEMPERATURE °F
Operating Room	Positive	4	20	NR	NO	20 – 60	68 – 75

Just as critical as temperature, relative humidity (RH) plays a key role in maintaining a comfortable and healthy OR environment. *Table 1* shows Standard 170 requiring RH to be maintained in a range from 20% to 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. Dry air below 40% RH has been shown to correlate with an increase in health-care associated infections.[3]

While ORs have an upper humidity limit of 60% RH, note that this value is relative to temperature and in some cases may be too high for the comfort of surgeons and staff who typically wear various layers of protective gowning that impedes their body's ability to reject heat and perspiration into the atmosphere. In this case, lower RH (and temperatures) values may be necessary in order to create an environment that can absorb perspiration and remove heat through multiple layers of clothing and into the surrounding dry air. Certain surgery classifications may require specific RH levels to help cure orthopedic cements and adhesives or to keep the space, equipment and delicate medical devices free from condensation on surfaces.

Determining Proper OR Environmental Conditions

With regard to the temperature and relative humidity range listed in Standard 170-2017, Table 7.1, normative note "1" states: "Systems shall be capable of maintaining the rooms within the range (listed in the table) during normal operation. Lower or higher temperature shall be permitted when patients' comfort and/or medical conditions require those conditions." The *HVAC Design Manual for Hospitals and Clinics*[2] 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.

TABLE 2 Typical OR requirements, from the ASHRAE HVAC Design Manual for Hospitals and Clinics.

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

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, both temperature and RH may end up being a metric that will simply be "asked for" by the surgeon or staff at the time of the procedure. *Table 2* may be of some guidance to the design professional when trying to pinpoint the proper requirements, but unless the engineer is fortunate enough to discuss this matter with the surgeon prior to designing the HVAC system, any guess may be as right (or as wrong) as another.

In my own experience, I have found that surgeons performing more intensive procedures prefer cooler, less humid surroundings. The point where the facility manager's cell phone stops ringing with complaint calls from the surgical staff, or what I refer to as "the point of diminishing complaints" occurs when OR conditions are capable of being held in a range between 60°F and 64°F (15.5°C/17.7°C) and 40% to 50% RH. Without a clear understanding of what the procedural requirements dictate (or what the staff desires) it may behoove the facility design professional to default on the safe side, designing a more flexible HVAC system that can achieve cooler and drier environments, should it ever be expected. Regardless of what space conditions are deemed acceptable, the HVAC system must be capable of delivering the supply air conditions necessary to maintain the combined temperature and RH.

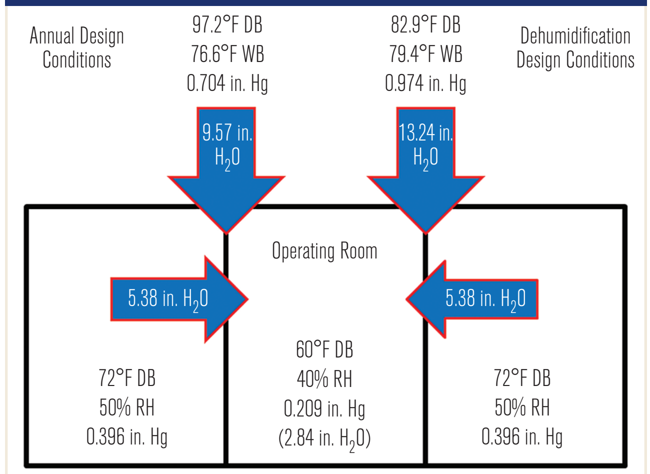
OR HVAC Load Analysis

In dealing with OR design where the mandate is for an environment that is both cool and not too humid, it is imperative to perform a comprehensive load analysis which includes all loads associated with the outdoor ambient conditions, desired indoor space conditions (both temperature and humidity), ventilation air requirements, building heat gain, infiltration, internal heat sources, and any additional factors that will influence HVAC system sizing. Achieving the desired environmental conditions require simultaneously satisfying both the sensible and latent load components. OR load analysis is a relatively straightforward process with the exception of a few key considerations.

One important aspect of the HVAC load analysis that should not be overlooked is properly defining the latent component contributed by the vapor pressure differential between the OR and all surrounding environments. Vapor pressure differentials result from the differences in absolute humidity between areas. Absolute humidity can be defined as the amount of water vapor present in a unit volume (cubic foot of air) and is measured in inches of mercury (in. Hg vp). Note that absolute humidity does not fluctuate with the temperature of the air. Air pressure is typically measured in inches of water (in. H_2O). Realizing that mercury weighs over 13 times more than water, it becomes apparent that the partial pressure of water vapor exerts a considerable force in comparison.

Figure 1 shows that this can create a substantial driving force, greatly contributing to the transmission of moisture from the ambient surroundings into the OR. Consider that the infiltration of air and its accompanying load must pass through cracks and penetrations in the construction, whereas water vapor can diffuse through the entire surface of a building component (permeation), impeded only by its permeance rating and any added resistance due to vapor barriers. Many interior and some exterior walls and ceilings within a hospital do not have true vapor barriers installed within, and if there may be poorly installed or severely damaged. An OR that is positively pressurized for an airflow differential of +0.01 in. H_2O/0.0025 kPa (+0.0007 in. Hg vp) may stand little chance of opposing the migration of moisture into the space due to the higher pressures driving the water vapor, along with the way moisture transfers through building materials.

FIGURE 1 Potential vapor pressure differentials across building components of the OR.



It is important to understand that underestimating the amount of vapor migration the space will experience can have a negative effect when trying to maintain a hospital OR designed for deeply cooled and dehumidified conditions such as 60°F (15.5°C) dry bulb and 40% to 50% RH. In addition, latent loads associated with people and other internal and external moisture sources must be addressed. An analysis of this magnitude may be outside the scope of traditional commercial building HVAC load calculation software, requiring additional psychrometric evaluation to confirm the humidity component of the load is properly addressed.

Another critical component of the load analysis is the contribution made by the outdoor ventilation air. Outdoor air ventilation requirements can contribute to over 40% of the peak air-conditioning load in an OR, depending on climate zone, so choosing the outdoor ambient conditions to be used in the load analysis, and properly assessing the HVAC system capacity requirement are important steps in determining its total impact.

When referring to climatic information, ASHRAE provides five different data sets from which to choose. We will discuss only two. The first, cooling dry bulb (DB)/mean coincident wet bulb (MCWB) 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 dew point (DP)/humidity ratio (HR) /mean coincident dry bulb (MCDB), 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 midsummer 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 George Bush Intercontinental Airport/Houston (WMO: 722430) at the 0.4 percentile: Cooling Design Day: 97.5°F (36.4°C) DB/76.4°F (24.7°C) MCWB, which translates to an enthalpy of 39.74 Btu/lb (92.4 kJ/kg). Dehumidification Design Day: 78.0°F (26°C) DP/146.1 HR/82.8°F (28.2°C) MCDB, which translates to an enthalpy of 42.78 Btu/lb (99.51 kJ/kg). 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 (4719 L/s) of outdoor air from Dehumidification Design Day conditions to a supply air temperature of 52°F DB/51°F WB (11.1°C DB/10.5°C WB), an HVAC system sized using the Cooling Design Day weather data would be undersized by approximately 25-tons (88 kW) of latent cooling capacity and 11-tons (39 kW) of 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 moisture levels. *Table 3* shows the same effect this scenario would have on other locations throughout the United States. Note that when developing HVAC equipment schedules it is important for the engineer to list both the cooling design day and dehumidification design day requirements and to make sure the selected HVAC equipment can meet both.

TABLE 3 Capacity shortfall using "cooling" vs. "dehumidification" design data.

CITY	LATENT TONS	TOTAL TONS
Minneapolis	18.3	11.6
New York City	17.9	7.7
Omaha, Neb.	17.3	9.5
Charlotte, N.C.	17.7	5.7
Orlando, Fla.	17.9	6.2
Atlanta	18.8	7.6
Chicago	17.4	10.4
Los Angeles	26.9	17.9

Equation 1 shows the various components that comprise the calculation used to determine the dehumidified supply air condition required to satisfy the latent load in the OR. Regardless of the method used to calculate this load, determining the OR environmental conditions, particularly the moisture control level (dew point), at the very beginning of system design will help build the foundation on which a properly sized HVAC system can be engineered.

$$Q = \frac{W_t}{d \times 60 \times (M_m - M_c)} \tag{1}$$

Q = Airflow rate required to remove OR moisture (cfm)
W_t = Total internal OR moisture load (gr/hr)
d = Density of the air (lbs/ft^3)
60 = Minutes per hour
M_m = Moisture control level inside the OR (gr/lb)
M_c = Moisture level of the dry air supplied to OR (gr/lb)

Regardless of location, most areas throughout the U.S. (and perhaps the world) require stringent dehumidification in order to meet the lower temperature and humidity requirements associated with critical OR environments. In addition, humidification may be necessary at certain times of the year, as the OR air can become too dry during cold winter months. This aspect of environmental control will not be addressed in this article.

HVAC System Requirements

It's important that the HVAC system be capable of delivering the supply air condition required to maintain the correct combination of temperature and RH in the OR. As an example of how environmental temperature and humidity requirements impact the HVAC system (and how the system can impact the resulting space conditions), consider that a chiller supplying chilled water at 42°F (5.5°C) will not be able to provide conditioned supply air (to the space) at a dew-point temperature below about 49°F (9.4°C) with a 7°F (3.8°C) chilled water to supply air temperature approach. Assuming traditional OR cooling loads, the lowest space dry-bulb temperature that can be achieved in an OR designed to maintain 50% RH is approximately 72°F (22.2°C). What this demonstrates is that while the chilled water temperature may be more than capable of satisfying even the coolest space temperature requirement, it may not be cold enough to produce the required dehumidification that results in satisfactory RH. This can be a major shortcoming for hospitals trying to please surgeons who are demanding more comfortable OR environments. Facility managers will turn down the thermostat to reduce temperature only to find that the staff continues to complain. The experience is chalked up to a doctor who can't be satisfied when in fact this isn't actually the case. The complaint is often legitimate and the issue can usually be resolved.

Table 4 lists the approximate chilled water temperature that must be supplied in order to maintain various combinations of OR space temperature and humidity. It is apparent that the space environmental requirements have a direct impact on both sizing and selecting the HVAC system, as well as what type of system can be used (chilled water, glycol or desiccant). Note that actual space load calculations are required to guarantee performance; this chart is only for approximation of temperatures.

Many times a hospital's central utility plant (CUP) will be designed using more traditional leaving chilled water temperatures, such as 42°F to 44°F (5.5°C to 6.6°C). If both the hospital and the ORs are fed from the CUPs distributed piping network, problems can arise. It can be seen from *Table 4* that there is a limited range of OR dew points that will be achievable using chilled water temperatures above 40°F (4.4°C). Clearly, attempting to provide cooler and drier conditions would be out of reach. In situations like this, two measures can be implemented. The first is to reduce the leaving chilled

TABLE 4 Chilled water and supply air temperatures required to achieve various OR environmental conditions (based on 7°F/3.8°C chilled water to leaving air approach).

SPACE °F DB	SPACE RH%	SPACE °F DP	SAT °F DB	CWT °F DB	REHEAT °F DB	CHILLED WATER
70	50	50.5	47.5	40.5	17.5	Yes
70	40	44.6	41.6	34.6	23.4	Glycol
68	50	48.7	45.7	38.7	17.3	Yes
68	40	42.8	39.8	32.8	23.2	Glycol
66	50	46.9	43.9	36.9	17.1	Yes
66	40	41.0	38.0	31.0	23.0	Glycol
64	50	45.0	42.0	35.0	17.0	Yes
64	40	39.2	36.2	29.2	22.8	Glycol
62	50	43.2	40.2	33.2	16.8	Glycol
62	40	37.4	34.4	27.4	22.6	NA
60	50	41.3	38.3	31.3	16.7	Glycol
60	40	35.6	32.6	25.6	22.4	NA

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water temperature from the CUP which serves the entire hospital. While this may remedy the problem in the OR, it will also result in an energy penalty on the entire plant of approximately 1.5% to 2% for each 1°F (0.56°C) reduction in temperature (along with an accompanying reduction chiller capacity). Many times it is determined that the associated energy penalty will be too large or that existing chillers are not adequately sized for the lift required to achieve the necessary temperature reduction.

The second measure is to provide a standalone HVAC system designed to produce the required dehumidified supply air condition to the OR. Options include traditional or glycol chilled water, solid desiccant and liquid desiccant systems. Of course, it's always best to design the job right from the beginning. Anytime existing installations must be retrofitted, excess cost is incurred and valuable time wasted. Most health-care operations are sorely lacking in both time and resources.

When it comes to making a determination of the system type to be considered, the following guidelines can be followed. If the required leaving chilled-water and leaving supply-air temperatures are safely above freezing, traditional chilled water can be employed. This may be the least expensive from a first cost and energy consumption perspective, but only when capable of producing the environmental conditions needed. Based on refrigerant suction temperature, and if the necessary leaving chilled-water temperature approaches or is below freezing, glycol must sometimes be introduced. A glycol chiller may be the next least expensive first-cost option, but possibly not the most energy-efficient choice. Situations that exclude the use of chilled water altogether include supply air temperature requirements closely approaching 32°F (0°C), where coil frosting and freezing of condensate become an issue of concern. If the required leaving supply-air temperature approaches or is below freezing, desiccant technology must be considered. There is a multitude of dynamics that will define the correct choice based on considerations of first cost, energy consumption, life-cycle cost and payback, system complexity, maintenance requirements, redundancy considerations and owner familiarity. These are beyond the scope of this discussion, but a future article will delve into this subject in great detail.

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Conclusion

Operating room 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 as health care. 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 health-care process. Engineers responsible for the systems that produce the temperature, humidity, air movement, ventilation and filtration within these environments are under increased pressure to ensure their designs meet stringent code mandates while also contributing to the complex dynamics of patient wellbeing and outcome.

References

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3. Taylor, S., W. Hugentobler. 2016. "Is low indoor humidity a driver for healthcare-associated infections" *Indoor Air*. Paper 340: Session 98 www.isiaq.org/docs/Papers/Paper340.pdf. ■