Environmental Design Considerations for Hospital Operating Rooms

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ELIMINATING WET AND MOLDY FINAL FILTERS IN HEALTHCARE AIR HANDLERS

Microbial Growth on Filters

Anyone who has experienced "wet-filters" inside a healthcare HVAC air-handling unit (AHU) knows this situation can create a breeding ground for mold and microbial growth, an unacceptable condition for patient care settings. In addition to health concerns, this moisture may reduce filter efficiency and add additional air-side pressure drop which increases fan operational costs.

This wetting situation may be more evident with blow-thru fan configurations, and when filters are positioned immediately downstream of cooling coils and humidification components in what is considered the "final-filter" position. 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. But even with the most judicious AHU design, filters may still become wet for what appears to be no good reason. There is a relatively simple explanation as to why this may happen. Cold air leaving a cooling coil will typically approach saturation (the air is near 100% relative humidity). When this airstream enters a final filter, or any component that increases its velocity, the temperature of the air will drop as the air accelerates. Even a slight drop in temperature may be enough to allow the airstream to cool to a point where moisture condenses. In cooling systems that operate for many hours a day, considerable amounts of moisture may condense and collect on filters or other internal surfaces within the AHU. If downtime is not significant to allow this moisture to evaporate, filters will remain wet.

When designing a healthcare AHU that includes final filters, consider using a "draw-thru" (cooling coil before fan) verses "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 condensation.

Additional environmental design considerations that need to be addressed when designing hospital operating room environments includes: air conditioning load analysis methodology, environmental space temperature and humidity requirements and outdoor air loads. The next section will cover these considerations in more detail.

Air-Conditioning Load Analysis Methodology

There is a saying; the devil is in the details. Nowhere is this more true than when it comes to designing hospital operating room (OR) environments. When sizing HVAC systems, load analysis software will typically estimate the cooling load and calculate the air-conditioning (A/C) unit capacity required. Cooling load considerations include the outdoor ambient condition, desired indoor space conditions (both temperature and humidity), ventilation air requirements, building heat gain and infiltration, internal heat sources, and additional factors that influence A/C unit sizing. The software determines the required conditioned supply temperature (dry bulb/wet bulb) and airflow (in cubic feet per minute), while usually calculating these conditions with an emphasis on satisfying the space sensible cooling requirement. This is because in reality, the A/C system will be controlled by a thermostat responding to temperature and not humidity. This can result in a room relative humidity that deviates (floats up or down) from the desired value. Considered non-critical environments, commercial buildings designed like this may have summer indoor comfort requirements calling for 75°F db (dry bulb) at 50% rh (relative humidity) with an allowable tolerance of (+/-) 5% from set point.

Unlike commercial buildings, hospital ORs are considered critical care environments and usually require more stringent space design and control, to conditions such as 60°F db at 40% rh with an allowable tolerance of (+/-) 1% from set point. ASHRAE and FGI standards mandate air-change requirements for the quantity of conditioned air that must be provided, and achieving the desired environmental conditions requires simultaneously satisfying both the sensible (temperature) and latent (moisture) load components. An analysis of this magnitude may be outside the capability of traditional load calculation software, requiring additional evaluation to ensure the humidity component of the load is properly addressed, particularly when designing for dry environments such as an OR.

Environmental Space Temperature and Humidity Requirements

The first determinations to make during the initial design of an OR are the environmental space temperature and humidity requirements. Recent Facilities Guideline Institute (FGI) and American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standards recommend temperatures ranging from 68-74°F db at 20-60% rh. It is important to note that these recommendations are considered minimum design values. The *ASHRAE HVAC Design Manual for Hospitals and Clinics, second edition*, 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. Surgeons often request space conditions that are both cooler and dryer than those listed in the standards for various reasons. The ASHRAE manual goes on to point out that the inability to maintain low OR temperature is probably the number one complaint by surgeons to facility engineers.

As an example of how OR environmental temperature and humidity impact the HVAC system, 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. The table below lists the approximate chilled water temperatures that must be supplied in order to maintain various OR conditions. It is apparent that the space temperature and humidity requirements have a direct impact on what temperatures the HVAC system must produce (both water and air) and what type of system must be utilized (chilled water or desiccant).

CW Temperature Required to Meet Space Dew Point

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

Source: Carrier Corporation

Outdoor Air Ventilation Loads

Once the OR space temperature and humidity requirements have been established, it's time to begin identifying the individual A/C load components and the impact each contributes to sizing the HVAC system. According to the *ASHRAE HVAC Design Manual for Hospitals and Clinics, second edition*, the purpose of the HVAC system in an OR is to minimize infection and maintain staff and patient comfort. Because of heightened infection concerns, ORs have prescribed air change and pressurization requirements. The current recommendation in 2014 FGI *Guidelines for Design and Construction of Hospitals and Outpatient Facilities* and ANSI/ASHRAE/ASHE Standard 170-2013 (per Table 7-1) is 20 air changes per hour (ach) supply air including 4 ach of outdoor air (20% outdoor air). This outdoor air requirement can contribute to over 40% of the peak air conditioning load, so choosing the outdoor ambient conditions (to be used in the analysis) is a critical step in determining its total impact.

The *ASHRAE Handbook of Fundamentals (2013)* 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 36 hours per year. The user must determine from which percentile category to select the weather data based on how many hours per year the A/C system can "miss the mark," possibly falling short of meeting the load if actual outdoor ambient conditions exceed the data set for a short period.

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 Houston Intercontinental Airport at the 0.4 percentile:

1. Cooling Design Day: 97.2°F db / 76.6°F wb = 39.95 Btu/lb.
2. Dehumidification Design Day: 78.2°F db / 147.1 HR / 82.9 MCDB = 42.95 Btu/lb.

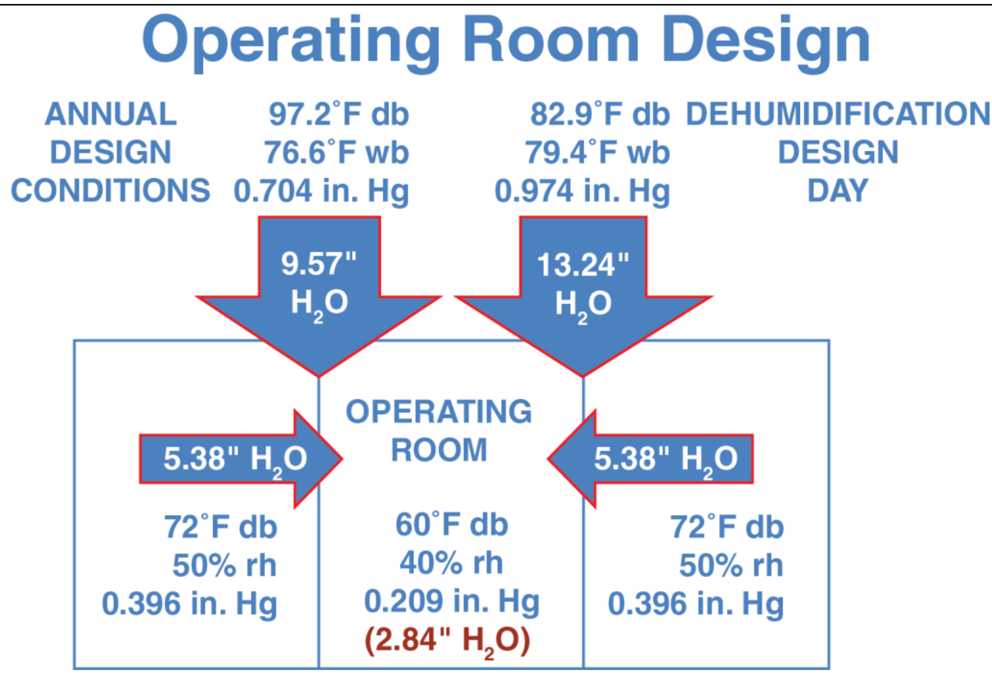
This small difference may seem insignificant, but it actually has a major impact on the HVAC system's ability to meet higher latent load requirements when necessary. If attempting to cool 10,000-cfm of outdoor air from Dehumidification Design Day conditions to a supply air temperature of 50°F db / 49°F wb, an A/C unit sized using the Cooling Design Day weather data would be undersized by 24.2 tons of latent cooling capacity and a little over 10 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.

Operating Room Moisture Migration Considerations

When we think of protecting patients and healthcare workers from contracting airborne infections in hospitals we regard space pressurization control, like the creation of isolation rooms, as a code required compliance strategy. The *ASHRAE HVAC Design Manual for Hospitals and Clinics, second edition*, states that an OR must be designed for a minimum positive pressure differential to surrounding spaces of +0.01 inches of water (in. H_20). This may require a 200-400 cubic feet per minute (cfm) supply-to-exhaust airflow offset. 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.

It is often believed that this type of space pressurization can also help prevent the migration of moisture from areas of higher relative humidity within the hospital to areas controlled for a lower relative humidity, such as ORs where cold and dry conditions are often desired. But is this really the case?

An industry dehumidification design manual states that moisture will diffuse through a solid material at a rate proportional to the vapor pressure differential across the material and inversely proportional to the material's porosity. Said differently, the higher the vapor pressure differential (between spaces) and the "worse" the permeance rating (resistance to moisture migration) of building materials, the more moisture will pass through. This diffusion of moisture will occur independently of any airflow or movement.



- 1-inch of water = .0735-inches of mercury
- 1-inch of mercury = 13.60-inches of water

Source: Carrier Corporation

Vapor pressure differentials result from the differences in the 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 as much as water, it becomes apparent that water vapor exerts a considerable force in comparison.

The accompanying graphic shows the vapor pressure differential, in both inches of mercury and inches of water, from one side of a space to another at various ambient conditions. It is apparent that vapor differential can create a driving force that greatly contributes to the transmission of moisture through a building. Consider that the infiltration of air and its accompanying temperature/moisture must pass through cracks and penetrations in the construction, whereas water vapor can diffuse through the entire surface of a building component, 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; if there, they may be poorly installed or severely damaged. An OR that is positively pressurized for an airflow differential of +0.01 in. H_2O (+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. A comprehensive analysis is required to correctly establish the moisture loads that any HVAC equipment will need to remove from within a space. The greater the difference in vapor pressure (moisture) between the controlled space and the surrounding environment, the greater the load will be from this load element.

Commercial HVAC load procedures or software may fall short in correctly determining the magnitude of moisture migration if airflow infiltration alone is the only analysis methodology considered. Proper calculations will take into account various factors such as permeation through floors, walls and ceilings, evaporation from people's clothing, breath and perspiration, desorption from moist products, evaporation from wet surfaces, air infiltration through leaks, holes and door openings, and fresh air ventilation from outside the space, to name a few.

Regardless of how you determine the amount of vapor migration a space will experience, it is important to understand that underestimating it can have a detrimental effect when trying to maintain a hospital OR designed for deeply cooled and dehumidified conditions such as 60°f dry-bulb temperature and 40-50% relative humidity.