WHY IS IT "RAINING" IN MY SURGERY SUITE?

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Getting the Humidity Factor Under Control

Is it “raining” in your operating rooms? Do you find that there are times throughout the year when the humidity levels are so high in the space that there are droplets of condensate dripping from the ceiling diffusers and suspended fixtures of the operating rooms? This is a common complaint being heard frequently in many hospitals today, especially throughout the southern climate regions. This paper is an effort to give its readers a better understanding of the cause of this moisture/humidity phenomenon. By understanding the cause of the “rain” and the probable cause of these higher than desired relative humidity levels, these problems can be resolved and/or prevented from occurring in the operating suite.

There are a number of reasons why controlling humidity in the operating rooms has been such a struggle for the hospital facilities management personnel. However, it is this author’s opinion that three of the fundamental reasons are: 1) a lack of understanding of basic psychrometrics, 2) the HVAC systems are being designed without consideration of ASHRAE’s more recently published weather design data and “real world” space condition design guidelines, and 3) inappropriate HVAC systems are being designed and installed for the task (technology and capacity).

Whether considering the retrofit of an existing HVAC installation or designing a new system, the fundamentals outlined in this paper will ensure that the wide ranges of temperatures desired by the surgical staff today can be readily achieved. With proper design considerations, HVAC systems can be designed without the threat of higher than acceptable humidity levels or condensate dripping from the ceiling and suspended fixtures.

What is meant by “raining”?

If you are a healthcare facilities operator you are probably used to the early morning calls from the surgical staff. Chances are they’re not calling to let you know the operating rooms are just perfect and they couldn’t let the morning go by without thanking you. It is more likely that they are calling with complaints about it being “too hot” or that it is “raining” in the rooms. While the “too hot” complaint seems easy enough to remedy, the root of that problem is often the same as with the “raining” complaint in the operating room. Both can be problems associated with excessive humidity in the space. We know that an environment with excessive humidity will make it “feel” warmer than it really is. This results in the “hot” calls. But what is this “raining” phenomenon, how common is it, and what causes it?

The expression of it “raining” in the operating room merely means that there is condensate dripping from the ceiling and/or any of the fixtures hanging from the ceiling. This problem isn’t new, but it appears that it is occurring far more frequently now than just a few years ago. Why? Many of the operating rooms today are being maintained at a temperature much cooler that the room’s HVAC system was originally designed to sustain. We’ll get into much more detail further in this paper as we discuss the applicable design guidelines and their limitations.

How common is this phenomenon? It is difficult to say with certainty; however, this author has had the opportunity to speak before many hospital engineering groups concerning humidity control, or lack thereof, in the operating rooms. When the question is asked of the audiences “how many have had problems with it “raining” in your operating rooms?” a show of hands typically reveals about 50% to 75% of the attendees have experienced this problem. Whether or not a formal industry-wide survey has been conducted hasn’t been determined; however, these informal surveys conducted at national and southeastern United States regional conferences indicate that this is a major concern in the healthcare industry.

What is the harm you ask? Unquestionably, there is the loss of productivity (with surgical staff as well as facility operations personnel) associated with the uncomfortable operating room conditions. But more importantly, there are serious health concerns associated with moisture condensing on a cool, probably unsterile, ceiling or suspended fixture. While it may often be considered just a nuisance to have the water droplets “raining” from the ceiling, it can become much more than simply a “nuisance” if these droplets were to fall into an open body cavity during a surgical procedure.

Before we can resolve the issue with the proper HVAC system design, its application and operation, we must first refresh our understanding of a few basics of psychrometrics.

Basic Understanding of Psychrometrics

Psychrometrics is simply the study of the physical and thermodynamic properties of air and water vapor mixtures. If the hospital facilities engineer and his/her design team have an adequate understanding of the basics of psychrometrics, then they are well on their way to designing and operating an HVAC system for the hospital and its surgical suite that will *actively control* the humidity in the space.

The most common terms used by the hospital staff, as well as their design engineers, are simply *temperature* and *relative humidity*. When the word *temperature* is used, it is most often referring to the *drybulb* temperature of the air. As its name implies, this is merely the space temperature as measured by a thermometer with a *dry* bulb. If a *wick*, or *sock*, were wetted with distilled water and placed around the bulb of the thermometer, such as would be seen with a measuring device known as a sling psychrometer, the *wetbulb* temperature of the surrounding air could be measured. As air passes over a thermometer with a wet wick over its bulb, some of the liquid from the wick evaporates into the surrounding air. For liquid water to evaporate into a vapor, it must gain heat. It takes this heat from the mercury within the thermometer as the water evaporates from the wick into the surrounding air. The drier the surrounding air, the more moisture that air can hold and the more readily the moisture will evaporate from the wick causing the *wetbulb* temperature to drop. The *wetbulb* temperature of the air is always at, or below, the *drybulb* temperature. What does the *wetbulb* tell us? When both the *drybulb* and the *wetbulb* temperatures are measured, many other properties of the air can be determined when these measured temperatures are plotted on a psychrometric chart (see Figure 1).

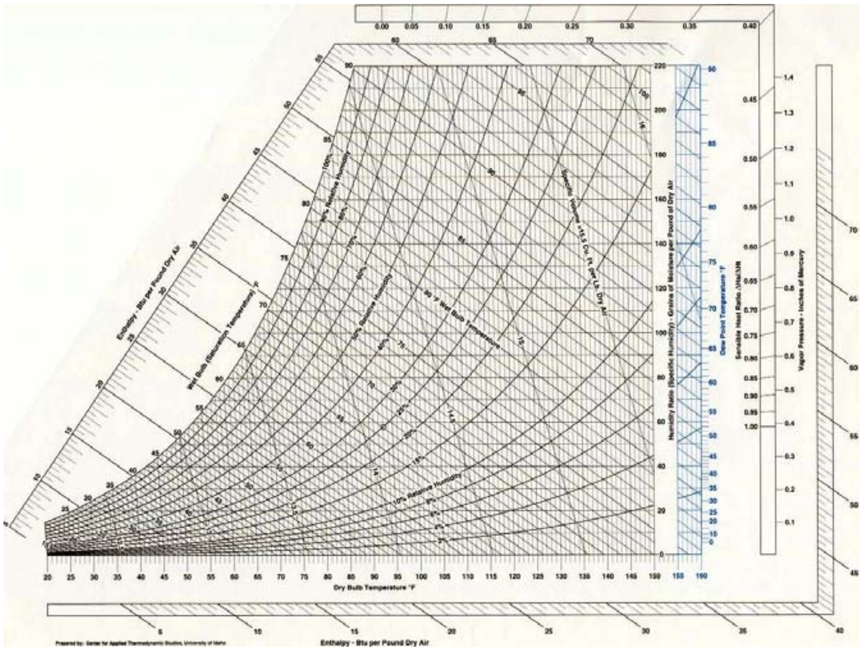


Figure 1 – Psychrometric Chart

Most commonly, the surgical staff wants to know the *relative humidity* of the space. The *relative humidity* is the ratio of the moisture content in the air to the total amount of moisture the air could hold at that given *drybulb* temperature. As the definition indicates, simply adjusting the *drybulb* temperature will alter the air's *relative humidity*. Therefore, a more *absolute* measurement of the moisture content of the air is necessary to know. This *absolute* measurement of moisture can be referred to as either *dewpoint* temperature, *humidity ratio*, or *specific humidity*.

The *dewpoint* temperature of the air is the temperature at which the air sample cannot hold any more moisture. The water vapor in the air will begin to condense into a liquid once it cools to its *dewpoint* temperature. This is what happens when humid air touches a cooler surface such as a cool ceiling surface or a hanging fixture in a 65^{0}F or cooler operating room. The *absolute* moisture of the air can also be measured in *grains* of moisture per pound of dry air and is expressed using the term *specific humidity*. A grain is simply a small unit of measurement (i.e., one pound equals 7000 grains). The moisture content, if expressed using the term *humidity ratio*, is a measurement of the *pounds* of moisture per pound of dry air.

Although there are many other properties of temperature and moisture that can be determined from the psychrometric chart (i.e., *vapor pressure, enthalpy, specific volume, density*, etc.) once the *drybulb* and *wetbulb* temperatures are measured, the most critical property to understand in this paper will be that regarding the *absolute humidity* of the air. In this paper, the absolute moisture will be expressed first in *dewpoint* temperatures and following in parentheses, the absolute moisture will be expressed as the corresponding *specific humidity* (grains of moisture per pound of dry air). For example, if the conditions within the space were measured to be 75^{0}F *drybulb* temperature and 62.5^{0}F *wetbulb* (50% *relative* humidity), the *absolute* humidity would be 55.1^{0}F *dewpoint* (64.9 gr/#). Throughout the remainder of this paper, if the temperature is listed and there is no reference to *drybulb*, *wetbulb*, or *dewpoint*, it should be understood that this author is referring to the *drybulb* temperature.

Design Considerations for Sizing the HVAC Equipment

Two important factors must be considered when determining the capacity requirements of the HVAC systems. First, it must be determined what conditions are expected to be maintained in the surgical suites. It is recommended that the design team (architect and engineer) and representatives of the hospital staff (facilities personnel as well as surgical staff) meet to determine the actual space conditions to be achieved and maintained by the HVAC system. Simply sizing equipment to achieve "normal" or "typical" conditions isn't sufficient. Secondly, the quantity of ventilation air, or outdoor air, is significant for a surgical suite. Therefore care must be taken when calculating the cooling and dehumidification requirements (as well as humidification requirements for winter months) that accurate ambient conditions are considered.

Understanding the Environmental Design Guidelines for the Operating Rooms

While the recommended design guidelines may vary by region of the country, it is generally accepted that the guidelines adhered to are usually that of the AIA (American Institute of Architects), the most current ASHRAE Standards or possibly the respective state's Health Department Requirements (which typically reference the AIA or ASHRAE standards).

For example, a portion of the table of the current design guidelines from ASHRAE's *HVAC Design Manual for Hospitals and Clinics* is as follows in Figure 2:

Comparison of Engineering Best Practice with AIA Guidelines and ASHRAE Handbook

Function Space	**Operating Room (100% Outside Air System)**	**Operating Room (Recirculating Air System)**	**Operating Room Surgical Cystoscopic Rooms**
Minimum Air Changes of Outdoor Air / Hour			
Manual	*	5	5
ASHRAE Handbook	15	5	*
AIA Guideline	*	*	3
Minimum Total Air Changes / Hour			
Manual	*	25	25
ASHRAE Handbook	15	25	*
AIA Guideline	*	*	15
Relative Humidity, %			
Manual	*	30-60	30-60
ASHRAE Handbook	45-55	*	*
AIA Guideline	*	*	30-60
Design Temperature, °F			
Manual	*	68-75	68-75
ASHRAE Handbook	62-80	*	*
AIA Guideline	*	*	68-73

** No Value Given*

Figure 2 – Environmental Design Conditions
(Excerpts from Table F-1 of ASHRAE's *HVAC Design Manual for Hospitals and Clinics)*

Although the range of acceptable conditions according to any of these guidelines allows for a fairly wide range of temperatures and absolute moisture levels (see Figure 3 for the generally accepted range) the more commonly targeted design condition among the design community appears to be 68^0F *drybulb* and 50% *relative humidity*, as it is in the center of the range. Looking on the psychrometric chart, it can be found that the *absolute* humidity at this condition is 48.7^0F *dewpoint* (51 gr/#).

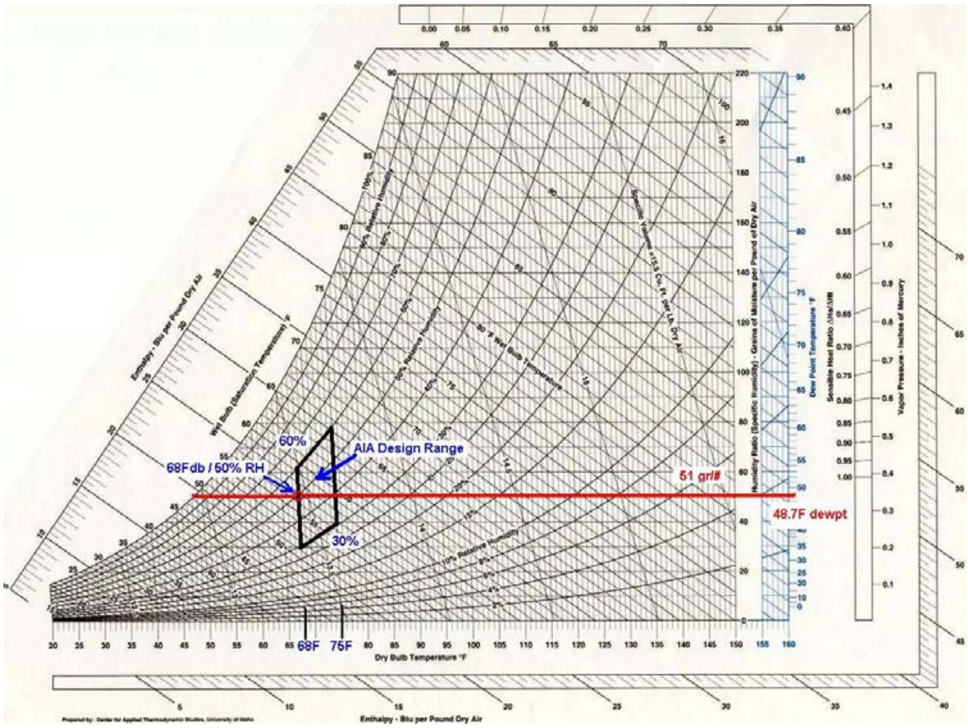


Figure 3 – Space Design Conditions

Real World Operating Room Conditions

However, it has become very common for the surgeons to request cooler temperatures than the HVAC system was designed to maintain under these AIA guidelines. Due to the heavy, multiple-layered gowning and the long procedures, many surgeons are requiring that their surgical suites today be maintained at 60^0F to 65^0F *drybulb* or lower during their surgical procedures. In addition to the concern for the surgeon's comfort, it is often necessary to maintain these lower drybulb temperatures in the operating rooms due to therapeutic reasons or to keep the adhesive cements used in orthopaedics from setting too quickly. Even at these lower *drybulb* temperatures, the *relative humidity* in the space is still expected to be maintained near 50% by the surgical staff. Looking again at the psychrometric chart, we see that the corresponding *absolute* humidity at a relative humidity of 50% for both 60^0F and 65^0F is 41.3^0F *dewpoint* (38.5 gr/#) and 45.9^0F *dewpoint* (45.9 gr/#), respectively. As you can see, if the installed HVAC system were only designed to achieve an *absolute* moisture level in the operating suite of 48.7^0F *dewpoint* (51 gr/#) (this is the *absolute* moisture level at 68^0F and 50% RH), that moisture level would be too high to maintain 50% RH when the *drybulb* temperature of the space is lowered. So what does this mean for the surgical suite's operating environment? If the *absolute* humidity in the space was designed to be 48.7^0F *dewpoint* (51 gr/#) and the *drybulb* temperature were dropped to 60^0F by the surgical staff prior to surgery, the resulting relative humidity in the room would be 66.1%, at best. (See Figure 4 below).

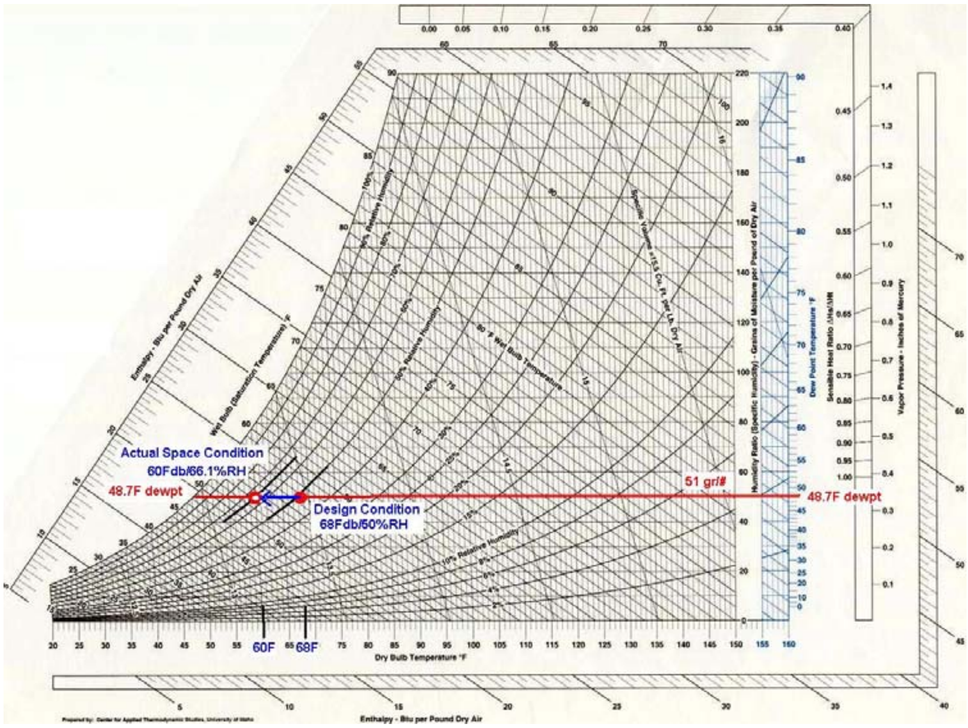


Figure 4 – Operating Room's Condition with Cooler Space Temperature

Understanding and Applying the Psychrometrics

With this little bit of review on psychrometrics and design standards, it can be demonstrated why the "raining" phenomenon occurs. Consider for example that the HVAC system installed is an air handler with chilled water coils. Assuming the entering water temperature is 44^0F, the supply air condition (i.e., leaving air temperature) would be approximately 52^0F saturated (i.e., 52^0F *drybulb*, 52^0F *wetbulb*, and also 52^0F *dewpoint* (57.8 gr/#)). Assuming the surgical team contributes a latent load (i.e., moisture gain) sufficient to raise the absolute moisture level of the operating room (which was designed to be maintained at 68^{0}F *drybulb* / 50% *relative humidity* (48.7^{0}F *dewpoint* (51 gr/#)) by 4 to 6^{0}F in dewpoint, the resulting space *absolute* humidity would be approximately 56 to 58^{0}F dewpoint (67.1 to 72.2 gr/#).

If the air being delivered through the supply air registers into the room were to be 55^{0}F (assuming heat gain in the duct from the air handler to the room to be only 3^{0}F), then the supply air register's surface temperature, as well as any other surface nearby, would also be approximately 55^{0}F *drybulb*. If the air surrounding these cooler surfaces had an *absolute* moisture content of 56 to 58^{0}F *dewpoint* (67.1 to 72.2 gr/#), moisture *will* begin to condense and begin to drip into the operating theater … it's now "raining".

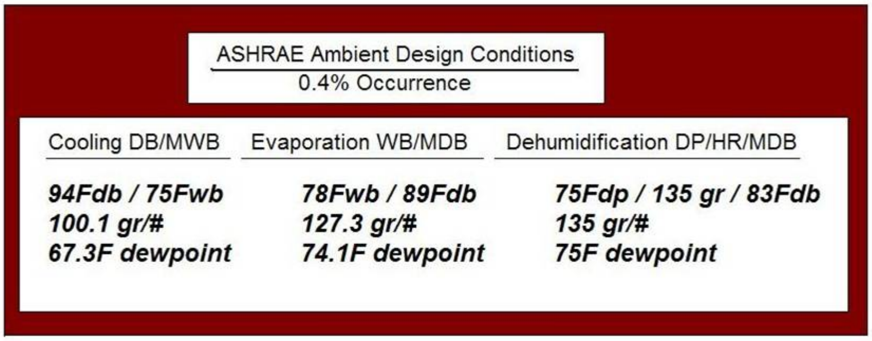
Typical Design Errors

Too often, the *drybulb* temperature concerns for the operating room are the primary concern of the HVAC designer. The humidity control aspect of the design is only secondary. It is felt that the humidity will simply "take care of itself" as long as the temperature is being controlled. However, understanding the *absolute* humidity needs of the space will reveal that the supply air *dewpoint* temperatures will likely need to be lowered, considering the lower temperatures the surgical staff is now demanding in the space. Consider, for example, that the intended space design condition was only 68^{0}F *drybulb* and 50% *RH*. Again, this is an *absolute* moisture level of 48.7^{0}F dewpoint (51 gr/#). If the scheduled supply air condition from an air handler is delivering 52^{0}F (sat) this means that the air is being supplied at a moisture level already greater than the intended space design condition (i.e., 52^{0}F *dewpoint* air being supplied into the space vs. 48.7^{0}F *dewpoint* desired) … and this doesn't even take into account the additional moisture that can be expected from the staff. To put this into perspective, this is similar to supplying 70^{0}F *drybulb* air into a space and expecting it to eventually cool the space down to something less, maybe 65^{0}F *drybulb*. Obviously, this is not possible, but this is the same erroneous logic that is often seen today with many designs in regard to the humidity control.

Considering the Correct Ambient Conditions When Designing

In addition to establishing the proper space design conditions, the second point of concern is regarding the design conditions used for the ventilation air (i.e., outdoor air, or ambient air). In calculating the cooling and dehumidification loads of the space, too often only the ambient peak design condition for *cooling* is considered ignoring the valuable weather data that is available in the ASHRAE *Fundamentals Handbook, 2001*. Past ASHRAE *Fundamentals Handbook* editions (1993 edition and earlier) only included the weather conditions for the occurrences of the *Drybulb / Mean Coincident Wetbulb* temperatures for a number of cities. This condition indicates the peak *sensible* condition of the ventilation air, but does not indicate the peak *latent* condition of the air. The 1997 edition of the *Fundamentals Handbook* for the first time included a set of tables to be used when sizing ventilation equipment and/or when humidity control is important to the end user. This table indicates the occurrences of the peak latent ambient condition … *Dewpoint / Humidity Ratio and Mean Coincident Drybulb*. In other words, we no longer have to guess at the peak latent design conditions for the ventilation air. We have historical data available for most major cities. The engineer must make certain that not only the peak *drybulb* temperatures of the hospital's geographic location are considered, but that the peak *dewpoint* temperatures are considered.

To demonstrate the importance of this available data, consider the ambient design conditions for Birmingham, AL (using the 0.4% occurrence data). If only the ambient peak *sensible* conditions are considered, the HVAC system might be designed using the outside air entering the system at 94^{0}F *drybulb*/75^{0}F *wetbulb*/67.3^{0}F *dewpoint* (100.1 gr/#). The peak *latent* conditions shown in the chart, however, indicates the same number of hours per year will yield outdoor air at 75^{0}F *dewpoint* (135 gr/#) at a coincident *drybulb* temperature of 83^{0}F (see Figure 5). How critical is this? For each 1,000 cfm of ventilation air entering each operating room, this difference in moisture content would be the equivalent of adding over 2.5 gallons of water per minute into the space!



ASHRAE Ambient Design Conditions
0.4% Occurrence

Cooling DB/MWB	Evaporation WB/MDB	Dehumidification DP/HR/MDB
94Fdb / 75Fwb	**78Fwb / 89Fdb**	**75Fdp / 135 gr / 83Fdb**
100.1 gr/#	**127.3 gr/#**	**135 gr/#**
67.3F dewpoint	**74.1F dewpoint**	**75F dewpoint**

Figure 5- Ambient Design Conditions for Birmingham, AL
(Excerpts from ASHRAE's Fundamentals Handbook)

Selecting the Right HVAC System for the Project

Before the proper HVAC technology can be selected, it is imperative that the appropriate design conditions be determined for the space, as mentioned earlier. Rather than only considering the applicable design standards available (e.g., AIA, ASHRAE, etc.), the design team should also seek input from the surgical staff. The obvious next step to take would be to calculate the expected latent gain (i.e., moisture gain) within the space.

If the design team determines that 68^{0}F *drybulb* and 50% *RH* is satisfactory (i.e., 48.9^{0}F *dewpoint* (51 gr/#)), and a latent gain from the surgical staff is expected to increase the *dewpoint* by 6^{0}F, then the equipment must be selected that would be capable of supplying air with a *dewpoint* of not more than approximately 43^{0}F.

If the staff indicated their desire to hold conditions in the space during surgery of 60^{0}F *drybulb* and 50% *RH* (41.3^{0}F *dewpoint* (38.5 gr/#)), then the supply air must be delivered at approximately 35^{0}F *dewpoint* (29.9 gr/#).

Once an educated consensus of the space design condition has been determined, and the moisture gain expected in the space from the staff is calculated, the design engineer can begin his or her design of the appropriate HVAC technology.

The HVAC equipment designed into the project must be capable of delivering air with the appropriate supply air *dewpoint*. It is important to understand that moisture can be removed from an airstream in only one of two ways. It must either be *condensed* out of the air (which would employ a mechanical-based system), or it must be *adsorbed* out of the airstream (using a desiccant-based system).

Mechanical Technology (Conventional Air Handling Systems)

As can be recognized, a conventional HVAC system that includes cooling coils with 42^{0}F to 45^{0}F entering chilled water temperatures will result in a supply *dewpoint* temperature of something in the 50^{0}F to 52^{0}F range. The *apparatus dewpoint*, or the *dewpoint* of the air being supplied from the cooling coils, is typically 6 to 8 degrees higher than the entering water temperature. This may be too high to achieve the desired humidity conditions in the surgical suite, when being maintained at the lower *drybulb* temperatures. For the general patient rooms and other less demanding spaces within the hospital, these supply air *dewpoint* temperatures will likely suffice; however, for the surgical suites, other technologies must now be considered.

If a low temperature chiller (i.e., a glycol-based solution) were to be used to supply cooler chilled water to the coils, the lowest water temperature likely to be considered would be 38^0F. With the entering water temperature of 38^0F the resulting supply air temperature from the coils is likely to be 44^0F to 46^0F *dewpoint*. If the *absolute* humidity of the operating rooms were to be designed to be anything greater than 50^0F to 52^0F (after considering the latent gain from the surgical staff), then this might be a viable solution.

Desiccant Technology

However, a more effective technology to consider for these lower *dewpoint* supply conditions would be a desiccant-based air handler. By incorporating a desiccant-based dehumidification system into the mechanical design for the hospital's operating suite, the overall system can be designed for optimal and *active* humidity control. No longer does the surgical staff have to tolerate less than desirable space conditions. No longer would there be a threat of it "raining" in the operating room during surgeries. The common problem of the fogging of microscope lens would also be eliminated with the lowering of the *dewpoint* temperature of the air in the operating rooms. By incorporating a desiccant system into the HVAC system design, the *absolute* humidity levels can be dropped much lower than the chilled water (or DX) coils are capable of achieving. Regardless of the *drybulb* temperature desired in the space, the humidity can be controlled to the lower levels without requiring low chilled water temperatures. A desiccant-based system can be added to strictly condition the ventilation air requirements of the surgery suite or it can be sized to treat the entire supply air requirements of the suite. As this technology is gaining favor in the design community and within the healthcare industry, further details will be given to explain how this technology works.

A "desiccant" is any material that has a great affinity toward moisture. In the majority of the commercially available desiccant-based dehumidification systems, the desiccant material is Silica Gel and is bonded onto the substrate material of the rotor (or wheel). The desiccant material on this rotor removes moisture in the vapor stage from the "process" airstream by adsorption. This is the airstream that is to be dehumidified, whether it is all outside air or a mixture of OA and return air. The moisture-laden rotor then rotates through a section of the air handler known as the *reactivation*, or regeneration, section. In this section, the desiccant material on the rotor is dried with heat using either a gas-fired burner, a steam coil, or even an electric resistance heater (see Figure 6). This process operates continuously as long as there is a need for dehumidification.

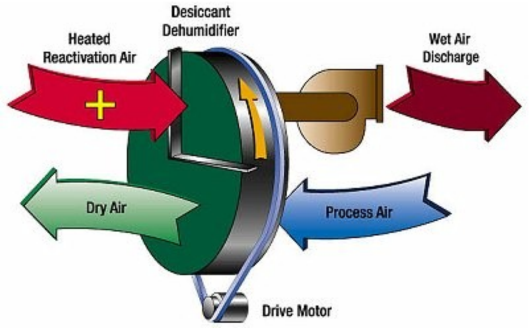


Figure 6 – Desiccant Dehumidification Rotor

As the compressor and the cooling coils make up the heart of the conventional HVAC system, the desiccant rotor and the reactivation heater make up the heart of the desiccant-based system. All of the other components within the air handlers (mechanical or desiccant) are the same (e.g., filters, blowers and motors, heating and cooling coils, controls, etc.)

Selecting the Right HVAC System

When and where to use desiccant-based HVAC systems? When and where to use mechanical-based systems? Understanding the benefits and limitations of each of these technologies, and applying the basic guidelines presented will benefit the entire design team and facilities managers on all future design projects.

While there are a number of factors to consider when choosing between these two technologies, the driving factor is usually the desired *absolute* humidity level of the supply air, or its *dewpoint*. Mechanical systems are limited to the lowest coil temperatures possible with the entering water temperatures, whereas the desiccant technologies are capable of achieving much lower supply air *dewpoints*. In general, when supply air *dewpoints* of 45^0F or less are required, then desiccant-based systems are the technology to install. As stated previously, the supply air *dewpoints* required for most operating rooms today are well below the 45^0F level. This is the reason that desiccant-based HVAC systems are being considered more frequently now for conditioning the surgical suites of hospitals and clinics.

HVAC system Installation Considerations

When designing the HVAC systems for most areas of the hospital, mechanical-based systems (chilled water or direct expansion (DX)) are usually considered because the required supply air *dewpoints* are higher than 45^0F. However, when these mechanical-based systems are installed for the surgical suites and the space temperatures are maintained around 65^0F or lower, the resulting *relative humidity* levels are higher than desired. In far too many instances, there is condensate forming on the diffusers and fixtures.

Because mechanical-based systems are installed in every hospital building, the following information will only address installing desiccant-based systems.

Desiccant System as a Retrofit Installation

Retrofitting an existing, and operational, mechanical-based HVAC system is usually rather simple ... assuming there is sufficient space to locate a new desiccant-based air handler and the necessary utilities are available. Typically, the desiccant system will be sized for the minimum quantity of outdoor air required for the existing system. This quantity of outdoor air will be pre-conditioned using the desiccant unit and will then be ducted into the outdoor air section of the existing air handler where it will mix with the return air prior to being sensibly cooled via the cooling coils of the existing air handler. As the pre-conditioned ventilation air will have a *dewpoint* temperature lower than the downstream cooling coils, these coils should remain dry, as well as the supply air ducts (see Figures 7 and 8).

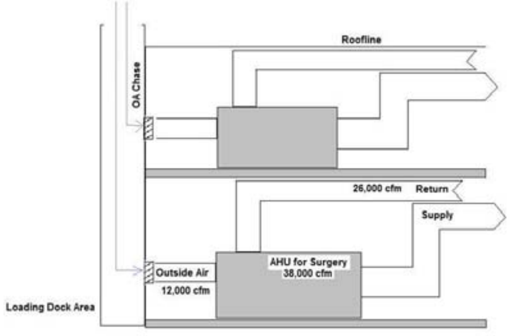


Figure 7 – Elevation Schematic of Existing Stacked Mechanical Rooms

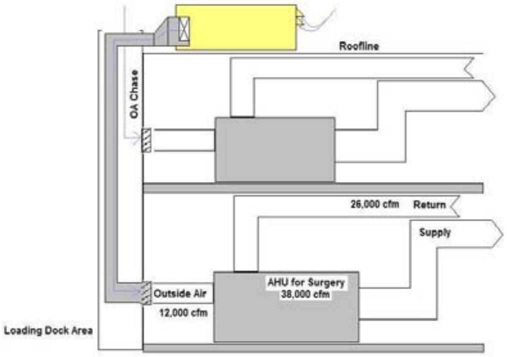


Figure 8 –Desiccant Installed to Pre-condition Ventilation Air to Surgery Suite AHU

When adding a desiccant pre-conditioner to an existing system, the installation work can normally be done without interrupting the operation of the existing mechanical air handler. The tie-ins to the natural gas piping (for reactivation energy) and the steam or hot water piping (if including heating coils), the electrical service and the chilled water lines (when including cooling coils within the desiccant system) can be done after hours. The ducting connecting the desiccant and the mechanical systems can also be tied in after operating hours.

Desiccant System as a New Installation

When designing a system for a new facility, it is usually more economical to incorporate the desiccant dehumidification components and the mechanical components (i.e., cooling and heating coils) into one single unit. A system including a combination of these components is often called a *hybrid* system. By combining these technologies, only one air handler is required which will save on overall equipment costs and floor space. This hybrid air handler will be larger than either technology by itself; however, smaller than the two independent systems. Figure 9 below is a schematic showing how some of the various components might be arranged to achieve both latent and sensible control. Often times, a set of cooling coils will be positioned upstream of the desiccant rotor in order to achieve a greater drop in the absolute humidity of the supply air without having to increase the physical size of the desiccant rotor. The schematic shows two possible locations for the coils (referred to as *pre-cooling* coils when placed upstream of the desiccant rotor).

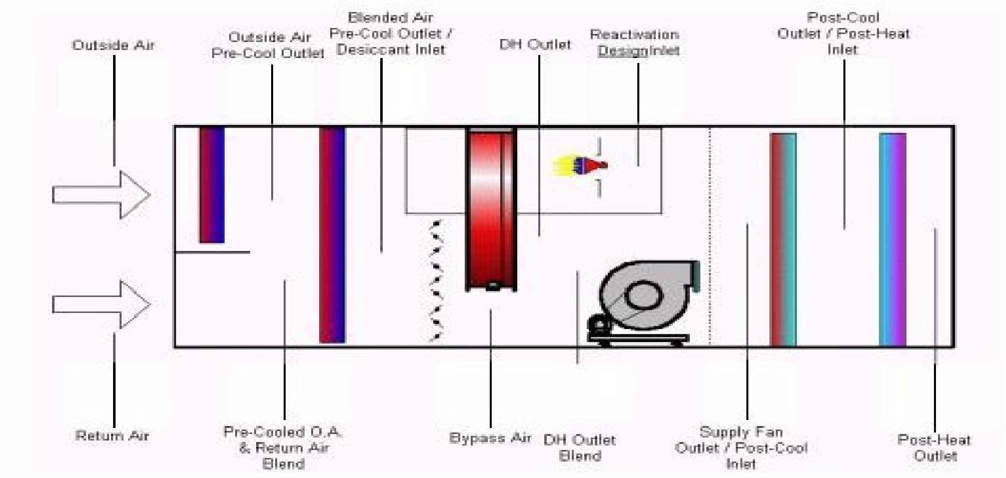


Figure 9 – Schematic Showing a Hybrid (Desiccant and Mechanical) System
(*Courtesy of Concepts & Designs, MS*)

Conclusion

While the currently installed HVAC systems for operating suites of the hospitals were likely sufficient for maintaining reasonably comfortable space conditions of just a few years ago, the demands to keep the operating rooms cooler today are causing the humidity levels in the space to be excessively high. Too often, these humidity levels are high enough to cause condensate problems to occur. With the weather data now available to the design community, a better understanding of designing for *absolute* moisture supply conditions, and a basic understanding of the technologies available today, this *raining* problem doesn't have to be a threat any longer.