Solutions to Surgical Suite Temperature and Humidity Control

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ABSTRACT

The demand for lower air temperatures inside the operating room (OR) has placed unrealistic expectations upon existing chilled water systems in hospitals. Lower temperatures are required to keep the surgical staff comfortable during extended procedures. Relative humidity (RH) must still be controlled at these lower temperatures per code guidelines and poses a major hurdle for facilities located throughout the southeastern United States. Heating, ventilating and air conditioning (HVAC) equipment designed to hold space conditions of 72°F and 60% RH is now attempting to hold 65°F and 50% RH or less. The lower temperature and RH reduce the space dew point from 57°F to 46°F (Figure 1). To obtain this lower dew point requires the removal of 33% more moisture from the air (Equation 1). It is this additional moisture removal that has become the concern of health care engineers, facility managers, hospital administrators and surgeons. Desiccant enhanced cooling systems can easily and efficiently achieve both temperature and humidity control within today's surgery suites while avoiding the pitfalls common to low temperature cooling systems.

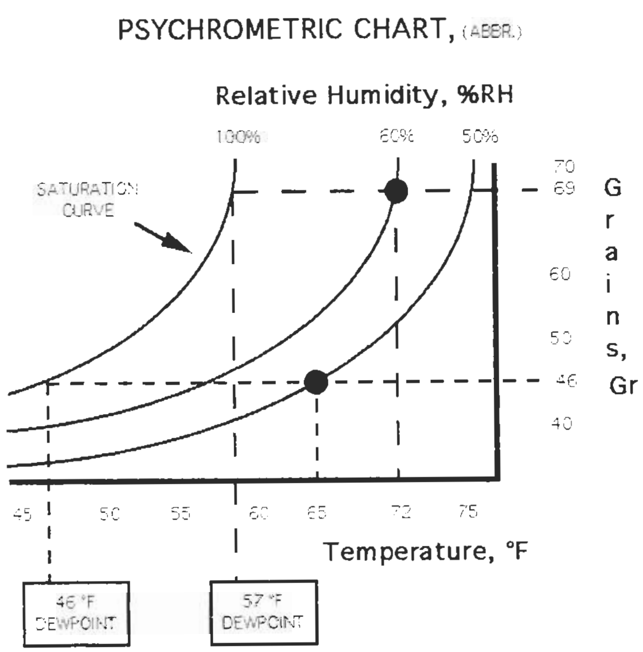

Figure 1 Surgery Suite Dew Points, Old and New

(69 Gr - 46 Gr) / 69 Gr = 0.333 Equation (1)

INTRODUCTION

With the introduction of human immunodeficiency virus (HIV) and the resurgence of Hepatitis B virus, surgical team members have been double and triple gowning their entire bodies. This multiple gowning procedure is an attempt to halt any contact with blood borne pathogens. Vaporproof gowns are now being designed and manufactured to address this concern. By using these gowns, though, bodily evaporation is impaired and an uncomfortable situation results. The typical human body perspires and exhales 4,250 grains of moisture per hour at 65°F when performing moderate work (1). For the surgeon to feel cool and dry, this moisture must not only be removed from the body, it must be evaporated by their body. Evaporative cooling assists the human body in regulating its internal temperature and avoiding fatigue. Gown data from manufacturers detail vapor transmission rates of less than half of the vapor generated by a surgeon (2). Furthermore, complex surgical procedures such as neurosurgery, whole organ transplants and hip/joint replacements have forced the surgical team to remain in the operating room for as long as 14 hours. It is this need to feel cool and dry for longer periods of time that has necessitated lower air temperatures inside surgery suites and specifically the OR.

COOLING BASED EQUIPMENT

Current attempts to achieve lower OR temperatures have been directed towards further cooling the air. The air must be cooled to the required dew point and then reheated to the supply air temperature if humidity control is to be retained. For example, the typical supply air temperature to a 65°F OR is 52°F. To achieve 50% RH at 65°F, the supply air must be cooled to a 42°F dew point and then reheated to the 52°F setpoint. This cooling and reheating overlap of 10°F uses an additional 10,800 Btuh per 1,000 cfm for sensible cooling and an additional 12,352 Btuh for latent cooling (Equations 2, 3). Furthermore, cooling equipment efficiencies decrease as the coolant temperature drops. Cooling air to 42°F necessitates a glycol coolant temperature of 36°F or lower.

1000 CFM x 1.08 x (52F - 42F) = 10,800 Btuh
Equation (2)

1000 CFM x .675 x (57.8 Gr - 39.5 Gr) = 12,352 Btuh
Equation (3)

Existing facilities do not have a dedicated low temperature glycol system and instead try to utilize the main chiller plant. Main chiller plant supply water temperatures range from 42°F to 45°F. Air cannot be cooled to 42°F with 42°F water. The result of this approach is a loss of humidity control while the temperature is maintained at 65°F.

The loss of humidity control comes about as the cooling system satisfies the temperature setpoint (52°F) and stops trying to cool the air to a lower temperature. Thus, the supply air dew point is 50°F as the air is nearly saturated upon leaving the cooling coil. The relative humidity within the OR rises above 60% once the internal moisture load blends with the 50°F dew point supply air (Figure 2).

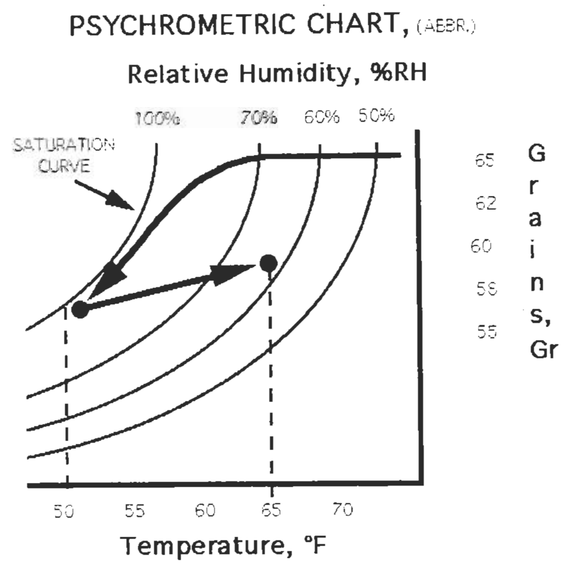

Figure (2) RH in the OR with Cooling Based Equipment

Health care facility guidelines recommend maintaining 50% to 60% RH inside the OR during surgical procedures (3, 4). Research by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) has also found that 50% RH is ideal for building occupants to avoid the hazards of fungi, bacteria, viruses and respiratory difficulties (Figure 3) (5).

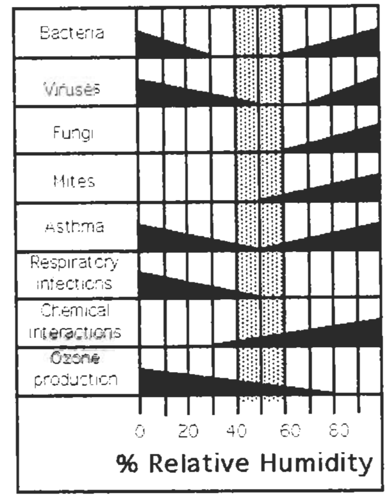

Figure (3) Ideal RH for Building Occupants

DESICCANT BASED COOLING EQUIPMENT

Desiccants are a group of materials that have a high affinity for moisture. There are two categories of desiccants: adsorbents and absorbents. Adsorbents have found their way to the commercial marketplace primarily due to their inability to become saturated with water molecules and change into a liquid form. Absorbents, which can state change into a liquid form if saturated, are typically used in highly controlled industrial processes only.

Desiccant based equipment transfers water in a vapor phase from the air to the surface of the desiccant as a result of the desiccant's low surface vapor pressure. As the desiccant attracts more moisture from the air, its surface vapor pressure increases and an equilibrium is reached. At this point the desiccant must be reactivated before it can remove any additional moisture from the air. Reactivation is accomplished by exposing the wetted desiccant to a second and separate airstream. The second airstream is heated to the point where its vapor pressure is lower than the wetted desiccant's. Now the moisture will travel from the surface of the desiccant to the heated airstream and be exhausted to weather (Figure 4) (6).

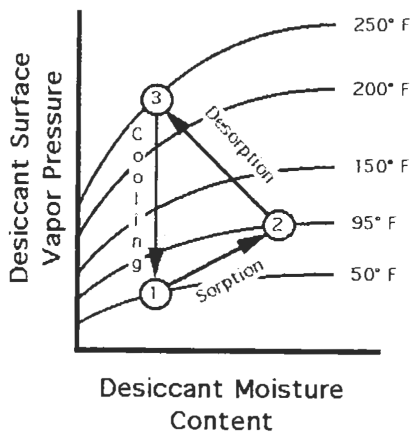

Figure (4) Desiccant Cycle

Desiccant based cooling systems are hybrid arrangements. Conventional cooling and desiccant dehumidification are combined in the same air handling unit. The advantages are numerous: (a) cooling equipment can be dedicated to sensible cooling only, (b) chilled water temperatures can be raised to 45°F resulting in increased equipment efficiency and decreased operating costs, (c) desiccant equipment removes the moisture in a vapor phase avoiding wet drain pans and the microbiological hazards they support. There is one liability with a desiccant based unit; the desiccant must be heated to remove the moisture and ready it for continued moisture extraction. Fortunately reactivation of the desiccant can be accomplished with less expensive thermal energies such as gas and steam. In many cases the steam used is waste steam during the humid summer months and no operating cost is associated with reactivating the desiccant. There are two main disadvantages with desiccant enhanced cooling systems: (a) a larger equipment foot print, (b) greater first cost when compared to conventional cooling systems.

The work performed upon the airstream by a desiccant based cooling system follows a characteristic pattern: first moisture is removed and second sensible cooling is executed. The desiccant removes the moisture, or latent load, first. In doing so, the temperature of the air is raised by the heat of vaporization and heat carry over from the reactivation sector. This process is opposite the evaporative cooling process, moisture is lost but temperature is gained. Once the proper amount of moisture has been removed, only sensible cooling needs to take place. Cooling systems can easily and efficiently achieve the 52°F supply air temperature and still utilize 45°F chilled water.

In the case of 100% fresh air systems some cooling before the desiccant is required. The efficiency of a desiccant improves as the inlet air temperature drops. Once this precooling has been accomplished the dew point needed can be obtained .

CASE STUDY

A hospital in Sherman, TX needed to control temperature and RH in the surgery suites to a design condition of 65°F and 45% RH, a 43F dew point. 32,000 cfm is required for the ORs, sterile corridors and ancillary storage areas. The supply air volume will provide 25 air changes per hour (ACH) in the 8 ORs. The high ACH rate permits 23,900 cfm of the air to be recirculated and only 8,100 cfm to be outside air. A decision was made to treat just the outside air with desiccant based equipment. Therefore, 8,100 cfm of dried outside air would be delivered to a standard cooling based air handler that would then blend it with 23,900 cfm of return air and perform the sensible cooling and heating functions.

A survey of internal moisture loads was conducted. This survey revealed a total internal moisture load of 57.6 lbs/hr, with the majority originating from the surgical staff. Each surgical team member exhales and perspires 4,250 grains of moisture (Gr) when in a 65°F space and performing moderate work (1). Each patient exhales and perspires only 400 Gr when in the same 65°F space and at rest (1). With 8 team members and one patient in each of the 8 ORs, the human moisture load totaled 39.3 lbs/hr (Equation 4). The remaining 18.3 lbs/hr of moisture load was due to infiltration and a reserve capacity in the event lower dry bulb temperatures were desired. Through calculations it was determined that the supply air needed to be delivered at 2.8 Gr less than the 42 Gr control set point (Equation 5). By doing so, moisture loads inside the ORs could be accounted for and the ORs are maintained at 65°F and 45% RH. For this to be accomplished, the desiccant equipment needed to deliver 8,100 cfm at 31 Gr of moisture, a 36°F dew point (Equation 6). The fresh air represents 89% of the moisture load upon the equipment while the surgical team generates the other 11% as internal loads (Equation 7).

((8 x 4250 Gr/Lb + 1 x 400 Gr/Lb) x 8 ORs) / 7000 Gr/Lb = 39.3 Lb/Hr Equation (4)

(57.6 Lb x 7000 Gr/Lb) / (32,000 CFM x 4.5) = 2.8 Gr Equation (5)

((32,000 CFM x 39.2 Gr) - (23,900 CFM x 42 Gr)) / 8,100 CFM = 31 Gr Equation (6)

23,900 CFM x (42 GR - 39 Gr) = 71,700 Gr

8,100 CFM x (114 Gr - 39 Gr) = 607,500 Gr Equation (7)

The fresh air is brought into the desiccant equipment, prefiltered by 30% 2" filters, heated during winter operation by a steam coil, cooled by a chilled water coil during humid months, dehumidified by the desiccant wheel and delivered to the cooling equipment by a process fan (Figure 5).

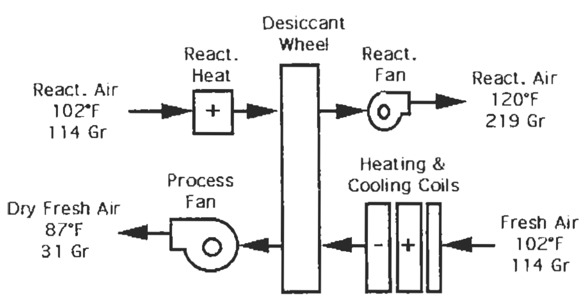

Figure 5 Desiccant Equipment Air Flow

During design summer operation, the precooling coil requires 760,180 BTUH and 152 GPM of 45°F chilled water. The desiccant wheel removes 166.6 pounds of water per hour from 4,900 cfm (Equation 8). 3,200 cfm of precooled air is bypassed around the desiccant wheel so that overdrying does not occur. 60 PSIG steam reactivates the desiccant wheel by heating 2,470 cfm of outside air to 250°F, a 349,348 BTUH load. Finally, the process fan blends the 4,900 cfm of dehumidified air with the 3,200 cfm of bypassed air and delivers 8,100 cfm of air at 87F and 31 Gr.

4,900 CFM x 4.5 x (63 Gr - 10.1 Gr) / 7000 Gr/Lb = 166.6 Lb Equation (8)

The cooling equipment then blends the dried fresh air with the return air and prefilters it with 30% 2" filters. Cooling the 32,000 cfm is completed with 760,320 BTUH and 152 GPM of 45°F water. The air is then delivered to each OR by a supply fan where individual heating coils and humidifiers can further condition the air during winter operation (Figure 7).

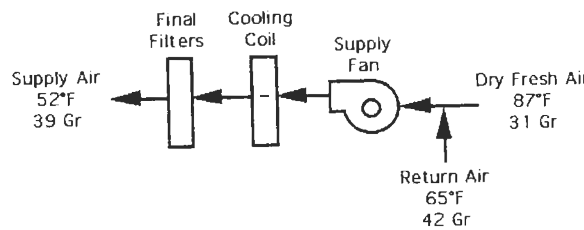

Figure 6 Cooling Equipment Air Flow

CONCLUSION

The ability to deliver 32,000 cfm of air at a 42°F dew point using only 127 tons of 45°F chilled water affords the advantages previously mentioned. A less efficient and more costly glycol system has been avoided, thereby allowing the main chiller plant to remain intact. The ductwork and air handling units deliver air that is below the recommended 70% RH threshold for avoiding microbiological growth (7). Less costly steam is being used to reactivate the desiccant and provides an operating cost savings when compared to the glycol chiller required to achieve the same dew point.

A comprehensive energy analysis has not been completed to date. Similar applications have yielded decreased operating costs that transfer to an equipment payback ranging from 2 to 10 years with the average being 5 years. This payback period is well within the life of the equipment and effectively removes one of the two disadvantages of desiccant based equipment and leaves equipment size as the one obstacle to be overcome. Furthermore, in a time when every dollar must be accounted for, health care facilities can maintain the surgical procedures that yield profit and not fear loosing surgeons to other facilities where operating conditions are more comfortable.

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