APC APPLICATION NOTE #128

Data Center Humidification Strategies

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Abstract

ASHRAE recommends maintaining relative humidity in the range of 40-55% at the air inlet of critical data center IT equipment. This application note first considers various methods of quantifying the expected humidification and dehumidification loads for this design humidity range. After determining latent loading, an approach to equipment selection is offered using APC-MGE InRow products; IR-RC, IR-RP and the FM product as an example.

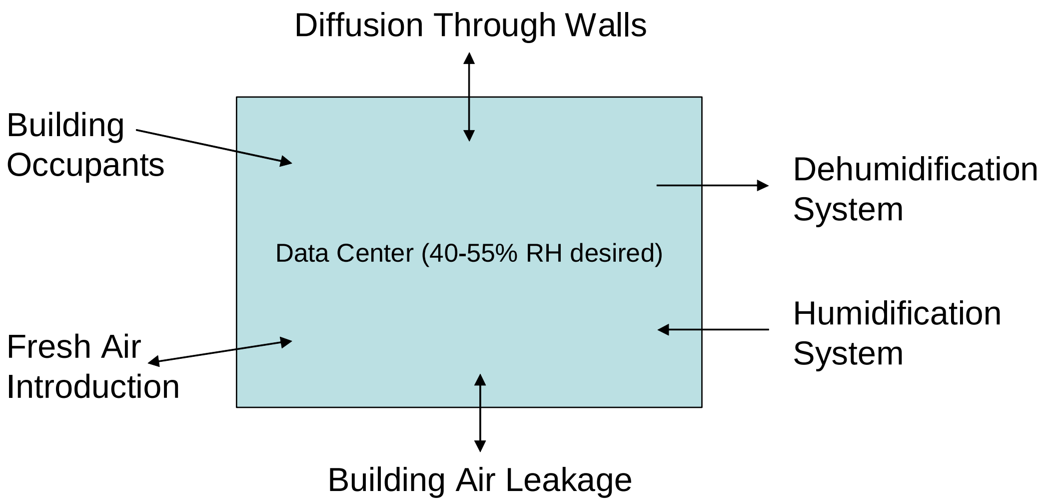
Introduction

In order to consider various approaches to controlling humidity in the data center within ASHRAE recommendations, one must first understand the origin and magnitude of the load that will be imposed on humidification control equipment. A procedure for quantifying the worst cast humidification and dehumidification loads is provided. The procedure may be applied to brown field (existing) or green field (new) construction facilities. The procedure allows for various construction methods and climatic regions. Once these numbers have been determined, the humidification and dehumidification systems can be sized in the most cost effective manner, incorporating an appropriate level of equipment redundancy to meet desired data center availability criteria.

Where Humidity Control Load Comes From

As previously stated, it is generally desirable to control data center humidity in the range of 40-55% RH, and dry bulb temperature in the range of 20-25 degrees C. If a data center could be constructed with materials that are completely impermeable to water vapor and contained no internal sources of humidity, we might be able to establish a humidity of 50% RH when the facility is commissioned, then seal up the room and never have to worry about altering the humidity level again. Unfortunately this is impractical from both a construction and an operational standpoint. Instead, several factors are often present which tend to drive humidity in the computer room higher or lower than we would prefer. These factors include air conditioners, diffusion through walls, fresh air introduction, building air leakage, and occupants. **Figure 1** shows a data center modeled as a block diagram for the purpose of illustrating sources and losses of humidity.

Figure 1 – Sources of humidity gain and loss in data centers



Note that several of the humidity sources and losses are represented in **Figure 1** by bidirectional arrows. This is because instantaneous air conditions outside the data center may be such that they tend to increase or decrease humidity in the data center. The reader is cautioned not to infer direction of water vapor propagation by relative humilities alone. Instead, the vapor pressure of air for indoor and outdoor air must be considered. Like any gas, water vapor will diffuse from regions of high pressure to those of low pressure. For example, outdoor air conditions on a hot summer day might be 40°C, 40% RH. This might lead one to believe that the indoor air at 20°C, 50%RH would loose water vapor by diffusion outward through the walls, however the reverse is actually true; such conditions would result in water vapor infiltration to the data center. This is because air at 40°C, 40%RH actually has over twice the water vapor pressure as does air at 20°C, 50% RH.

In any case, it is evident from **Figure 1** that if steady state ASHRAE recommended conditions are to be maintained in the data center, the humidification system must be sized to overcome the sum of all worst case humidity losses, and the dehumidification system must be capable of overcoming the sum of all worst case humidity gains. This principle and methods for quantifying each humidity gain or loss are set forth in the section to follow.

How to Determine a Data Center's Latent Load

General procedure

Each of the humidity gain and loss mechanisms from **Figure 1** must be quantified, or determined to be insignificant. For mechanisms that can result in humidity gain or loss, a worst case of each must be determined. Worst case humidification loads and dehumidification loads are then summed to determine a design load for each. From this number, equipment can be selected and any desired redundancy can be added. Although this method may seem laborious, it is generally necessary to perform at least once for a particular construction method and climactic region. High variability in construction quality, vapor barrier effectiveness, and outdoor climates make the publication of a rule of thumb (for example: use 2kg / hr of humidification capacity per 100 square meters) of little or no use. Actual loading would likely differ by more than 100% for many users.

Diffusion through walls

Water vapor will propagate through the walls of a data center whenever water vapor pressure is different on each side of the wall, and semi-permeable materials have been used in construction of the wall. Equation 1 governs the rate of water vapor diffusion through walls.

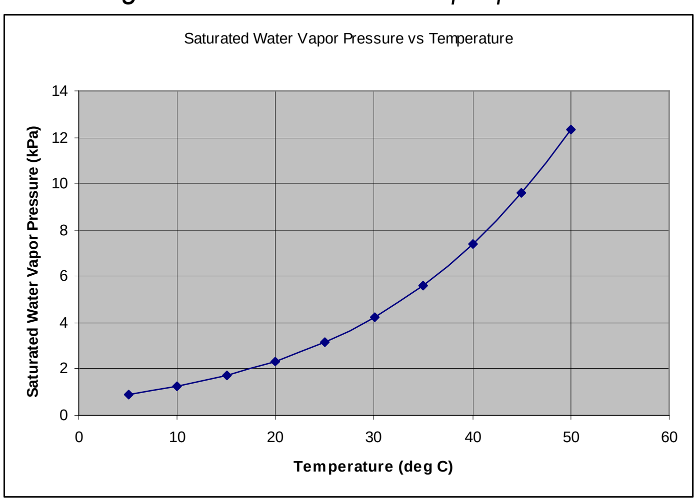
$$\dot{m}_{H_2O} = 2.06x10^{-4} \cdot M \cdot A \cdot \Delta P_v$$

Equation 1: Water vapor diffusion through walls

Where;

- $\dot{m}_{H_2O}$ is the mass flow rate of water vapor through the wall in kg / hr.
- M is the permeance of the wall assembly in units of *Perms*, or $\frac{kg}{m^2 \cdot hr \cdot kPa}$. Note that for composite wall assemblies with N separate layers; $M_{wall} = (M_{layer1}{}^{-1} + M_{layer2}{}^{-1} + ...M_{layerN}{}^{-1})^{-1}$. Permeance for various materials can be obtained from the manufacturer of the material or from generalized publications such as ASHRAE 2005 Fundamentals Chapter 25.
- A is the area of the wall under consideration.
- ΔP_v is the differential vapor pressure between either side of the wall. Air conditions are most commonly expressed in terms of dry bulb temperature and % relative humidity (RH) and must be converted to vapor pressure by multiplying the relative humidity by the vapor pressure obtained from **Figure 2**.

Figure 2 – Saturated water vapor pressure



Example 1: Suppose a 2000 square meter, data center is to be constructed in a climate where worst case outdoor summer conditions are 38°C dry bulb temperature, 80%RH. Worst case winter conditions are 5°C / 10%RH. Building plans indicate the data center will have 270 square meters of exterior wall area. Exterior wall construction consists of a layer of standard hardboard, 3.5" dry blown cellulose insulation (1.9lb / ft^3), and 1/2" standard gypsum wallboard. (Actual commercial buildings are unlikely to use such a wall assembly, these materials were chosen for illustrative purposes) Adjacent spaces indoors are continuously conditioned at nearly the same set points as the data center, allowing water vapor diffusion through interior walls, floor, and ceiling to be neglected. Determine humidity control loads in the data center due to diffusion through walls.

- First, determine the permeance of the wall assembly, M_{wall}.
  From ASHRAE 2005 Fundamentals Chapter 25, we find that $M_{hardboard}$ = 5 perm, $M_{insulation}$ = 30.57 perm, and $M_{wallboard}$ = 50 perm. Therefore $M_{wall} = (5^{-1}+30.57^{-1}+50^{-1})^{-1}$ = 3.95.
- Use Figure 2 to find the vapor pressures corresponding to given air conditions.
  $P_{v\ data\ center}$ (22C / 45%RH) = 2.5kPa * .45 = 1.125kPa
  $P_{v\ outdoor\ humid\ season}$ (38C / 80%RH) = 6.5kPa * .8 = 5.2kPa
  $P_{v\ outdoor\ dry\ season}$ (5C / 10%RH) = .1kPa
- Using equation 1, determine humidification and dehumidification loads.
  humidification load:

  $$\dot{m}_{H_2O} = 2.06x10^{-4} \cdot M \cdot A \cdot \Delta P_v = 2.06x10^{-4} * 3.95 * 270 * (1.125-.1) = \underline{.23\ kg / hr}$$

  dehumidification load:

  $$\dot{m}_{H_2O} = 2.06x10^{-4} \cdot M \cdot A \cdot \Delta P_v = 2.06x10^{-4} * 3.95 * 270 * (5.2-1.125) = \underline{.92\ kg / hr}$$

Aside:

It is interesting to note that if a vapor barrier consisting of 6 mil polyethylene sheet had been used as part of this wall assembly, the humidity control loads, in theory, could have been almost entirely eliminated. A 6 mil polyethylene sheet has a permeance of .06 perm. This would have resulted in a wall permeance of .05 perm, and therefore a humidification load of only 3 grams per hour, and a dehumidification load of 11 grams per hour. In practice, it is likely that much more humidity would pass through the wall. This is because where adjacent sheets of the plastic are joined, and holes through the plastic due to fastening methods will result in significant leakage opportunities for water vapor. Even so, it is likely that the addition of the vapor barrier would result in at least a 50% reduction in diffusion humidity loading. Vapor barriers are a very cost effective way to minimize latent loads and strongly recommended for data centers.

Building occupants

Humans contribute to the latent load due to their introduction of water vapor into the air by perspiration and respiration. Although data centers rarely have permanent occupants, certain circumstances can result in moderate numbers of temporary occupants for prolonged periods. It is good engineering practice to include such situations in humidity control loading calculations.

Example 1 (continued): Determine the dehumidification load imposed by 10 workers who will be installing new network cabling in the data center.

The sensible and latent heat output of humans during various activity levels has been well studied. One source of the information is ASHRAE 2005 Fundamentals, Chapter 30, Table 1. A person engaged in light work, such as the activity of installing network cables, is found to dissipate approximately 73 watts of latent heat. Therefore our 10 workers in the data center will contribute 730 watts to the dehumidification load. To convert this into the same units as the previously calculated diffusion latent load, the latent heat of vaporization, a property of water, is used.

- dehumidification load: 730 watts (3600 sec / 1 hr) (1kg / 2465560 J) = 1.07 kg / hr

Fresh air introduction

Although it is generally not a code requirement to introduce fresh air to a building space with no permanent occupants, it is not an uncommon practice in data centers. The reason for this practice is often to establish a slight positive pressure in the room for cleanliness concerns, and as a precautionary measure to ensure good indoor air quality. Generally fresh air is conditioned to some extent by the building HVAC system, but its conditions may still differ significantly from desired data center conditions, thereby necessitating the associated load calculations. The quantity of fresh air should be kept to a minimum necessary in order to limit unnecessary latent load. The problem is treated as a simple continuous mixing problem whose solution is based on conservation of water vapor mass.

Example 1 (continued): Fresh air is introduced to the data center at a rate of 850 m^3 / hr with worst case conditions 15°C / 30% RH. Return air leaves the data center ambient at assumed design conditions of 22°C / 45% RH. Determine the latent load imposed on the data center from the fresh air introduction.

- First determine absolute humidity from a psychrometric chart;
  fresh air: .0045 kg water / m^3 air
  data center ambient air: .010 kg water / m^3 air
- The humidification load is the difference between the water loss rate and water introduction rate;
  850 m^3 / hr (.01 kg water / m^3 air - .0045) = 4.7 kg / hr

Building air leakage

Buildings are rarely, if ever, perfectly sealed against unintended air exchange with the out of doors. Air leakage in older buildings can be a large source of unwanted sensible and latent heat exchange. Due to advanced construction techniques and materials, new data centers may have a negligible amount of air leakage. In positively pressurized data centers, air leakage beyond that created by the deliberate pressurization can often be neglected. The method for calculating humidity control loads from building air leakage is identical to that of fresh air introduction and therefore is not repeated here. The only added complication is determining what the building air leakage rate actually is. For new construction it is best to request this number from the consulting engineer responsible for base building design. Alternatively, a blower door test can be performed to estimate leakage rates in an existing facility. An engineer can combine these test results with wind data for the region and estimate a worst case building leakage rate.

Summary of data center latent load determination example

The various mechanisms of latent heat load that have been calculated are summarized in **Table 1**.

Total worst case humidification and dehumidification loads of 4.93 kg / hr and 1.99 kg / hr are predicted. In a large new construction data center such as the 2000 sq m facility used in the example, there is likely to be 2 Megawatts or more of

Table 1 – Summary of latent load determination

Mechanism	Worst Case Humidification Load (kg / hr)	Worst Case Dehumidification Load (kg / hr)
Diffusion Through Walls	.23	.92
Building Occupants	-	1.07
Fresh Air Introduction	4.7	-
Total Load	4.93	1.99

cooling capacity spread amongst 20 or more precision cooling units. Often each unit is equipped with a humidifier with a capacity between 2 and 7 kg / hr. This would yield a total humidification capacity of 100 kg / hr or more. Similarly, when operated in the traditional flooded return air distribution pattern (for more information on air distribution architectures in data centers, see APC white paper #55) each CRAC unit will typically have several kg / hr of dehumidification capacity. So it is likely that the worst case loads as shown in **Table 1** could easily be accommodated by CRAC units that would need to be in place anyway to cool the design IT equipment load. A reasonable question to ask is; "why is it a common practice to equip a data center with humidification capacity that exceeds the anticipated worst case humidification load by 20 times or more?" The reason is that the CRAC units are part of the problem and the solution. Due to traditionally low return air temperatures, CRAC units will often exhibit sensible heat ratios of .8 - .95. This means that up to 20% of the total cooling capacity of the CRAC unit is producing undesired dehumidification as a side effect of the cooling process. This eclipses all other sources of humidity loss, and necessitates a massively oversized humidification capacity in order to maintain humidity in the desired range. To learn more about the costs associated with humidity control, see APC white paper #58.

How To Optimize the Humidity Control System

The sources of humidification and dehumidification presented in **Table 1** are in large part unavoidable. However, the undesired dehumidification that occurs in traditional perimeter mounted CRAC units is much larger and entirely avoidable.

Any air flow architecture that sufficiently elevates return air temperatures such that saturation conditions are not reached as the air passes through the CRAC unit will not produce the undesired dehumidification. Ducted return systems accomplish this, as do APC In-Row Cooling solutions including the IR-RC and IR-RP products. The IR-RC is a chilled water air conditioner designed to provide precision sensible heat removal for mid to large sized computer rooms. Its price is moderated by the fact that it contains no provisions for humidification or controlled dehumidification (a condensate pump is provided for initial room pull down, but is unused in normal operation). This allows the more rational approach of right-sizing the equipment that will accommodate the unavoidable latent loads in **Table 1**. There are several options for such equipment including the APC IR-RP, APC FM series, or other commercially available unitary humidifier / dehumidifier products. The procedure to determine the number of IR-RP's or FM's is outlined below.

Example 2:

In Example 1, it was determined that the hypothetical 2000 sq m. data center would experience worst case latent loads of 5 kg / hr humidification and 2 kg / hr dehumidification, assuming 100% sensible operation of the cooling system. How many IR-RP's or FM units would be necessary to accommodate this load?

- Humidification Load Balance:
  Using FM product: (5 kg / hr) / (4.5 kg / hr humidifier per FM) = 1.1 FM's, round up to <u>2 FM's</u>.
  Using IR-RP product: (5kg / hr) / (3 kg / hr humidifier per IR-RP) = 1.7 RP's, round up to <u>2 IR-RP's</u>.
- Dehumidification Load Balance:
  First determine Latent capacity from each product's technical data manual;
  FM-35: 2.3kW latent capacity at 22.2C / 50% RH.
  Note: Given its intended role of dehumidification, the FM should be installed in a manner that results in return air conditions representative of those present in the data center ambient, or 22C / 40-55% RH in this case.
  IR-RP: 1.1kW latent capacity at 26.7C / 38% RH.
  Note, the IR-RP's latent capacity will be strongly affected by it's positioning in the computer room. A conservatively high temperature rating point is chosen to allow for the possibility of some high temperature IT exhaust air being present in the RP return air stream.
- Determine Number of FM-35's and IR-RP's that would be necessary for the dehumidification load.
  FM-35: 2.3kW * 1.46 kg / (hr kW) = 3.4 kg / hr, (2 kg / hr) / (3.4 kg / hr) = <u>1 FM-35</u>
  IR-RP: 1.1kW * 1.46 kg / (hr kW) = 1.6 kg / hr, (2 kg / hr) / (1.6 kg / hr) = <u>2 IR-RP's</u>
- Answer: A minimum of 2 IR-RP's would be required to be included in the 2000 sq m data center for humidity control. Although only 1 FM is sufficient to accommodate the dehumidification load, 2 are required to accommodate the humidification load, so if FM's were used for humidity control, 2 would be required.

Since humidity diffuses very quickly through the data center, the overall position of the IR-RP's or the FM's in the data center is relatively unimportant. As previously mentioned however, they must be positioned in a manner that results in their return air stream being as representative as possible of the design ambient conditions. Positions should be selected based on individual characteristics of each unique room, however good positions for humidity control FM's tend to be located on the perimeter of the room. Good positions for the humidity control IR-RP's can be found in low density regions, at the end of rows, in regions with un-racked equipment, and on the perimeter of the room. Under no circumstances should an IR-RP that will be relied upon for dehumidification be located in an APC Hot Aisle Containment System (HACS) or Rack Air Containment System (RACS). Return air temperatures will normally be too high in such configurations to allow for dehumidification. If unitary humidifiers are used, they should be positioned such that saturated water vapor is not discharged near any cold surfaces where condensation should occur. Discharged vapor should have sufficient opportunity to mix thoroughly with ambient air prior to intake by IT equipment, dehumidifiers, or CRAC units.

Conclusions

Computer rooms have traditionally been designed with extremely wasteful and oversized humidity control systems. By avoiding the use of flooded return cooling architectures, large amounts of undesired dehumidification and subsequent re-humidification can be avoided. Once this obvious cost saving step is implemented several other humidification and dehumidification loads become apparent. To right-size the humidity control system, it is necessary to perform detailed worst case load calculations. Substitution of a simple thumb-rule for this calculation is difficult due to several factors that vary widely between data centers. The use of a good vapor barrier, air tight construction, and minimal fresh air introduction go a long way to minimize latent loading. Despite its apparent cooling benefit, it is generally a bad idea to introduce cold unconditioned air directly to the data center unless a system is in place to prevent doing so when humidity of the fresh air is outside the desired range. To do otherwise necessitates a greatly increased amount of humidifier capacity, maintenance, and electrical cost. Once latent loads have been quantified, selection of humidification and dehumidification equipment can occur. Readers are encouraged to only specify enough such equipment to accommodate the load as calculated plus a margin for error and any desired redundancy, rather than specifying the inclusion of a humidifier in every CRAC unit for example. Several options exist for placement of humidifiers and dehumidification units in the data center, subject to some constraints as discussed. In general the optimal locations and type of equipment should be considered on an individual project basis.

About the Author:

Jim Fink is manager of cooling systems business development at APC. He has 13 years of experience in critical facility design and operation. Jim holds a Bachelor's of Science degree in Electrical Engineering from Union College in 1994, and a Master's in Business Administration from University of Rhode Island in 2005. He is a licensed professional engineer in the state of Rhode Island, and a member of ASHRAE.