Humidity Control in Conditioned Spaces

Pharmaceutical manufacturing typically requires RH between 45% and 55%

By Shridhar Gokhale
Chief Executive Officer
United Engineering Services, Mumbai

Introduction

It is possible to achieve humidity control in air conditioning through a carefully designed system which integrates the equipment and controls to complement each other. The best of controls – even the most accurate ones – will not be able to control humidity if the system design is not right. Conversely, the best designed system will not be able to maintain humidity within acceptable levels if accurate controls are not used. But the first step to achieve good humidity control is to start at the basics.

Relative and Absolute Humidity

Relative Humidity (RH) is called so as it is always related to the moisture holding capacity of air at a given temperature. Simply put, relative humidity in percent is the measure of actual moisture content in air at a given temperature as compared to the maximum moisture the air can hold at that temperature, i.e. at 100% saturation.

Absolute humidity, however, is a gravimetric measure of the actual amount of water in the air in g/kg. Absolute humidity of air will not change over the range of its sensible heating or sensible cooling range. The relative humidity that a single absolute humidity can generate over the same temperature range is from 0 to 100%.

The human comfort zone is quite wide. We are reasonably comfortable with temperatures in the range of 23 to 28°C and RH of 30% to 60% on a typical summer day, while in the winter we can tolerate temperatures between 20 and 24°C within the same RH band (as per the ASHRAE defined comfort zone).

However, many industrial processes and applications are less tolerant to fluctuations in RH. These fluctuations affect the process or production quality, leading to rejections and production loss.

For instance, in many electronic and pharmaceutical manufacturing areas, the optimum RH required is between 45 and 55%, at temperatures between 20 and 24°C. Such applications require dehumidification and cooling during summer and monsoon, and humidification during the winter and to maintain the correct RH. On the other hand, some products and processes like data centers, textiles, food and beverages,

About the Author

Shridhar Gokhale is a science graduate with more than three decades of experience in HVACR. His design build firm caters solely to industrial applications. He has successfully designed and installed a number of industrial air conditioning systems with RH control for a variety of applications. His firm also represents JS Humidifiers plc of UK in India. He can be contacted at *smg@uesindia.com*

tobacco, etc. need high RH – between 60% and 70% or sometimes even 80%. For such applications, humidification is required in the summer also. If RH drops below 40% in an electronic or semiconductor production area or data center, electrostatic charge can build up and damage equipment, causing downtime and replacement or repair costs. Conversely, some products are hygroscopic and will absorb moisture from the air which can affect their shelf life or have some other detrimental effect.

How does one decide what levels of RH are the best for a product or process? While various handbooks provide general guidelines, they are just that – general in nature. The best option is to ask the customer to specify the internal conditions desired with tolerances for their product or process.

Designing for Latent Load

A major and often overlooked requirement in the design of an air conditioning system needing RH control is the introduction of fresh air in the air handling system. Unless the conditioned area is slightly pressurized, untreated outside air can enter the building structure through gaps and cracks in the rooms and disturb the RH in the conditioned space, leading to unstable room conditions which vary with the ambient.

In systems where fresh air is introduced in the air handling unit but the cooling coil design is inadequate to cater to the sensible and more importantly the latent load of the uncontrolled fresh air ingress. Latent loads are very high during the monsoon and form a major part of the fresh air load. The cooling coil has to cater to not only the room load but also the fresh air ingress load. While sensible cooling and heating of air is relatively easy, adding or removing moisture to achieve the desired level of humidity and controlling it is more challenging. It involves an understanding of psychrometrics and requires detailed calculations. A lot depends on the system designer's experience and judgment.

The first step is to plot the room conditions on a psychrometric chart along with design ambient conditions of the three seasons – summer, monsoon and winter. These conditions will indicate the absolute moisture content, i.e. grams of water per kg of ambient air. Whenever the absolute moisture content is higher than that at the desired room condition, dehumidification will be necessary to remove the moisture added by the fresh air, and this latent load has to be accounted for in designing the cooling coil, along with the sensible load. Conversely, when the absolute moisture content in the air is lower than that at the desired room condition, humidification will be required to add moisture to the fresh air being introduced in the air conditioning system. The conditioned space can also have some latent load which has to be factored in while estimating the room heat load to arrive at the dehumidified air quantity.

Manufacturing areas can have high sensible loads due to the installed equipment requiring high cooling capacity and air flow rates. Any miscalculation in the dehumidified air quantity will defeat all attempts to control RH. For high RH applications, the design supply air quantities can sometimes be as high as 600 CFM per ton, while for low RH applications generally low supply air quantities are required. Thumb rules such as CFM per sq ft or TR per sq ft cannot be applied. The one thumb rule to apply is not to apply any thumb rule!

An undersized design will lead to unsatisfactory conditions, while an oversized one can be somewhat sluggish to control and will consume more power.

Processes Involved in Humidity Control

Cooling and heating of air

This is simple enough – cooling coils are used to cool during the summer and monsoon and electric heaters, hot water or, if possible, condenser heat can be utilized in the winter.

On-off type control is not suitable for precision RH control applications as fluctuations in temperature will also vary RH in the conditioned space even if actual moisture content (absolute humidity) in the air remains constant. Modulating controls for both cooling and heating are best suited for RH control applications.

Dehumidification and humidification

A number of options are available for these processes, and one that is the most suitable for the application should be adopted. As with cooling and heating, modulating control works best in controlling moisture addition or removal.

Types of Dehumidifiers

A. Refrigerated Dehumidifiers

Although dehumidification is typically not the primary purpose of a cooling coil, it acts as a refrigerated dehumidifier in most commercial buildings during the summer. Refrigerated dehumidifiers have been successfully employed in process applications for obtaining dew points as low as 2°C using glycol at –2°C or liquid refrigerant evaporating at about the same temperature. As long as air continues to flow over the cooling coil, no frost formation occurs – unless the cooling fluid temperature drops below –3°C. Their advantage is simplicity in operation.

B. Desiccant Dehumidifiers

For dew points below 0°C the only option is to install desiccant dehumidifiers. They are of two types: solid and liquid.

Solid desiccant dehumidifiers (see *Figure 1*) are rotary heat exchangers impregnated with a desiccant material (typically silica gel). Desiccant wheels are divided into a process side and a regeneration side. The process (supply) side air is dried by the desiccant material, while on the regeneration side another airstream is preheated and runs in counter flow through the opposite side of the desiccant wheel, releasing the absorbed moisture to the atmosphere. The dry-

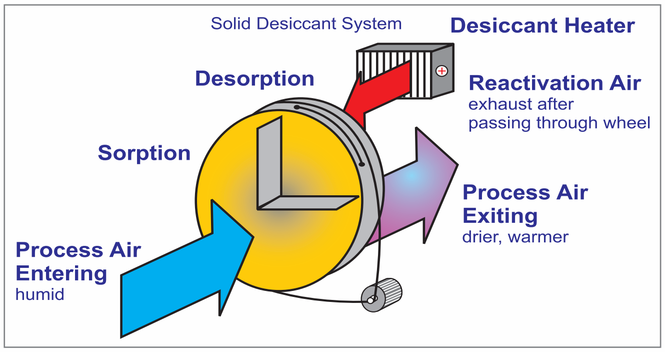

Figure 1: Schematic of solid desiccant

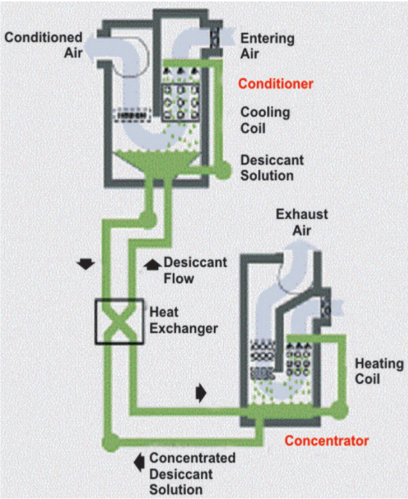

Figure 2: Schematic of liquid desiccant dehumidifier

ing capability is related to the temperature of the regeneration air. The more the regeneration air is heated, the lower the relative humidity and the greater the drying potential on the supply side. The heat source for regeneration is generally electric or steam.

The advantages of desiccant dehumidifiers include the ability to dry air to sub-zero dew points. The disadvantages are higher initial cost and additional cooling load to remove the added sensible heat.

Liquid desiccant dehumidifiers (*Figure 2*) operate in a manner similar to solid desiccants but use a spray tower instead of a wheel with solid desiccant. The process side air runs in counter flow with a dry desiccant spray (usually lithium chloride or lithium bromide), and the desiccant is then regenerated by a heated air stream in the regeneration side of the spray tower. Liquid desiccant systems are more expensive than solid desiccants, but offer effective microbial decontamination.

For economic considerations, generally only a part of the total dehumidified air quantity is routed through the desiccant dehumidifier, while the rest is cooled and dehumidified through the cooling coil in the air handling unit. The two streams are mixed to achieve the desired moisture content in the total air supplied.

Types of Humidifiers

A. Isothermal Humidifiers

In the isothermal humidification process, water vapor is generated using an external source of energy. Moisture is added in the form of steam by boiling off water. Unlike adiabatic humidification, isothermal humidification is independent of the condition of air entering the humidification section. Isothermal humidifiers are most commonly used. They inject steam in the air stream to raise its moisture content. Steam is injected in the air through a steam dispersion pipe (see *Photo 1*). Care should be taken that steam and air are mixed thoroughly to prevent condensation of steam inside the air handling unit or duct. Condensation in the AHU or duct will add sensible heat, and this will cause an increase in supply air temperature and can lead to microbial contamination due to stagnant water. If steam is dispersed in the AHU, sufficient length (empty space) is required downstream of the dispersion pipe for thorough mixing of steam with the air. This distance is known as HD (humidification distance) and is a function of the temperature and RH of air entering the humidification section and the final RH desired. The more the increase in desired RH, the more is the humidification distance. It is also critical to calculate HD to ensure that downstream objects such as filters and control sensors are positioned so that they do not get wet due to steam impingement. In cases where sufficient HD is not available, multiple steam dispersion pipes could be a solution – though an expensive one.

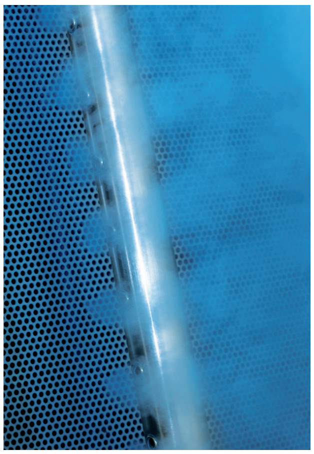

Photo 1: Steam dispersion in AHU

Steam humidifiers have the advantage of better control accuracy, and there are no microbial issues. The energy required for generation of steam can be either electric or, for large requirements, gas based. The energy requirement is typically 0.75 kW per kg of steam generated.

Isothermal humidifiers can be further sub-divided into four categories:

i) Resistive type

With immersion type electric heating elements, these humidifiers can work with demineralized, deionized, reverse osmosis treated or softened water including drinking water to generate pure steam which is suitable for clean room and pharma applications. (*Photo 2* shows a resistive steam humidifier). The initial cost of this type of humidifier is high but the maintenance costs are very low. Some types of resistive steam humidifiers employ a patented cold pool technology which removes scale formed inside the boiling vessel, which is collected in a cylinder below the boiling vessel for quick disposal. The simplest form of resistive type steam humidifier is a pan humidifier, but this is suitable only for small requirements of less than 5 kg per hour. Beyond this capacity, steam generation and dispersion is inconsistent and, as a result, so is the absorption of steam in the air. For high humidification requirements (greater than 40 kg per hour), gas fired humidifier is the most energy and cost efficient.

Photo 2: Resistive steam humidifier

ii) Electrode type

In this type of humidifier, steam is generated by passing an electric current through water in a boiling vessel. This process essentially requires conductive water, hence it is not suitable for use with reverse osmosis treated or demineralized water. The advantage is very low initial cost while the disadvantage is high maintenance costs and relatively inconsistent performance owing to scale formation on electrodes and inside the cylinder. The cylinders need to be cleaned or replaced at regular intervals. See *Photo 3* for a photo and exploded view.

continued on page 49

continued from page 46

Photo 3: Electrode steam humidifier

iii) Direct steam injection

Where clean pure steam is available, a specially designed steam dispersion pipe with modulating valve to control steam flow can be employed, which will again be suited for clean room and pharma requirements – provided the source steam is 100% pure with no additives. *Figure 3* shows a photo and the internal view of a direct steam injection humidifier.

iv) Steam-to-steam

If impure steam is available, it can be circulated through a steam-to-steam humidifier to generate pure steam. In this case, instead of electricity, steam is used as the energy source for boiling water (see *Figure 4*).

B. Adiabatic Humidifiers

Adiabatic humidification is a process in which no energy is added from any external source. The heat required to convert water from liquid to vapor state is supplied by the air passing over the atomized water body, thus cooling the air.

Adiabatic humidification is dependent on the condition of the incoming air, and the amount of moisture that can be absorbed by the air is limited based upon the difference between dry and wet bulb temperatures. The higher this difference, the more is the air cooling effect. Adiabatic humidification is ineffective if the difference between the dry bulb and wet bulb temperatures of the entering air is low, i.e. in humid conditions.

Adiabatic humidifiers evaporate water in the air stream. Typical examples are cooling pads with extended wetted surface and spray nozzles (see *Photo 4*) using pressurized water or compressed air to atomize water. As the heat for evaporation of water is drawn from the air passing over it, the air gets cooled in the process.

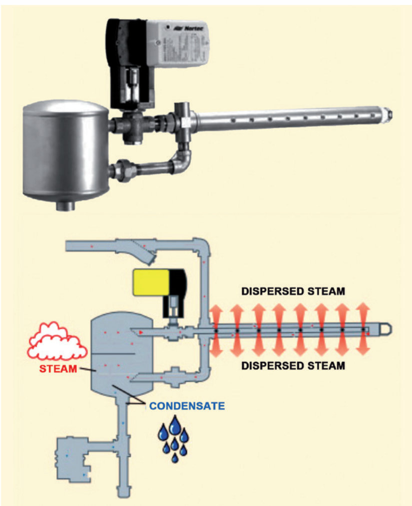

Figure 3: Direct steam injection humidifier

Wetted pads are typically of two types – the cellulose paper which is low in cost but is associated with shorter working life as well as bacterial growth leading to odors emanating from the pads and contaminating the air, or the more expensive glass fiber (see *Photo 5*) which has a longer working life and can be made suitable for clean room application with additional accessories. Typical applications of adiabatic humidifiers are in evaporative cooling, spot cooling and humidification of large areas. A second type are spray nozzles, which use compressed air to atomize water into particles of 7 to 10 microns; these can also be installed in conditioned spaces where it is difficult to install ducting. They are typically used in high roof industrial buildings requiring some cooling and humidification.

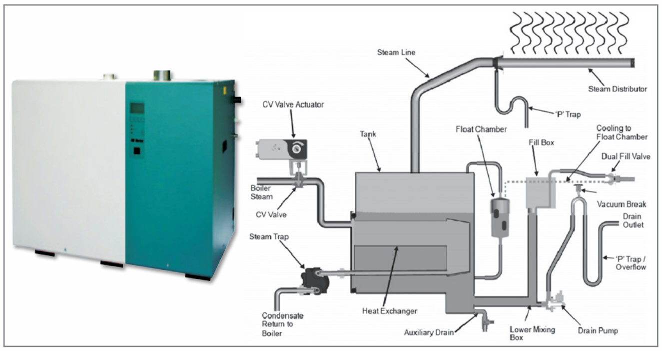

Figure 4: Steam to steam humidifier

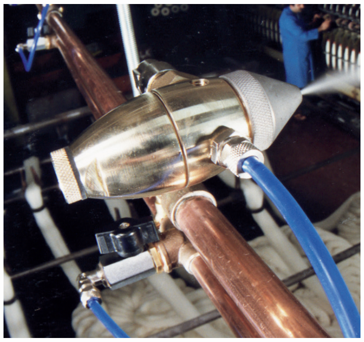

Photo 4: Spray humidifier nozzle

Photo 5: Glass fiber evaporative cooling pads

C. Ultrasonic Humidifiers

Ultrasonic humidifiers employ piezoelectric transducers mounted at the base of a tank. The tank is filled with water covering the transducers. An electric current activates the transducers, producing ultrasonic waves which break water particles into fine droplets (aerosolization). A stream of air directs this cool aerosol out of the tank. The aerosol is generated at room temperature and pressure. The operating costs are low but the piezoelectric transducers need regular replacement, so maintenance costs are high. There is one piezoelectric transducer per 0.5Kg/hr of output, so large duty systems can be very expensive to maintain. Additionally, ultrasonic humidifiers must be run on Reverse Osmosis water of exactly the right quality; too pure water can damage the transducer, and water not pure enough causes scale formation which can shorten the life of the transducer These types of humidifiers are not used widely in European countries as they can be a potential source of Legionella bacteria.

System Design

Once suitable equipment is selected, the next step is to design

continued on page 51

continued from page 49

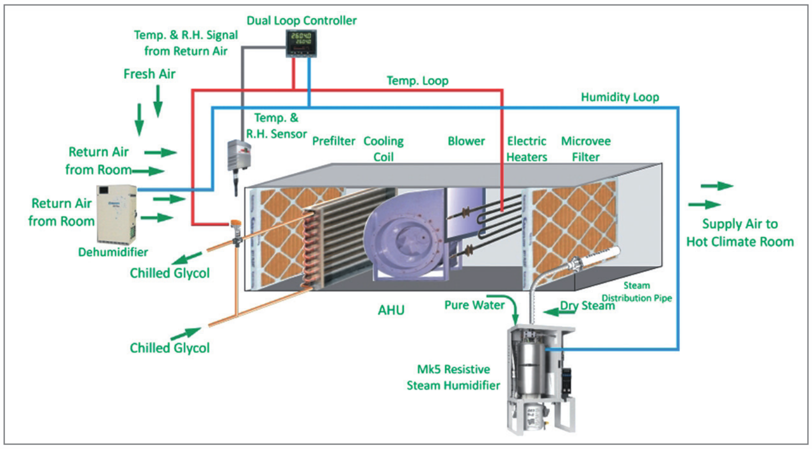

Figure 5: Section of an AHU showing the various equipment, systems and controls

the Air Handling Unit (AHU – see *Figure 5*). Manufactures of both humidifier as well as dehumidifier should be consulted at this stage. When technical data is provided, these manufacturers can select suitable equipment and confirm the space required for installation of their equipment. The AHU should be sized only after such details are received. This is most critical in humidification applications where the moisture absorption distance can vary greatly with inlet conditions (temperature and RH) to the humidifying section, final RH required and the AHU or duct width and height.

Along with the AHU design, chilled water or glycol circulation systems can be designed (see *Figure 6*), which will complete the system design. Alternatively, DX air conditioning system with modulating control can be incorporated as shown in *Figure 7*.

Fluctuations in chilled water temperature and flow can adversely affect RH control in the conditioned space. Generally, modulating valves are installed for control of chilled water through cooling coils and hot water through heating coils. These valves vary chilled water flow through the coils to control heating and cooling. Adding another variation – that of chilled water temperature or flow from the source – makes the controller hunt as it now has to cater to too many variables (see *Figure 8*). This results in poor control. It is therefore desirable to install constant chilled water flow pumps, constant flow air handling units and a large chilled water/ glycol tank with hot and cold wells to ensure sufficient water storage to restrict fluctuations in the chilled water temperature.

Energy saving through the modulation of chilled water pump and AHU blower is not suited for an RH control application as there are too many variations – in chilled water flow, air flow and room internal load.

A Proportional Integral and Derivative (PID) controller works on the error correction method. It measures the difference between the set point and the process value, and the rate at which the process value changes with respect to time. It starts implementing corrections to minimize the errors. Adding too many variations will only cause the controller to hunt as it cannot detect if the change in the process value is due to a change in the internal load or due to an over or under supply of the cooling/ heating media. PID controllers applied for both temperature and humidity controls provide good control accuracy. However, if very high accuracy is desired, dual loop or even triple loop controllers are available. The dual loop controller

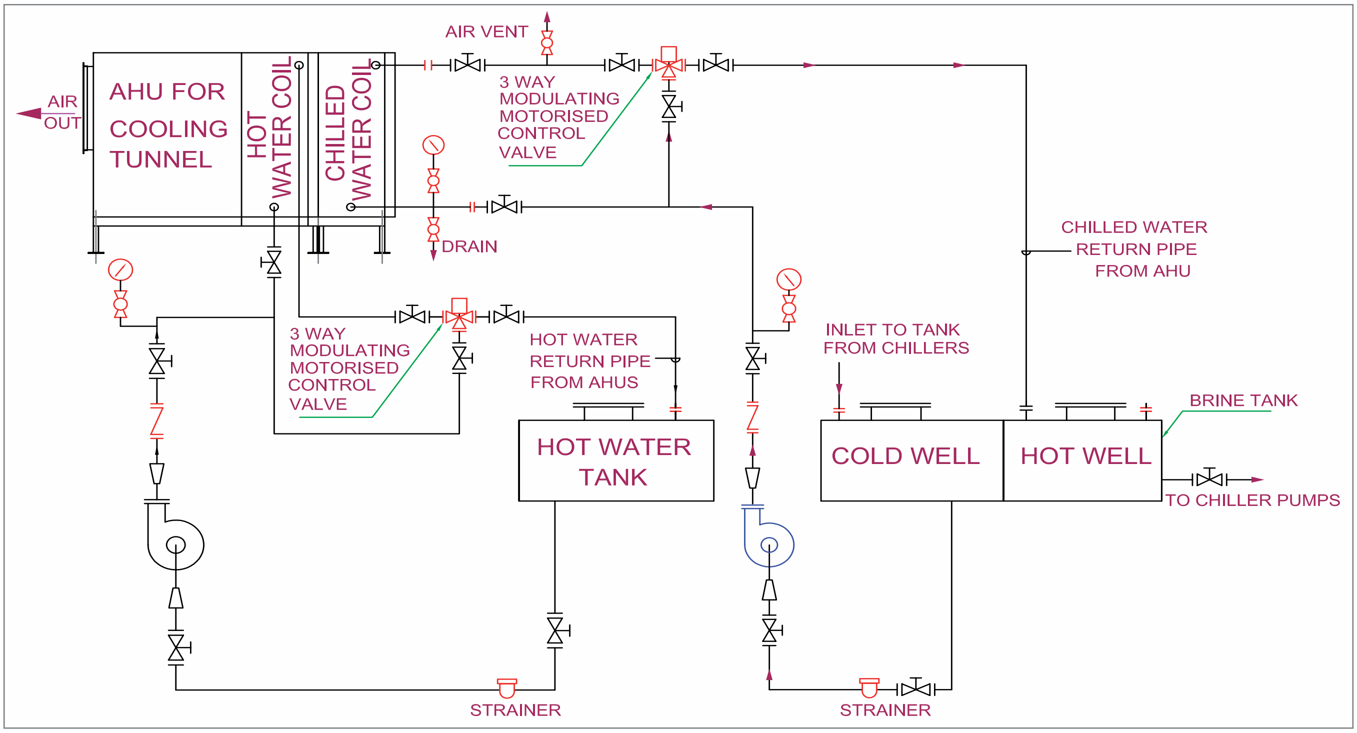

Figure 6: Schematic chilled water piping

continued on page 53

continued from page 51

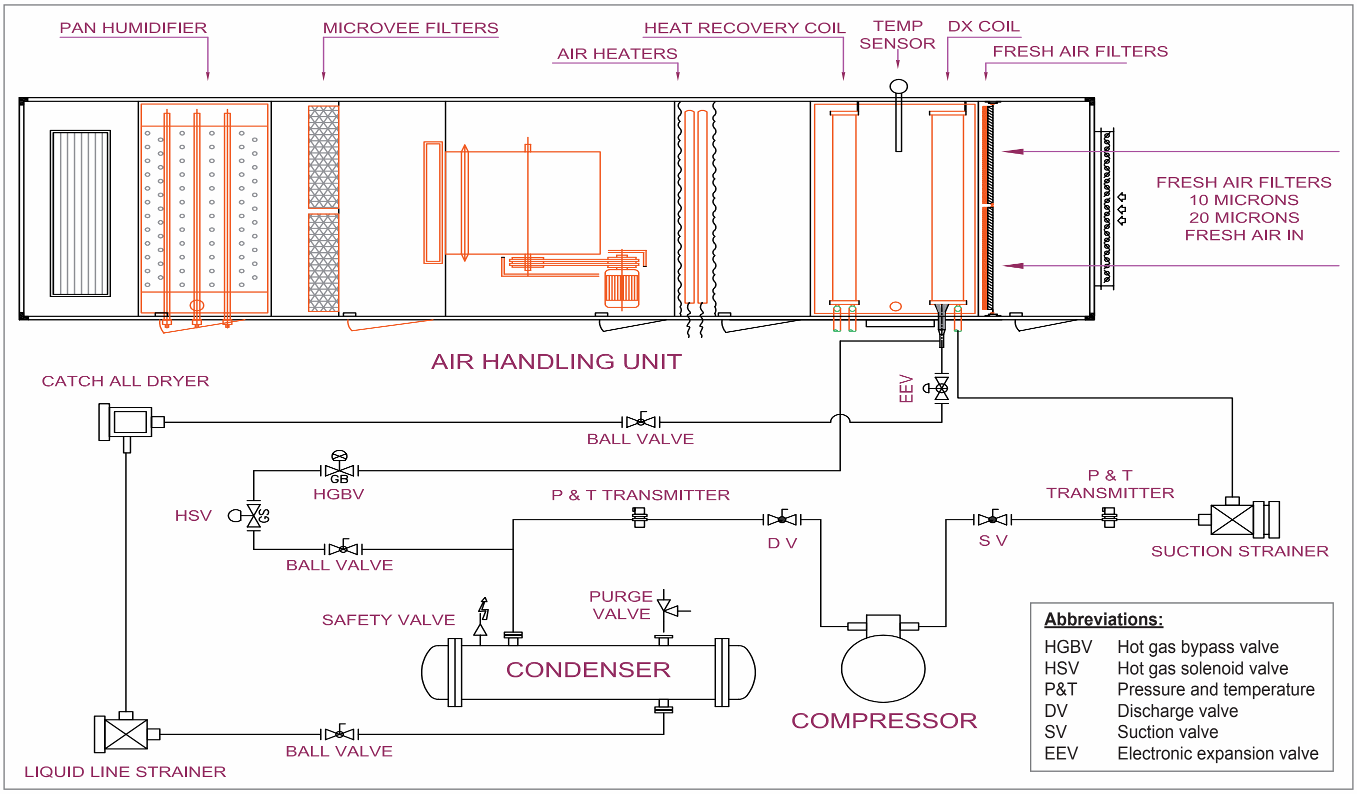

Figure 7: Schematic refrigeration circuit for 100% fresh air application

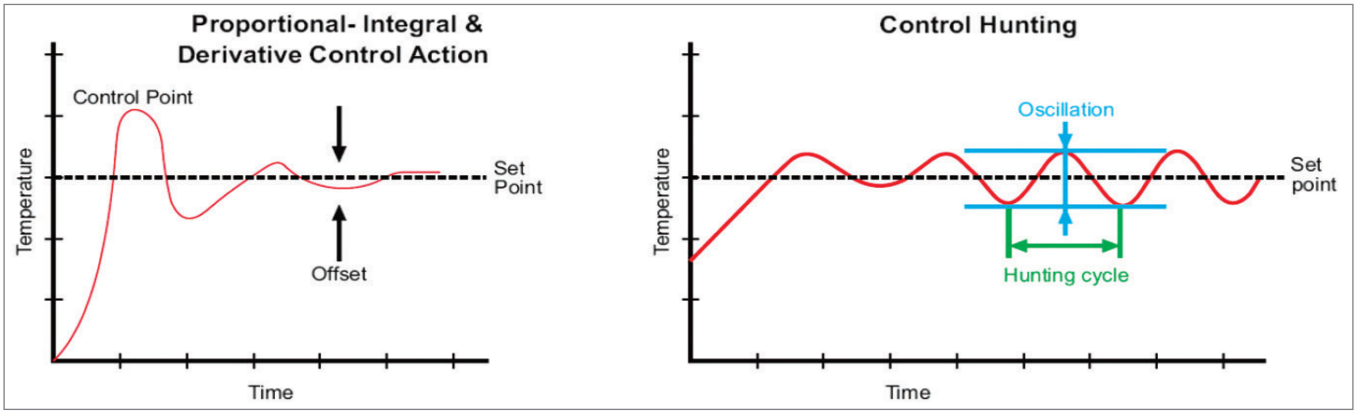

Figure 8: Schematics of PID control and control hunting

is a single controller that controls both temperature and humidity, while the triple loop adds the function of pressure control to the same controller.

Control System

The control systems for cooling and heating typically comprise of control valves, sensors and controllers. Controls can be classified into digital and analog. Digital controls provide on-off action while analog controls provide modulating action.

A properly selected water flow control valve can adjust fluid flow in both directions – it can increase fluid flow through the cooling/ heating coil when more cooling/ heating is required, and is also able to throttle flow through the coils when they are required to perform at low capacity. Selection of the control valve should be based on valve coefficient data provided by the valve manufacturer, for correct pressure drop across its ports. Unless proper sensors and controls are integrated with the system, correct temperature and RH control cannot be achieved.

For temperature sensing, a platinum resistance sensor, commonly known as PT-100, is the most stable and linear, giving accurate readings in the temperature ranges normally encountered.

For RH sensing, various sensor options are available varying greatly in cost, accuracy, repeatability and stability. Capacitive type sensors are widely used in industrial applications. They consist of a substrate on which a thin film of polymer or metal oxide is deposited between two conductive electrodes. The sensing surface is coated

continued on page 55

continued from page 53

Some Case Studies

Case Study 1

For a 100% fresh air application where the air was to be used for pneumatic conveying and finally exhausted, the fresh air needed to be cooled down to 2°C dew point and subsequently reheated to supply at 14°C and 45% RH (see *Figure 9*). The customer did not wish to install a desiccant dehumidifier and was also unwilling to consider a glycol system. Another issue was that the location of the plant was in north India and the ambient wet bulb varied from 28.5°C in the monsoon to 5°C in the winter. As the air was not recirculated, it had to be cooled online. Cooling was required to be continuously ON and at the same time to modulate based on varying incoming air condition. Lower RH than the design condition of 45% was, however, acceptable to the customer. Chilled water was available.

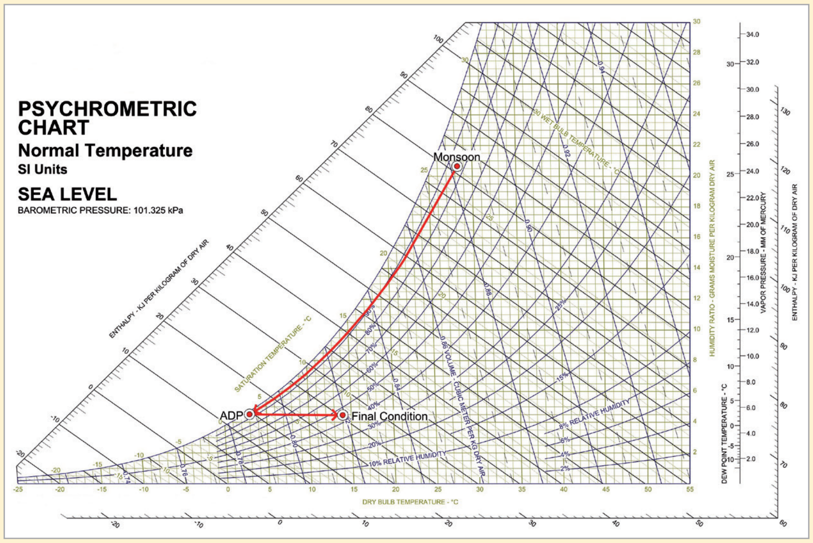

Figure 9: Psychrometrics of Case Study 1

The solution was to cool the air down to an intermediate level of 14°C using available chilled water. From 14°C to 2°C the air was cooled by passing over another DX coil. The coil was artificially loaded with hot gas from the compressor to maintain the minimum evaporating temperature to prevent frost formation.

Case Study 2

A PVC film manufacturing plant located near Pune had a requirement of air conditioning with high RH to prevent wrinkling of the film during the manufacturing process. An air conditioning company was awarded the contract to supply and install the system which comprised of air handling capacity of 68,000 cubic meters per hour (40,000 CFM). As the conditioned area was to be certified for Class 1,00,000 condition, some fresh air was introduced in the AHU. However as Pune has hot and dry ambient during the summer and low ambient temperatures during the winter, humidification of fresh air was necessary to raise the space RH. Unfortunately the air conditioning company had completely overlooked this aspect and was struggling with the system to achieve the desired room RH, especially during the winter. The client suffered heavy losses due to material rejections. A couple of humidifying options were considered and two of them were employed. The client did not have any steam source available, which ruled out live steam or steam-to-steam humidifiers. A resistive steam humidifier was added to achieve the desired RH level during the summer and winter. Subsequently, to improve the cooling effect of the installed air conditioning system, jet spray nozzles were installed in the conditioned space. This not only humidified the area but also provided additional cooling.

Case Study 3

A pharma manufacturing company needed air at a temperature of around 55°C and RH of minimum 65%. Air has absolute moisture content of 70.4 g/kg of dry air at that condition. The process involved air intake at 25°C and 50% RH (10 g/kg of dry air), and raising its temperature and RH to the desired level of 55°C and 65% RH.

The process equipment manufacturer had supplied equipment which first added steam for humidification and subsequently heated the air (see *Figure 10*). However, even as air at 25°C and 50% RH was humidified directly, it reached saturation at moisture content of 20.2 g/kg with a resultant relative humidity level of 20% at the desired temperature of 55°C as the air was heated. Any further addition of moisture was impossible.

The solution was to heat the air to 55°C first and then add steam (see *Figure 11*). Fortunately the client had a supply of pure steam available. A steam dispersion pipe fitted with a modulating valve to control the steam supply, complete with condensate drain arrangement, was proposed.

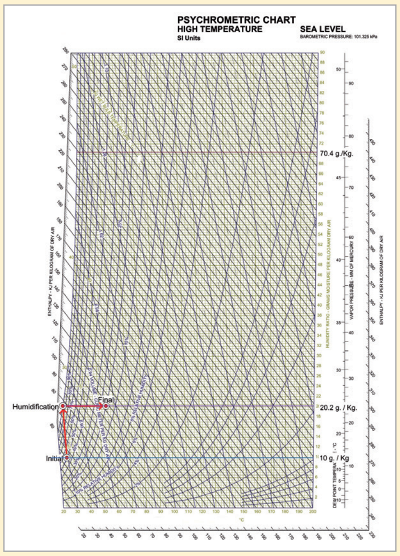

Figure 10: Psychrometric chart – old process

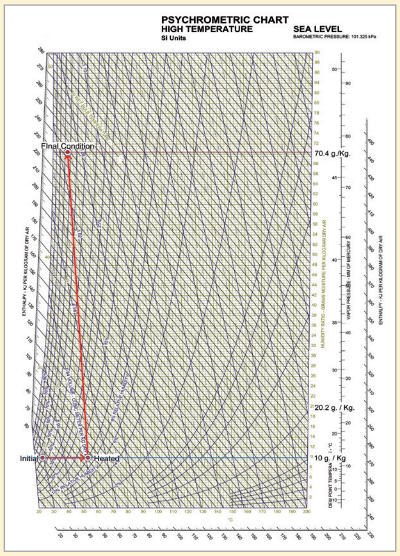

Figure 11: Psychrometric chart – new process

with a porous metal electrode to protect it from contamination and exposure to condensation. The substrate is typically glass, ceramic or silicon. Increment al change in the dielectric constant of a capacitive humidity sensor is directly proportional to the relative humidity of the surrounding environment. Capacitive sensors are able to recover fully from condensation. They have minimum long term drift. The typical uncertainty of these sensors is ±2% in the range of 5% to 95% RH, making them most suitable for a majority of RH control applications. Interchangeability of sensors in the field can be a problem unless the sensors are laser trimmed to reduce the variance to ±2%. (Laser trimming vaporizes the top layers of a multi-layer plate capacitor to fine-tune its capacitance for increased sensing accuracy).

Resistive humidity sensors measure changes in electrical impedance of a hygroscopic medium such as a conductive polymer, salt or treated substrate. Impedance change typically has an inverse exponential relationship to humidity. A distinct advantage of the resistive sensor is its direct field interchangeability, usually within ±2%. However, exposure to chemical vapors and other contaminants can lead to premature sensor failure.

Digital indicating PID controllers are more accurate and some have very effective control algorithms.

Control Schemes

The HVAC system can be controlled in numerous ways in conjunction with different types of systems, and explaining all such control schemes will be beyond the scope of this article. However, the two main schemes are:

i) Directly sensing and controlling room temperature and RH

In this scheme, return air sensing is generally advisable as it reflects the average room conditions.

ii) Dew point control

This scheme can be adopted successfully if there is no moisture addition in the conditioned space. Once the room dew point is determined, the coil leaving conditions are controlled, effectively controlling dehumidification in the cooling coil. Room temperature control can be used to maintain the RH automatically as the process involves only sensible heating post the cooling coil. The biggest advantage of this scheme is that control based on RH sensor is completely eliminated. Since platinum resistance type temperature sensors are accurate, stable and linear, this type of control scheme is most stable.

Conclusion

In industrial air conditioning, where humidity control systems are critical to production, a single or simple solution is not always feasible. Humidification or dehumidification in the broadest sense is a much more complex subject than many designers believe.

India's economic future depends on improvements in technology, and old ideas and methods have to give way to contemporary solutions. If a company wishes to manufacture world class products in its facility, they clearly need to install world class equipment for manufacturing as well as utilities. ❖