10-POINT GUIDE TO HUMIDITY CONTROL IN CLEANROOMS

Humidification, Dehumidification
and Evaporative Cooling

condair

CONTROLLING HUMIDITY IN CONTROLLED ENVIRONMENTS

Most commercial buildings have air treatment systems to manage the quality of the atmosphere, but cleanroom environments often have very specific requirements based upon the needs of the processes being undertaken.

Cleanrooms are classified based on the permitted number of particles in a set volume of air. The fewer permitted particles, the tighter control needed to achieve the required environment.

Controlling humidity in cleanrooms can require consideration of not only very accurate air moisture management, but also any potential for particulate matter introduction, and how the humidity control process may impact room temperature, or vice versa.

This document presents an introductory 10-point guide for cleanroom designers, production managers and facility managers who need to manage a cleanroom's humidity.

This guide focuses on elements associated to either humidification or dehumidification technology. It highlights the most important elements to consider for technology selection, system layout, sizing, energy considerations and service requirements.

CONTENTS

1 WHAT LEVEL OF HUMIDITY DOES MY CLEANROOM NEED?

The answer to this question depends on the purpose and application of the cleanroom environment and the products and processes taking place within it.

Humidity is often regulated to create an equilibrium moisture content between a material and its surrounding environment. The objective is to prevent moisture movement from a product to the air or from the air into a product. Material-specific sorption isotherm graphs can be used to determine what level of air humidity is needed to maintain a certain internal moisture content for different materials.

As well as drying or wetting effects, incorrect levels of air humidity can also lead to a chemical reaction in some materials. This can range from a simple corrosive effect to explosive reactions.

Static discharge is more prevalent at low humidity, so it is common to maintain humidity above 45%RH to mitigate electrostatic build-up and the problems it can create. However, excessive humidity can also cause issues if it results in condensation, leading to the potential for mould growth on surfaces.

> depends on the purpose and application of the cleanroom environment

In a cleanroom environment, different processes or materials may require different levels of humidity control. It is often more practical to manage extreme control or very specific requirements within isolated glovebox environments than control a whole room.

Application	Typical humidity level
Prevent electrostatic build-up	>45%RH
Human health	40 – 60%RH
Food • Chocolate • Bottling • Fish canning	 40 – 60%RH 45 – 55%RH or below Td of bottle surface 90%RH during cooling
Pharmaceutical • Tablet coating • Fluid bed drying	 35%RH <10%RH
Lithium-ion battery production	<1%%RH
Printed circuit board	50 – 55%RH
Semiconductor manufacture	50%RH
Automotive paint spray • Aqueous • Solvent	 65%RH 50%RH
Medical device • Production • Packaging	 50 – 98%RH <11%RH

Table 1: Example cleanroom processes with their typical humidity levels

2 WHAT IS TEMPERATURE'S IMPACT ON HUMIDITY?

The term "relative humidity" refers to the air's ability to hold moisture at any given temperature, expressed as a percentage of the maximum amount of moisture it could possibly hold at the same temperature. So, if the air could potentially hold 40% more water at a certain temperature, it is 60% relative humidity.

As warm air can hold more moisture than cold air, applying heat to an atmosphere, without changing its moisture content, will lower its relative humidity. This is because the air's ability to hold moisture increases. The same is also true in reverse. Cooling air without altering its moisture content, will increase its relative humidity.
This is important to understand when maintaining a specific humidity in a controlled environment.

Wherever the temperature profile across an area fluctuates, so will the relative humidity. This could be due to heat from machinery, a chemical process or even from people in the area. To obtain the correct level of moisture introduction or removal from a humidity control system, it is vital to position sensors at the point of criticality for the process in question. This minimises the impact of a room's varying temperature profile.

A product's temperature can also impact humidity control. If the temperature of a product being processed is different from the ambient room temperature, the air adjacent to it will be affected. If the product is colder, then a local micro-climate with a high humidity can result, potentially leading to condensation or moisture absorption. If the product is warmer than the room air, a low humidity micro-climate can result, with adverse drying and moisture loss from the product.

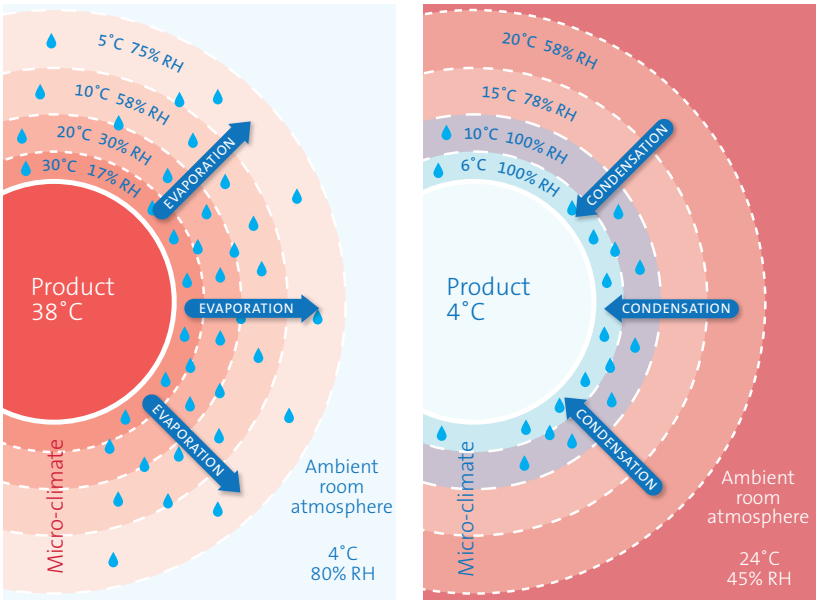


Fig.1: Micro-climate resulting from temperature differences

> "warm air can hold more moisture than cold air"

Condair offers free expert advice on humidity levels and system design

3 WHAT LEVEL OF HUMIDITY CONTROL ACCURACY IS POSSIBLE?

There are four main elements that determine the potential accuracy of humidity control in a cleanroom environment.

1 – The humidity control technology
The humidifier or dehumidifier's ability to deliver or remove moisture on demand from a control signal. Close control systems must be able to react quickly to a control signal and fully modulate performance, from 0-100% output.

2 – The humidity sensor
The accuracy of a humidity control system is usually two times the measurement accuracy of its associated sensor. If a sensor's accuracy is ±2%RH, then the tightest control possible from the overall system will be approximately ±4%RH (see Fig.2).

3 – The temperature management system
As detailed in point 2, relative humidity is closely linked to temperature. Any fluctuation in temperature will result in a change in relative humidity, without an appropriate level of humidification or dehumidification. As an example, a ±2°C change in temperature can lead to a ±6%RH fluctuation in relative humidity.

4 – The temperature sensor
Management of temperature is also dependent on the control accuracy of its associated sensor.

Alongside a responsive humidity control system, to precisely control a cleanroom's humidity, the temperature and humidity sensors must be highly accurate, and the room temperature must be consistent.

Typical humidification control		Typical dehumidification control	
- Standard HVAC controls (±1°C) - Resistive steam humidifier - Mains water	±4%RH	- Standard HVAC controls - Desiccant dehumidifier (stage control heater)	±4%RH
- Advanced HVAC controls (±0.2°C) - Process version resistive steam humidifier - RO water	±1%RH	- Advanced HVAC control - Desiccant dehumidifier (modulating control heater)	±2%RH

Table 2: Typical control levels from system configurations

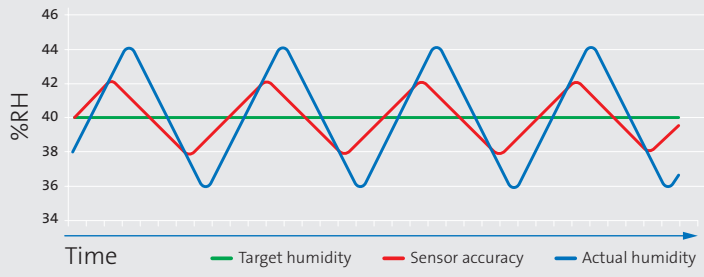


Fig.2: Humidity control is typically twice the measurement accuracy of its associated sensor.

> "sensors must be highly accurate, and the room temperature must be consistent"

4 WHAT HUMIDIFICATION SYSTEM SHOULD I USE?

Resistive steam humidifier

Hybrid adiabatic humidifier

Live steam humidifier

Ultrasonic humidifier

> a humidifier's ability to fully modulate its output from 0-100% is key

A humidifier's ability to fully modulate output from 0-100% is a key feature that enables it to accurately manage humidity. A close control humidifier must be able to deliver the precise amount of moisture to maintain a specific air relative humidity. Humidifiers with on/off control or multi-stage operation will result in a greater fluctuation in air humidity, as they provide a less precise response to a control signal.

Some types of humidifiers will need to pause or reduce output when performing routine flush cycles. This could be to mitigate mineral build-up in the water system, as water is boiled-off or evaporates. When this happens, humidity control will be negatively impacted. So this type of humidifier might not be suitable for close control applications.

Reverse osmosis (RO) water treatment systems remove minerals from the humidifier's supply water and limit or remove the need for routine flush cycles to control mineral build-up. However, some humidifier technologies, such as electrode boiler steam humidifiers, need minerals in the supply water to operate, so cannot be used with RO water making them less suitable for cleanroom applications.

As very pure water can be aggressive, operating humidifiers on very low mineral water can reduce the operational lifetime. To minimise issues with mineral build-up and maximise operating lifetime, it is recommended water purity for humidifiers is limited down to 2MΩ.

Control	Technology	Modulation	Output (single unit)
±1%RH	Resistive electric steam (process version)	0-100%	2-160 kg/h
	Live Steam (rotary disc valve)	0-100%	1-2,000 kg/h
±2%RH	Ultrasonic (AHU)	0-100%	3-25kg/h
±3%RH	Resistive electric steam (standard version)	0-100%	2-160 kg/h
	Hybrid (AHU)	5-100% Stage then modulating	4-2,000 kg/h

Table 3: Close control humidifiers typically used in cleanrooms

5 WHAT DEHUMIDIFICATION SYSTEM SHOULD I USE?

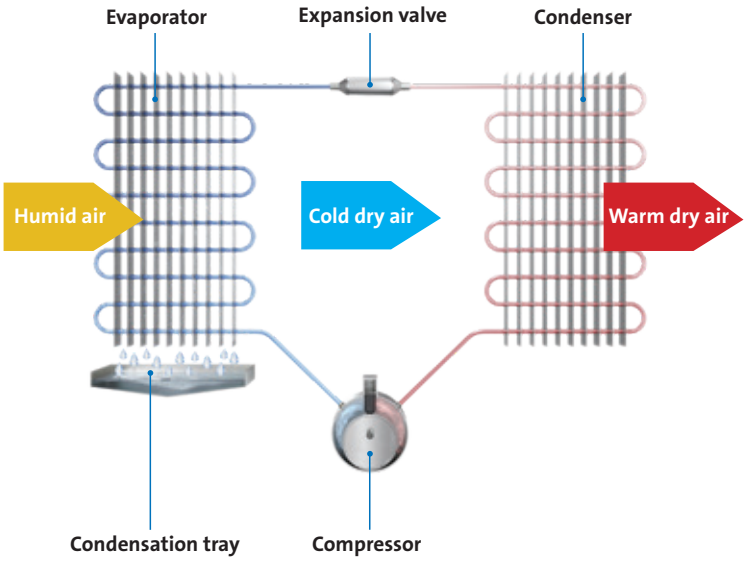
There are two main types of commercial dehumidifier: condensing and desiccant.

Condensing dehumidifier
A condensing dehumidifier removes moisture from the air by creating a cold surface upon which water vapour condenses. It chills the air below its dew point, using the evaporator side of a standard refrigerant circuit. It reheats the dried air with the hot condenser side of the circuit before supplying the dry air to the room and sending the condensation to drain.

As the process relies on condensation forming, the lower the temperature of the ambient air, the less condensation forms in the dehumidifier. Drying performance is also limited by the cooling coil's ability to condense moisture without freezing it.

This means that condensing dehumidifiers are ideal for mid-range temperatures, around 20°C, and humidity above 50%RH.

A condensing dehumidifier's operation is either on or off, depending on the signal from the control sensor. For this reason, typical control accuracy tends to be ±10%RH.



> "control accuracy tends to be ±10%RH"

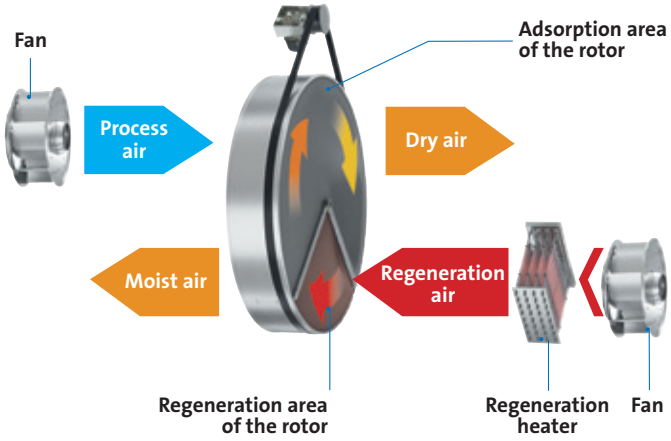
Condensing dehumidifier		
Dehumidification principle	Refrigerant circuit	
Effective operating temperature	15°C to 36°C	
Achievable %RH	>50%RH	
Control tolerance	±10%RH	
Power consumption per kg removed	0.5 – 1.5kW	
Room heat addition	Moderate	
Ducting required?	No	
Typical installation type	Mobile or fixed	

Desiccant dehumidifier
A desiccant dehumidifier removes moisture from the air by adsorbing it in a slowly turning desiccant wheel. Similar to a sponge literally soaking up water, the desiccant wheel adsorbs moisture from the air passing through it.

To avoid saturation, very hot air is forced through a section of the wheel, during its rotation. This process is called regeneration. The hot air has a very low relative humidity and draws water from the desiccant wheel, as it slowly rotates through the regeneration area. This hot, wet air is then vented externally, rejecting the moisture and ensuring the system can continuously dry the air.

Desiccant dehumidifiers can be placed in series, enabling them to provide humidity levels as low as 1%RH. They can also effectively dry at extremely low temperatures, as the desiccant will absorb moisture from the air, irrespective of its ambient temperature.

The drying performance of a desiccant dehumidifier can be modulated by adjusting the volume of air flowing through the regeneration airflow or by adjusting the heat applied to the regeneration airflow. For this reason, control accuracy can be around ±2%RH.



> “control accuracy can be around ±2%RH”

Desiccant dehumidifier	
Sorption wheel	**Dehumidification principle**
-30°C to 40°C	**Effective operating conditions**
1%RH	**Achievable %RH**
±2%RH	**Control tolerance**
1.0 – 3.0kW	**Power consumption per kg removed**
High	**Room heat addition**
Yes	**Ducting required?**
Fixed	**Typical installation type**

6 HOW DO I SIZE MY HUMIDITY CONTROL SYSTEM?

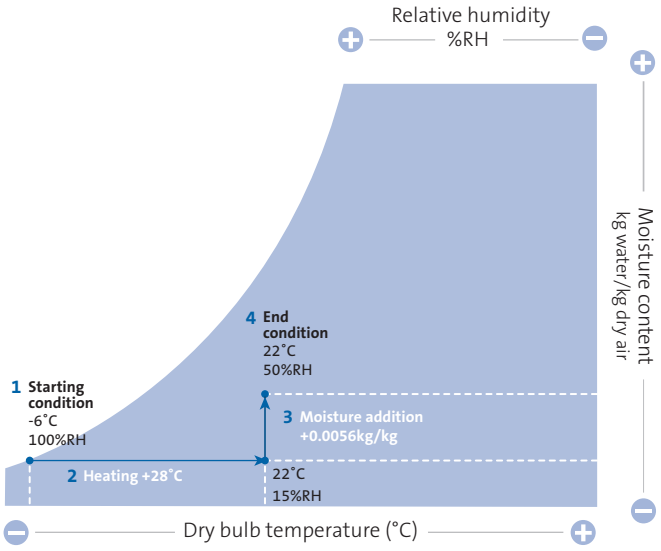
Humidifiers and dehumidifiers are sized on their ability to add or remove an amount of water from the air. This size could be expressed in kilos or litres per hour, or per day (for condensing dehumidifiers). For any given project, there are two steps to correctly sizing a humidifier or dehumidifier.

Step 1 – Perform a psychrometric calculation
Determines how much moisture needs to be added or removed from a single kilo of air, to change its humidity from the starting condition to the desired end condition.

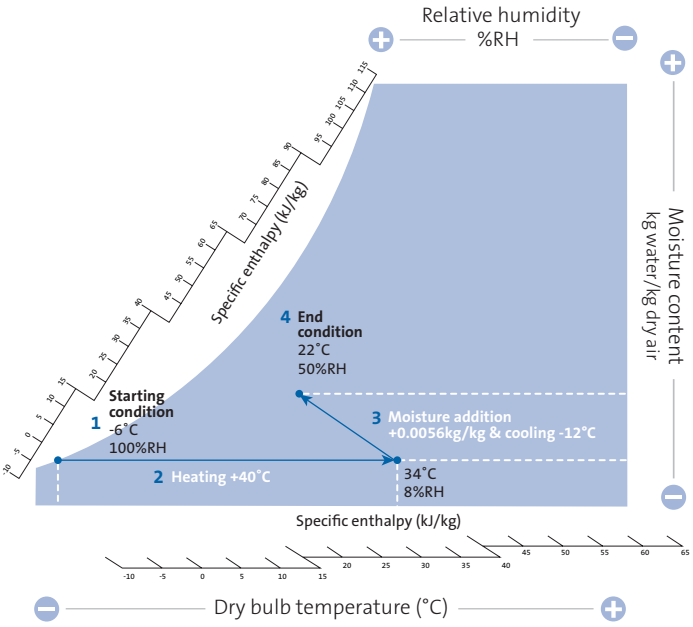
Step 2 – Perform a load calculation
For the total volume of air being considered, determines what the overall volume of moisture is that must be added or removed per hour (or per day).

Step 1 – Humidification psychrometric calculation

Typical isothermal (steam) humidification process



Typical adiabatic (cold water) humidification process



1 – Starting condition -6°C 100%RH – based on the coldest possible outdoor temperature and the lowest RH.

2 – Heating +28°C – chart shows the pre-humidification RH level.

3 – Moisture addition +0.0056kg/kg – to the required RH level. Chart shows the amount of moisture needed to raise the humidity to the desired level per kilo of dry air.

4 – End condition 22°C 50%RH

1 – Starting condition -6°C 100%RH – based on the coldest possible outdoor temperature and the lowest RH.

2 – Heating +40°C – chart shows the pre-humidification RH level and the corresponding amount of pre-heating required.

3 – Moisture addition & cooling +0.0056kg/kg -12°C – diagonally up the line of specific enthalpy to the required RH level. Chart shows the amount of moisture needed to raise the humidity to the desired level per kilo of dry air.

4 – End condition 22°C 50%RH

Step 2 – Humidification load calculation

AHU humidification load calculation

$$\frac{\text{Airflow m}^3\text{/hr} \times \text{\% of fresh air} \times \text{Moisture addition kg/kg}}{\text{Specific volume m}^3\text{/kg}} = \text{Humidity load kg/hr}$$

Example:

$$\frac{7{,}200\ \text{m}^3\text{/hr} \times 20\% \times 0.0056\ \text{kg/kg}}{0.84\text{m}^3\text{/kg}} = 9.6\text{kg/hour}$$

Direct room humidification load calculation

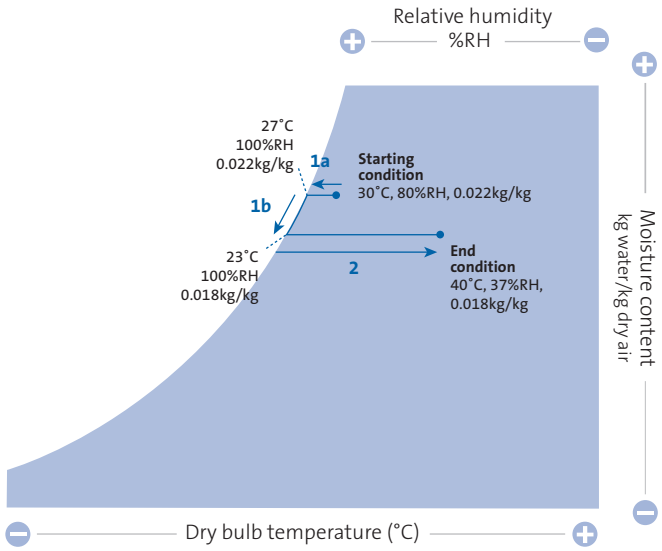
$$\frac{\text{Room air volume m}^3 \times \text{Air change rate per hr} \times \text{Moisture addition kg/kg}}{\text{Specific volume m}^3\text{/kg}} = \text{Humidity load kg/hr}$$

Example:

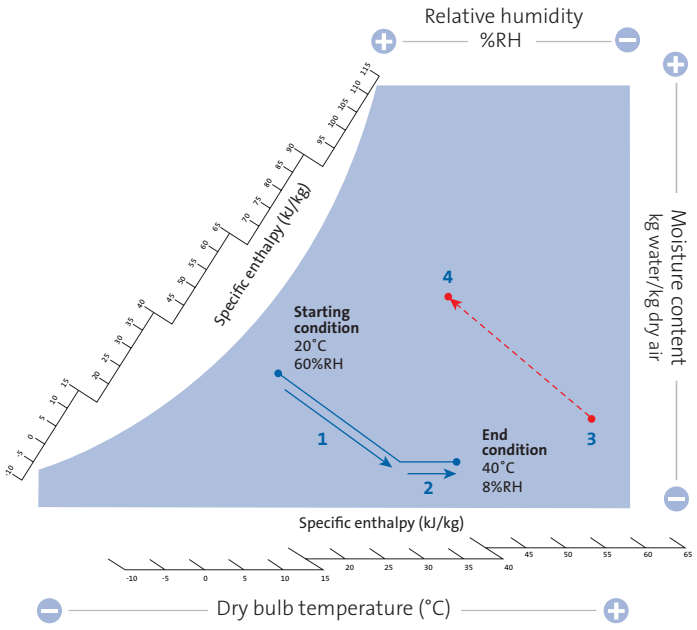
$$\frac{3{,}500\ \text{m}^3 \times 2.5 \times 0.0056\ \text{kg/kg}}{0.84\text{m}^3\text{/kg}} = 41.2\text{kg/hr}$$

Step 1 – Dehumidification psychrometric calculation

Typical condensing dehumidification process



Typical desiccant dehumidification process



1a – Sensible cooling on the evaporator heat exchanger surface. Temperature reduces by 3˚C to 27˚C and humidity increases to 100%RH (reaches dew point). No moisture quantity reduction yet.

1b – Latent cooling on the evaporator surface. Temperature reduces by a further 4˚C to 23˚C, humidity remains at 100%RH, and the moisture quantity reduces by 0.04kg/kg dry air.

2 – Air heating from the compressor and condenser. Temperature increase by 17˚C to 40˚C, and humidity reduces to 37%RH. No change in moisture content.

1 – Air is drawn in and passes through the desiccant rotor, where moisture is adsorbed. The temperature increases by 13˚C, due to the latent heat of vaporisation and the relative humidity drops by 49%RH (from 60%RH to 11%RH). Moisture reduction by 0.05kg/kg dry air (0.009 to 0.004kg/kg).

2 – The air increases temperature further due to the residual heat in the revolving desiccant rotor from the hot regeneration process. The temperature increases another 7˚C and the relative humidity drops from 11%RH to 8%RH, but the moisture content remains constant.

3 – Air is heated to around 90-120˚C (chart shows indicative start and end condition, to illustrate rise in temperature and drop in relative humidity), to dry out the rotor and extract moisture.

4 – Hot wet regeneration air is vented externally.

Step 2 – Dehumidification load calculation

External load calculation	Internal load calculation
Duty = Moisture difference x Air volume / Specific volume	**Duty =** No. of occupants x Working intensity intensity - (see Table 3) + Additional moisture
Total Duty = External Load + Internal Load	

Occupant working intensity	Moisture addition per person, per hour @20˚C
Low (eg sitting at a desk)	35g
Medium (eg working in a factory)	110g
High (eg exercising in a gym)	185g

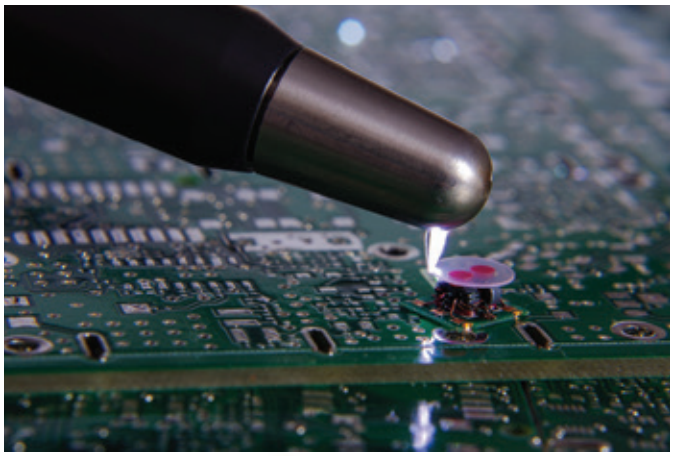
Table 3 – Occupant's working intensity moisture addition

> there are two steps to correctly sizing a humidifier or dehumidifier

7 HOW DO I CONTROL STATIC WITH HUMIDITY?

Electrostatic can occur whenever there is an imbalance of electric charges within or on the surface of a material. This is frequently the result of friction between surfaces, allowing negative or positive charges to transfer from one surface to another and build-up.

Static can result in materials becoming attracted to each other, repelling away from each other or an electrostatic discharge (spark) can occur. Any of these effects can be greatly detrimental in a cleanroom manufacturing or research environment.



A successful way to control static build-up in a cleanroom environment is to maintain air humidity above 45%RH. At higher levels of air humidity, electric charge will naturally dissipate through the air, rather than remain static in a material.

Static can be controlled using specialist flooring, worksurfaces, wrist straps and packaging. These can be very effective, locally applied solutions, but humidity control presents a holistic solution across a room or building. Humidity control offers an additional level of protection to reduce risk to sensitive processes used in combination with local solutions in a cleanroom environment.

Table 4 shows the reduction in the level of electric charge produced by various activities when maintaining a high rather than low humidity.

Activity (@ 21˚C)	Static voltages		
	10-20% RH	**65-90% RH**	**Reduction**
Walking across vinyl floor	12,000V	250V	98%
Walking across synthetic carpet	35,000V	1,500V	96%
Arising from foam cushion	18,000V	1,500V	92%
Picking up polythene bag	20,000V	600V	97%
Sliding styrene box on carpet	18,000V	1,500V	92%
Removing Mylar tape from PC board	12,000V	1,500V	87%
Shrinkable film on PC board	16,000V	3,000V	81%
Triggering vacuum solder remover	8,000V	1,000V	87%
Aerosol circuit freeze spray	15,000V	5,000V	67%

Table 4: Reference Military Handbook, 1991, USA, Department of Defence, MIL-BDBK-263B

> “maintain air humidity above 45%RH”

Condair offers free expert advice on humidity levels and system design

8 WHAT ASSOCIATED PRODUCTS NEED TO BE CONSIDERED?

Humidification systems

Water treatment
RO – Reverse osmosis water filtration removes virtually all the minerals from the supply water to greatly reduce maintenance and enhance hygienic performance in cold water systems.

UV – Ultraviolet sterilisation will kill bacteria in water. This is particularly beneficial in water tanks but is also used on water supply lines and recirculating water lines. Frequently used in the food sector.

Silver ion – Silver ionisation offers a powerful antimicrobial effect and is widely regarded as one of the most effective prevention and remediation methods for Legionella.

Water softener – Used alongside high capacity (>500L/D) RO water systems to improve the performance of the RO membrane and prolong operational lifetime.

Pumps + tanks
Used when the water supply or pressure may be inconsistent or when high capacity water supply is required.

High-end humidistats
A sensor that sends an "off" signal to a humidifier in the event of an excessively high humidity level, indicating faulty operation.

Stands and enclosures
Provides proper operational positioning when wall-mounting is not an option, and protection from the elements when located outside.

Leak detector
A sensor that sends an "off" signal to a humidifier on detection of water.

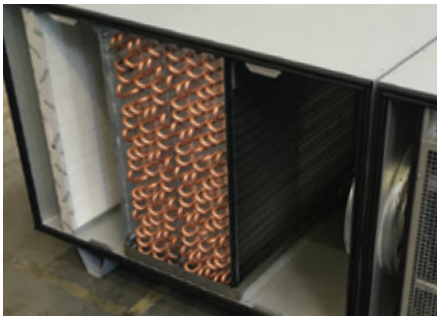
Drain water cooling
Tempers hot (>90°C) drain water from steam humidifiers with fresh, cold water to provide <60°C drain water.

Commissioning
Should be carried out by the manufacturer to ensure humidification equipment is installed correctly, with optimum controls and operational performance.

Servicing
Routine professional maintenance is required for all humidification systems to maintain efficient and hygienic operation.

Dehumidification systems

Pre / post cooling modules
For achieving very low humidity levels or for air delivery at specific temperatures, cooling coil modules can be positioned before or after the dehumidifier.

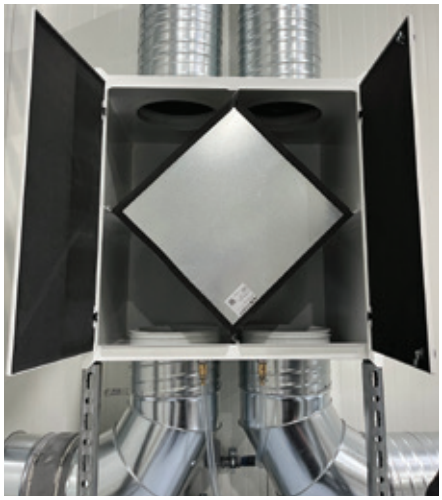


Air dampers
Applied to the air intake and exhaust, allows the airflows to be set correctly at commissioning and ensure optimal air pressures through the system.

Filter guard
An air proving switch to monitor air pressure prior to the dehumidifier and warn of filter blockages.

Air cooled condenser
Fitted on a desiccant dehumidifier's regeneration exhaust airflow if outside venting is not possible, so moisture can be condensed and sent to drain.

Crossflow heat exchangers
Recovers thermal energy from hot regeneration exhaust air from a desiccant dehumidifier, to preheat incoming regeneration air, thus saving energy.



Floor trolleys
Used with condensing dehumidifiers to assist in positioning and relocation.

Modulating heater control
On desiccant dehumidifiers, this adjusts the regeneration airflow temperature to provide closer humidity control than on/off heaters.

Condair offers free expert advice on system design

9 WHAT ARE THE ENERGY CONSIDERATIONS OF HUMIDITY CONTROL?

Humidification

As a rule of thumb, for every 1kg of steam humidification, 0.75kW of electrical power is needed. Electric steam humidifiers are often the most appropriate solution for a cleanroom, but if adiabatic (cold water) humidifiers are used, the energy use can vary depending on the system design.

The same overall amount of energy is required for adiabatic humidification, but the energy consumption is relocated to a heater ahead of the humidifier. This is so that the air will be able to absorb moisture from the humidifier and to counter the cooling effect from the evaporation.

If waste heat from a process is available for this pre-heating, an adiabatic humidification system can provide very low energy operation. For instance, an electric steam humidifier delivering 30kg/h of steam might consume around 22.5kW/h. An equivalently sized hybrid adiabatic humidifier could produce the same humidification capacity from less than 1kW/h, excluding the pre-heat energy.

Other energy considerations include the power used by any water purification systems. The energy required for RO water will vary on system size, but it can range from 0.03kW per litre of RO water on smaller capacity units to 0.005kW for larger systems.

> “energy use can vary depending on the system design”

Sizing rules of thumb

Humidity control system	Energy rules of thumb for 1kg moisture
Electric steam humidification	0.75kW
Condensing dehumidification	0.5-1.5kW
Desiccant dehumidification	1-3kW

Dehumidification

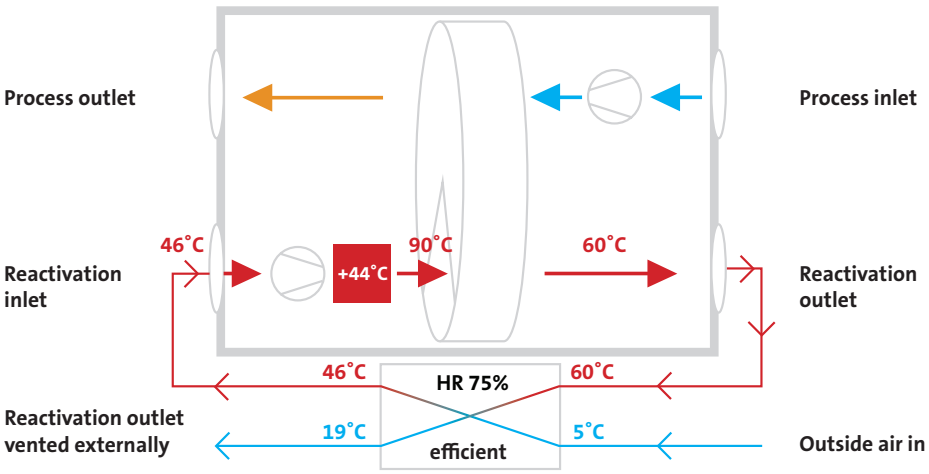
As a rule of thumb, dehumidification with condensing systems will consume between 0.5-1.5kW of electricity to remove 1kg of water. A desiccant system's consumption is higher at 1-3kW per kg of moisture.

If a condensing system can deliver the drying performance, it is often a lower energy option than desiccant technology. However, there are many applications where only desiccant drying will provide the required conditions.

The main energy requirement in a desiccant dehumidifier is to heat the regeneration airflow to between 90 and 120°C. This is typically done with an electric heat exchanger, but a gas-fired heat exchanger or heat recovered from another process can also be used, to either fully heat or pre-heat the incoming regeneration airflow.

The outgoing regeneration airflow, after it passes through the wet desiccant rotor, can be up to 60°C. By passing this air through a heat exchanger, 75% of the heat can be recovered to pre-heat the incoming regeneration airflow. This can reduce the overall energy use by around 50%.

To further reduce the energy consumption of a desiccant dehumidifier, the size and speed of the rotor, and the temperature of the incoming regeneration air can be modified on a project-by-project basis. This optimisation can ensure the required drying performance is achieved with minimal energy use.



> Heat recovery can reduce the overall energy use by around 50%.

Condair offers free expert advice on energy projections for humidifiers or dehumidifiers

10 WHAT ARE THE SERVICE REQUIREMENTS OF A HUMIDITY CONTROL SYSTEM?

Humidification

All humidification systems will need routine maintenance. The frequency will depend on the water quality and operating hours of the system.

When operating on RO water, a steam humidifier may only need one service visit per year but a similar unit operating 24/7 on hard water may need servicing as often as every two months. A steam humidifier's main service requirement is to manage scale build-up and replace consumable items.

The service requirements of an adiabatic humidifier extend beyond this to include chlorination and disinfection, to guarantee hygienic operation. The frequency of this service requirement is typically at least every six months. Regional regulations on water management in commercial premises can also determine this frequency.

> "will depend on the water quality and operating hours of the system"

Dehumidification

A quality dehumidifier is a robust system and if installed and operated correctly, should provide many years of drying performance with very little maintenance needed. However, as with any system managing airflow, filters and inlet grilles will need to be routinely cleaned or replaced when needed.

As condensing dehumidifiers incorporate refrigerant gases, any maintenance work needed to the refrigerant circuit must be carried out by a trained individual, with the appropriate regional accreditations. However, unless there is a malfunction, the refrigerant circuit should not need any routine maintenance.

> very little maintenance needed

Condair offers advice and servicing for humidity control systems

WORLD LEADING HUMIDITY CONTROL SPECIALIST

Condair is a world leader in humidity control and evaporative cooling. It has manufacturing facilities in Asia, Europe and North America, sales operations in 23 countries and distributors in over 50 more.

As well as benefiting from the most advanced humidity control technology available, clients are supported by local specialist engineering teams, which can offer installation, commissioning, maintenance and spares support.

Condair offers free expert advice and guidance to HVAC consultants and building designers who are specifying humidity control systems. Many factors influence correct system design.

Having Condair support you on your humidifier or dehumidifier project will ensure all elements have been fully considered by experts who specialise in this niche field.

Condair Limited
Artex Avenue, Rustington, Littlehampton, West Sussex, BN16 3LN, UK
Tel: +44 (0)1903 850200 - uk.sales@condair.com - www.condair.co.uk

10/2024