10-POINT GUIDE TO HUMIDITY CONTROL IN HERITAGE BUILDINGS

Humidification, Dehumidification
and Evaporative Cooling

condair

CONTROLLING HUMIDITY IN HERITAGE BUILDINGS

Maintaining stable indoor humidity levels in museums, galleries, archives and stately homes is vital for the successful preservation of artefacts and the building interiors.

Museum exhibits, artworks and antiques contain a variety of materials that are hygroscopic, which means they can be affected by the moisture content of their environment. Tiny fluctuations in internal moisture content can result in the degradation of materials over time. If an atmosphere is too humid, condensation from excess moisture can also lead to damage from fungal growth and mould.

However, climate control systems can account for a considerable percentage of a museum or gallery's energy consumption. So, a responsible approach to controlling indoor humidity in the heritage sector requires understanding across a range of topics. These include the hygroscopic qualities of the materials being conserved, what influences indoor humidity, the humidity control technology available, and strategies to minimise energy use.

This document presents an introductory guide to the issues surrounding heritage humidity control, and how to monitor and manage it for successful conservation. It is ideal for museum managers, curators, facility managers and consultants working in the heritage sector.

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1 WHY IS HUMIDITY IMPORTANT IN THE HERITAGE SECTOR?

Museum artefacts, works of art and antiques consist of various hygroscopic materials, which means they can be influenced by the moisture content of their environment. Materials like wood, textiles, paper and animal products can release or absorb water from the air, leading to changes in their internal moisture levels.

As a material's internal moisture content fluctuates, its dimensions also change, particularly at the surface where moisture movement is most significant. Over time, these minor dimensional changes can result in cracking, warping, shrinking and general degradation, leading to costly restoration and repairs.

Furthermore, humidity control is crucial in the heritage sector, as exhibits are borrowed and insured with the stipulation that their environment is carefully managed. Humidity, temperature, light and UV levels can all require strict regulation from the moment items arrive at a loan venue until they depart.

If conditions fall outside the required range, benefactors may choose not to allow the loan, and insurance companies may refuse to cover
the artefacts.

> "long-term conservation requires a stable environment"

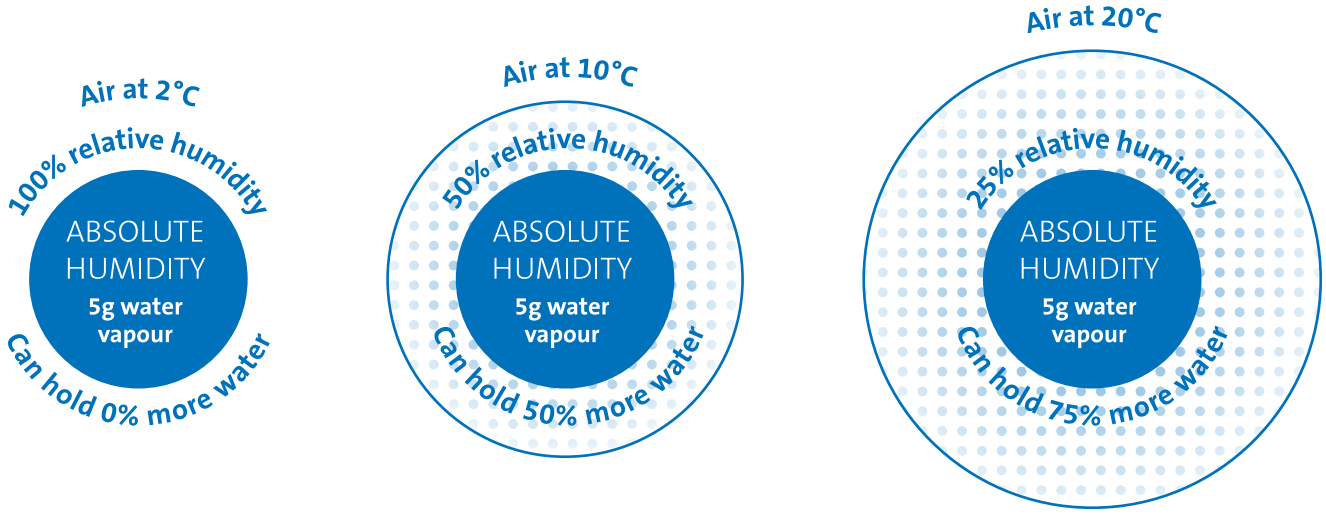
2 WHAT IS RELATIVE HUMIDITY?

Absolute humidity

The amount of water air contains, e.g. 5g

Relative humidity

The amount of water air contains, expressed as a percentage of the maximum amount it could contain at the same temperature, e.g. 50%RH



The amount of water air can hold depends on its temperature. Cold air can hold less moisture than warm air. This means that as air is heated, its capacity to retain water increases. Conversely, cooling air reduces its ability to hold moisture.

Heating air does not remove water from it. Instead, it expands the air's capacity to absorb moisture. If no additional moisture is introduced, the relative humidity decreases as the temperature rises.

During this process, the air will draw moisture from any material with a high moisture content until an equilibrium is established between the air and the object.

Recognizing the relationship between temperature and humidity is crucial, particularly in heritage conservation. Understanding temperature and humidity variations across a space is essential for managing an atmosphere's effect on historic materials.

> relative humidity decreases as the temperature rises

Condair offers free expert advice on humidity levels and system design

3 WHAT AFFECTS INDOOR HUMIDITY?

The seasons
Cold winter air holds little moisture due to its low temperature. The cold outside air has high relative humidity but low absolute moisture content (see point 2).

When this cold saturated air enters a building and is heated, its relative humidity drops as its moisture-holding capacity increases. For example, air at 0°C and 80%RH, when heated to 20°C, may drop to around 20%RH.

The building
A poorly insulated building, or one in poor condition, can be a source of moisture ingress and may create thermal bridges that encourage internal condensation and mould growth.

Ventilation
Natural ventilation, from open doors and windows, and mechanical ventilation, from HVAC systems, will impact the indoor humidity. The impact on the indoor environment will depend on the condition of the incoming fresh air and any heating, cooling or humidity control that is applied to it. Ventilation rates are determined by building regulations and are often dependent on the number of occupants, indoor pollutant control, such as dust and VOCs, balanced against the need to create a stable environment for the collection.

Open sources of water
Evaporation from fish tanks or frequently used sinks can lead to an increase in indoor humidity.

The weather
Irrespective of the season, when it's raining, visitors entering a museum or gallery are going to be introducing a lot of moisture to the indoor air. Evaporation from raincoats, umbrellas and soggy clothing is going to rapidly raise the internal humidity.

Solar heat gain
Sunlight from windows and glazing will increase the thermal energy of a space, and therefore impact humidity levels.

Heating and cooling systems
Systems that manage temperature will influence humidity levels. Air conditioning can cause a localised increase in relative humidity, as it chills the air. However, condensation sent to drain from the AC system lowers the absolute humidity level. So, as the cooled air is warmed in the room, the overall relative humidity can be low. Radiators and in-room heaters will also lower humidity levels, as they heat cold winter air.

People
Alongside the number of people determining the ventilation rates of an area and introducing moisture from wet clothing, people also directly add to the indoor humidity through respiration. Moisture introduced from people is calculated on their level of activity, with sitting at a desk resulting in 35g per person per hour, up to intense exercise being 185g per person per hour.

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4 HOW CAN I MONITOR AND MANAGE INDOOR HUMIDITY?

Monitor

There are many instruments available to measure the air's humidity. A simple hygrometer will tell you the current humidity level. These are small devices and are ideal for placing around a museum, or in a display case, and provide a current humidity reading.

Humidity data loggers can be used to monitor, record and display humidity levels across a period of time. Historically they recorded graphs with ink on paper reels, but modern data loggers will now typically connect to a computer to display results, either via a USB or wifi connection.

Larger buildings may incorporate a Building Management System (BMS) that centralises the monitoring and control of all building services. Strategically located humidity sensors will feedback information to the BMS and humidity control systems. Optimal positioning is to place these sensors in return air ducts, which monitor the air being extracted from the space, to give an accurate understanding of a room's condition.

Any professional humidity control system will incorporate some form of humidistat. This could be either on-board or remotely located. It will monitor the ambient humidity and send a control signal to unit, so it can adjust its operation accordingly.

The control accuracy of humidity sensors play a major role in the overall accuracy of a humidity control system. Typically, the level of control possible will be, at best, two times the measurement accuracy of its associated sensor. So, if a sensor's accuracy is ±2%RH, then the tightest control possible, even with an extremely responsive humidity control system, will be approximately ±4%RH.

> "many instruments available to measure the air's humidity"

Manage

Humidity can be managed by limiting the external elements that impact it or by proactively removing or adding moisture with a humidifier or a dehumidifier.

To minimise the outdoor elements influencing indoor humidity, entrances can incorporate vestibules or revolving doors, windows can be kept shut, and building insulation well maintained. However, ventilation is necessary to maintain a healthy indoor environment, so keeping the outdoors air out is never going to be a comprehensive strategy.

Humidifiers are used to add moisture and raise the humidity to the required level. Dehumidifiers will remove moisture from the air to lower humidity. When employing both technologies in the same area, it is important to have a buffer zone in the settings of both systems, where neither humidifier nor dehumidifier will be operating. Otherwise, one system could be fighting against the other.

When is it not practical to control a complete area to the level required for the materials in question, display cases are often used. This allows for a more tightly controlled atmosphere without needing to manage the whole room.

Enclosed displays are also a good solution for when exhibits are placed in an area with unacceptable fluctuations in humidity, like near an entrance.

Lastly, adjusting temperature set-points to lower levels in the winter and higher levels in the summer, can be used as a strategy to maintain humidity within an acceptable range. This reduces energy across heating and humidity control systems. For example, reducing the temperature set-point from a summer condition of 23°C to 18°C in the winter, can maintain a comfortable atmosphere for people whilst reducing the humidification needed to remain above 40%RH.

> “by proactively removing or adding moisture”

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5 WHAT IS THE IDEAL INDOOR HUMIDITY?

Over the years, various conservation organisations have published guidelines on how the environment inside museums and galleries should be maintained. This was prompted by the realisation that climate plays a critical role in the long-term protection of materials and advancements in climate control technologies that enable this.

The current common standard for heritage buildings is to maintain a stable relative humidity (RH) in the range of 40–60% and a stable temperature in the range 16–25°C, with fluctuations of no more than ±10% RH per 24 hours within this range (the Bizot Group).

Rapid fluctuations cause more damage to materials than gradual changes, as materials have less time to adapt to changes in moisture content. This is why guidance is provided not only for a range but a drift within that range over time.

The "ideal" humidity for any material, to prevent any moisture loss or gain, is an air humidity that is in equilibrium with the moisture content of the object. This is often referred to as the equilibrium relative humidity (ERH). As the moisture content of different materials vary, so does their ERH (see Table 1).

> "a stable relative humidity (RH) in the range of 40–60%"

While a blanket range of humidity, with an acceptable margin of variance, may be a practical solution for managing heritage buildings, it may not be the most economic approach. Humidity control consumes energy, so customising climate control in heritage buildings to better meet the specific needs of the exhibits can lower operational costs and reduce energy consumption.

The need for a more sustainable approach was acknowledged in the 2023 Bizot Green Protocol, which promoted the adoption of a "greener practice first mindset" for object care. Although it still supports the 40-60%RH range, it suggests that set-points should be based on a conservator's evaluation and be tailored to the specific requirements of individual exhibits.

> "tailored to the specific requirements of individual exhibits"

Material	Recommended %RH
Stone & ceramics with unstable salts	20-30
Iron	<15
Unstable or corroding metals	10
Minerals, rock & fossils containing pyrite	30-50
Lacquer wares	50-60
General textiles	30-50
Ivories & bone	50-60
Parchment and vellum	55-60
Stretched paper (screens & stretched frames)	45-55
Paper (general)	40-50
Photographs & film	30-45

Table 1: recommended humidity levels for conservation, ref: Stolow N., . (1987). Conservation and exhibitions. London: Butterworths.

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6 WHAT HUMIDIFIER OPTIONS ARE THERE?

Typical requirements

As individual galleries can be full of people one minute and empty the next, humidification systems should be capable of responding rapidly to a control signal and providing close humidity control. Zone-based control is also beneficial to provide appropriate conditions across different areas of a building.

Any system directly located in a public area needs to be tamper-proof and intrinsically safe in its mode of operation. Internal components with high voltage or hot components, can present a risk to the public if accidentally left unsecured, so should be considered in any risk assessment.

Hygienic operation is a must, and this will be the result of a properly designed and well-installed humidifier combined with an appropriate maintenance schedule.

Automatic regulation and control offer peace-of-mind, so any system that needs to be manually filled presents a risk of being overlooked, detrimentally impacting humidity control.

Heritage settings often have beautiful, well-designed interiors, so if an in-room system is being used, it is preferable to have an unobtrusive design that blends into the surroundings. Mobile systems can also be beneficial, if they can meet the required output, as they are easy to install and can be stored when not required.

Technologies

Humidification systems can introduce moisture directly to a room or into a central air handling unit (AHU).
The water can be boiled and released as steam, evaporated from a wet surface through which air is blown, or turned into an aerosol and introduced as a spray.

Steam humidifiers can generate their own steam by using electricity or gas to boil water or they can use a

	Mobile	Resistive electric steam	Electrode electric steam	High-pressure spray	
Location strategy	In-room	In-room | In-duct	In-room | In-duct	In-room | In-duct	
Max output (single unit) kg/h	1-2	2-40 | 2-160	2-40 | 2-160	30-800 | 30-1,300	
Ideal for	Small areas & temporary installations	Close control	Low to mid-sized capacity	Large areas | Multiple AHUs	
Modulation	On/off	0-100%	20-100%	5-100%	
Control	±10%RH	±2%RH RO water ±5%RH mains water	±5%RH	±5%RH	
Est. mains water consumption @ 100kg/h output	100	120	120	215	
Water type	Mains / RO	Mains / RO	Mains	RO	

Resistive steam humidifier

High pressure spray humidifiers

Evaporative humidifiers

Mobile humidifiers

> “introduce moisture directly to a room or into a central air handling unit”

building’s existing supply of steam to provide sterile humidification. The steam can be supplied directly from the humidifier to the room via a connected fan unit, or into a central AHU with steam pipes. Steam humidifiers offer a rapid response to a control signal and provide very accurate humidity control, making them a popular choice for large heritage applications with AHUs.

Evaporative humidifiers are typically used in AHUs and offer high output and low energy operation. Air passing through the AHU travels through a moist evaporative cassette, absorbing water is it does so.

High pressure spray humidifiers are often used in larger areas and consist of a water treatment system, which purifies and pressurises the water, and a series of nozzles located around a room from which aerosols are released.

Ultrasonic humidifiers use a rapidly oscillating diaphragm submerged in water to create a mist. This is dispersed into the air with a fan. These types of humidifiers can be used in-duct or directly into a room in industrial environments but are rarely used to directly humidify in heritage buildings.

Mobile humidifiers are ideal for single rooms up to 1,000m³ and are popular in smaller museums and galleries, as they can be easily installed when needed and then stored when they are not.

	Evaporative AHU	Hybrid AHU	Gas-fired steam	Ultrasonic	
	In-duct	In-duct	In-duct	In-room | In-duct	**Location strategy**
	30-1,200	4-2,000	23-272	3-25	**Max output (single unit) kg/h**
	High capacity, low maintenance & cooling	Close control	High capacity	Low capacity | close control	**Ideal for**
	30-100%	5-100%	20-100%	0-100%	**Modulation**
	±10%RH	±2%RH	±10%RH	±2%RH RO water	**Control**
				±5%RH mains water	
	120	205	120	120	**Est. mains water consumption @ 100kg/h output**
	Mains / RO	RO	Mains / RO	RO	**Water type**

7 WHAT DEHUMIDIFIER OPTIONS ARE THERE?

To remove moisture from an atmosphere it can either be condensed out on a cold surface or absorbed by a desiccating substance. Commercial dehumidifiers use one of these two strategies to lower humidity.

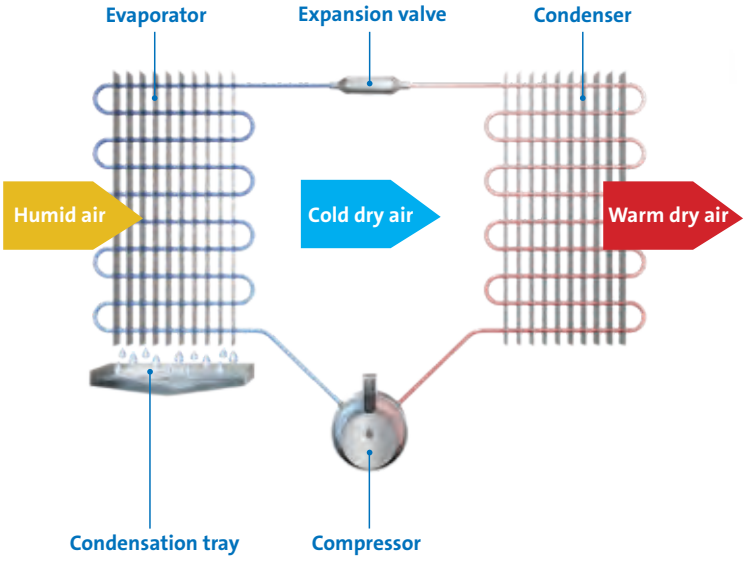
In deciding which technology is most appropriate for a museum or gallery, it is important to consider the required humidity level and the room temperature. Condensing dehumidifiers are ideal for areas that require a humidity of 50%RH or more and ambient temperatures of above 15°C. Below these levels desiccant systems are often more effective.

Both systems can be employed as direct room dryers or connected to a building's central air handling system. Although condensing systems tend to suit in-room heritage applications more due to their simplicity of installation and operating range.

Condensing dehumidifier process

A condensing dehumidifier uses the same type of refrigerant circuit found in split air conditioners or refrigerators. Through the expansion of refrigerant gas, a cold coil is created over which room air is passed. Moisture condenses on the cold surface and drips into a tray, where it is either collected in a water tank or sent directly to drain.

The cold air is then heated by the compression of the refrigerant gas and reintroduced to the room at a low humidity.



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

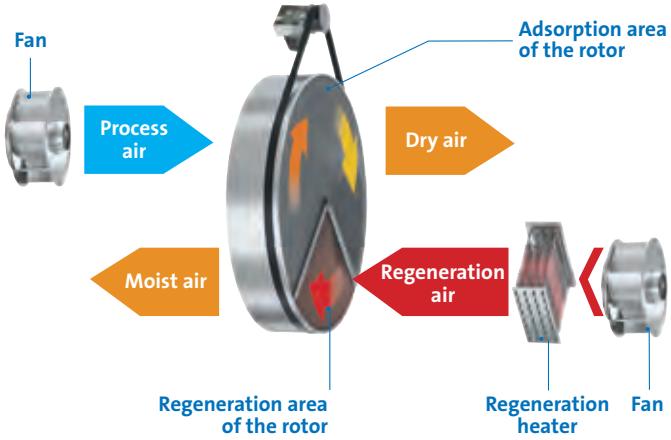
Condensing dehumidifier	
Dehumidification principle	Refrigerant circuit
Effective operating temperature	15°C to 36°C
Achievable %RH	>50%RH
Control tolerance	±10%RH
Power consumption per kg removed	0.5 – 1.5kW
Room heat addition	Moderate
Ducting required?	No
Typical installation type	Mobile or fixed

Desiccant dehumidifier process

Desiccant dehumidifiers draw in moist ambient air and pass it through an absorbent desiccant wheel. Water is absorbed by the desiccant material and the dry air is passed back into the room. In order to remove the moisture from the wheel, hot air is continually passed through a small portion of it. This hot air absorbs the moisture, dries the wheel as it slowly rotates, and is then exhausted either outside or to an appropriate area.

As this hot regenerating airflow heats the wheel, some of this heat is passed back into the room as the hot section of the wheel rotates back into the process airflow.

Desiccant dehumidifiers require the waste regeneration air to be vented somewhere. Therefore, air ducting is required, which makes them less convenient for in-room use. Given the more flexible range of control than condensing technology, desiccant systems are more frequently used to support close humidity control in air handling units.



> "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**

8 WHAT ARE THE ENERGY CONSIDERATIONS OF HUMIDITY CONTROL?

Humidifiers

As a rule of thumb, for every 1kg of steam humidification, 0.75kW of electrical power is needed. Electric steam humidifiers are a common choice for heritage humidification, but if adiabatic (cold water) humidifiers are selected, the energy use can vary depending on the system design.

The same overall amount of energy is required for adiabatic humidification as steam, but the energy consumption is relocated to a heater. When cold water evaporates there is a cooling effect on the air. So, when adiabatic humidifiers introduce humidity to room, the additional cooling needs to be off-set with more heating.

The overall energy across both strategies is very similar unless the evaporative cooling is a welcome side-effect. If waste heat is available, either directly in the space or via a heat recovery system, then adiabatic humidification can not only provide low energy humidification but also improve temperature control and potentially reduce air conditioning costs.

For instance, an electric steam humidifier delivering 30kg/h of steam might consume around 22.5kW/h. An equivalently sized adiabatic humidifier could produce the same humidity from around 1kW/h, excluding the energy required to off-set the cooling effect, and offer around 20kW of cooling to the room.

Both steam and adiabatic humidifiers can use water treatment systems, which also consume energy. This will depend on the system but can range from 0.03kW per litre of RO water on smaller capacity units to 0.005kW for larger systems.

Lastly, energy concerns stretch beyond the quantity consumed to whether the energy was sustainably generated. An electric steam humidifier can operate on 100% sustainable energy, whilst an adiabatic system operated in combination with a building's gas-fired heating has a larger carbon footprint due to the fossil fuels being burned

> "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

Dehumidifiers

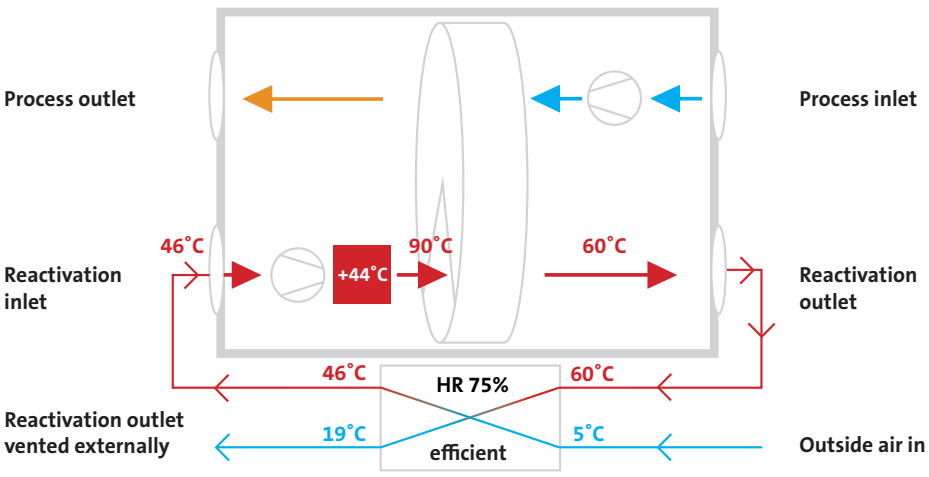
As a rule of thumb, dehumidification with condensing systems will consume between 0.5-1.5kW of electricity to remove 1kg of water. A desiccant system's consumption is higher at 1-3kW per kg of moisture.

If a condensing system can deliver the drying performance, it is often a lower energy option than desiccant technology. However, if very low humidity, very close control or drying in a cold area is needed, then desiccant drying will mostly be the only option.

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

9 WHAT SIZE HUMIDITY CONTROL SYSTEM DO I NEED?

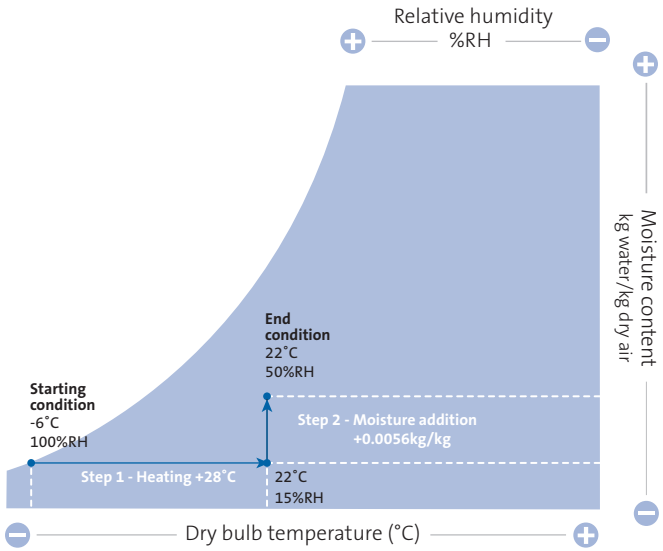
Once an ideal air humidity level has been determined for an area, it is necessary to calculate how much moisture you will need to add (humidify) or remove (dehumidify) to maintain this level.

A humidification system will typically be needed in the winter, so the capacity of a humidifier will be sized on the most extreme demand, given the region's historic winter conditions. Once this condition has been established, a psychrometric calculation will be performed that determines how much water needs to be added to 1kg of outdoor winter air, once it's heated to room temperature, to increase its humidity to the target condition. Multiplying this figure by the overall air volume and factoring-in any additional sources of moisture will provide the humidification load that a humidifier should be capable of providing.

A similar psychrometric calculation is undertaken to calculate a dehumidification load, but with a starting point of the highest possible humidity condition, and factoring in all sources of additional moisture from activities in the room and sources of ventilation.

It is always strongly recommended psychrometric calculations are carried out by a humidity control professional.

> "psychrometric calculations are carried out by a humidity control professional"



Example isothermal (steam) psychrometric calculation

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

Humidification

All humidifiers 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.

Dehumidification

A quality dehumidifier is a robust system and if installed and operated correctly, should need very little maintenance. 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

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

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.

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05/2025