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White paper

Air humidification in hospitals

How to find the right balance between health and sustainability

Regulating air humidity is of fundamental importance for hospital facilities, as the health conditions of patients, correct functioning of medical equipment, well-being of doctors and visitors and healthcare spending are closely related to it.

The objective of this document is to explain the reasons why it is necessary to humidify hospital rooms as well as the standards that regulate the matter so as choose the most suitable solution.

Knowledge Center

For further information on the contents of this document, do not hesitate to contact us:

Knowledge
Center

CAREL Industries
carel@carel.com
(+39) 0499 716611

Contents

Why regulate air humidity in hospitals?

The regulation of air humidity plays a fundamental role in a hospital environment, first and foremost to safeguard patients from nosocomial infections. The following paragraphs will examine in detail its influence on the life cycle of bacteria, from their development and diffusion to patient infection.

Secondly, a correct level of relative humidity guarantees the good functioning of medical machinery, which is essential for hospital operations.

Lastly, avoiding dry air helps maintain an acceptable level of comfort for the well-being and performance of patients and medical staff.

1. Humidification to preserve patient health

The most important impact of air humidification in healthcare facilities certainly regards the protection of patients from bacterial and microbial attacks of a various nature.

Hospital patients find themselves in an environment where there are usually many pathogens, which are resistant enough to survive anti-bacterial treatments and normal cleaning and disinfection procedures. In addition, these micro-organisms can reproduce quickly and find suitable hosts precisely in the numerous patients.

Furthermore, patients are particularly vulnerable to infections due to their decreased immune defences and the fact that internal parts of the body are in direct contact with the surrounding environment after operations and injuries.

Considering these unfavourable conditions, we can see how humidity strongly affects the capability of bacteria to develop, propagate and overcome our defences. Therefore, if suitably managed, it can result in an excellent tool to limit the number of hospital infections, safeguard health and lower costs.

Humidity and bacteria development

Managing humidity is first of all important in impeding the **growth** of **bacterial colonies** in the building as, to develop, they need water and nutrients. It is therefore necessary to avoid the formation of areas where humidity condensates and forms stagnant water, for example in air conduits.

In addition, when relative humidity rise above 80% for a prolonged period of time, mould can form as well as superficial condensation and, if inhaled, its spores can constitute a health hazard.
This enables the setting of a maximum limit for the desired humidity range in a hospital environment, but it is not enough to ensure a healthy environment and reduce the number of infections.

Hospitals are physiologically hotbeds of bacterial load which is impossible to eliminate entirely considering the presence of sick people. The true challenge when managing humidity therefore goes from eliminating pathogens to impeding their transmission and helping our natural defences to ward them off.

Humidity and the diffusion of diseases

Most modern hospitals implement very strict surface and equipment cleaning procedures. Nonetheless, air analysis shows this is not enough to reduce the number of circulating bacteria, especially since the number of connected infections are in continuous growth [1]. A large quantity of microbes is in fact constantly emitted by people even by just talking, breathing or coughing, incorporated into thousands of minuscule water droplets floating in the air. Some report estimates that between 10 and 33% of all pathogens causing hospital infections occur due to airborne transmission.

When these droplets are introduced into a room with a relative humidity below 40%, they rapidly lose up to 90% of their volume. They shrink and manage to float for a long time, covering considerable distances. This of course increases their chance of reaching another host, re-hydrating and infecting him.

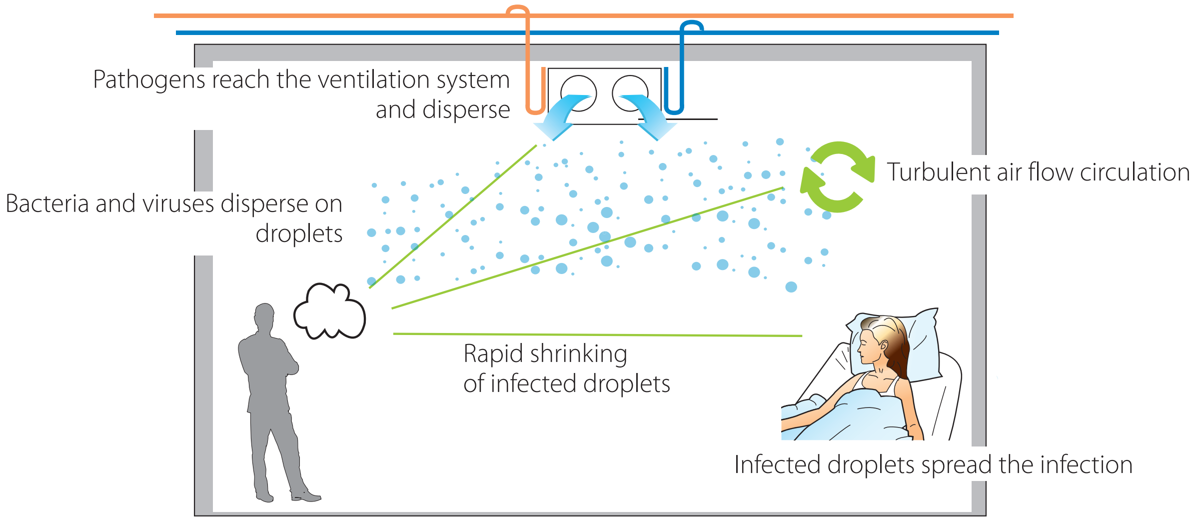


Figure 1 - High transmission UR < 40 %

If however the room has a relative humidity of between 40 ad 60%, the droplets maintain approximately the same size (≈ 100 µm) and tend to precipitate much quicker, approximately within 1-2 m from the source, where they can be eliminated much more effectively by traditional cleaning methods.

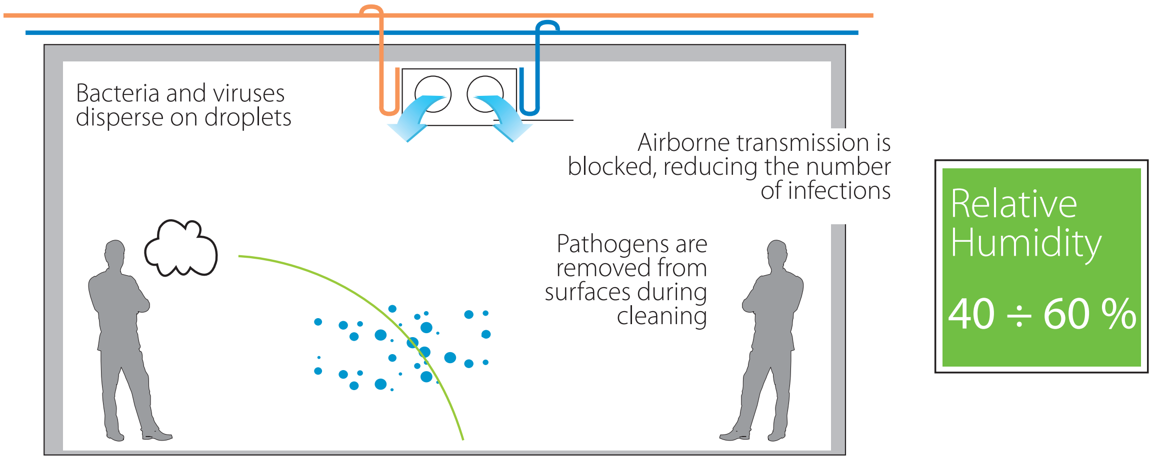


Figure 2 - Transmission is reduced considerably when 40 % < UR < 60 %

Several researches suggest in fact how relative humidity is the most important factor in environmental control for the **airborne transmission** of bacteria and viruses.

A first study, conducted for one year in a US hospital, monitored all environmental parameters in ten rooms as well as the medical conditions of the patients who stayed in these rooms [2]. Relative humidity was the variable with the closest connection to the number of infections contracted by the patients.

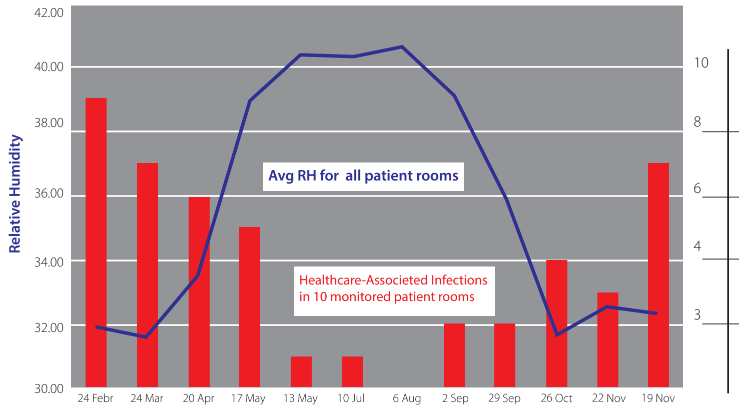


Figure 3 - Relative humidity is the most important parameter among those analysed to reduce the number of nosocomial infections.

When relative humidity reaches and exceeds 40%, infections are drastically reduced from a maximum to 10/month to zero!

Another study was conducted using mannequins simulating people coughing with influenza and people breathing standing two metres away [3]. Aerosol samples were collected in proximity of the breathing mannequin's mouth at different moments and their infectiousness was assessed, providing the following results.

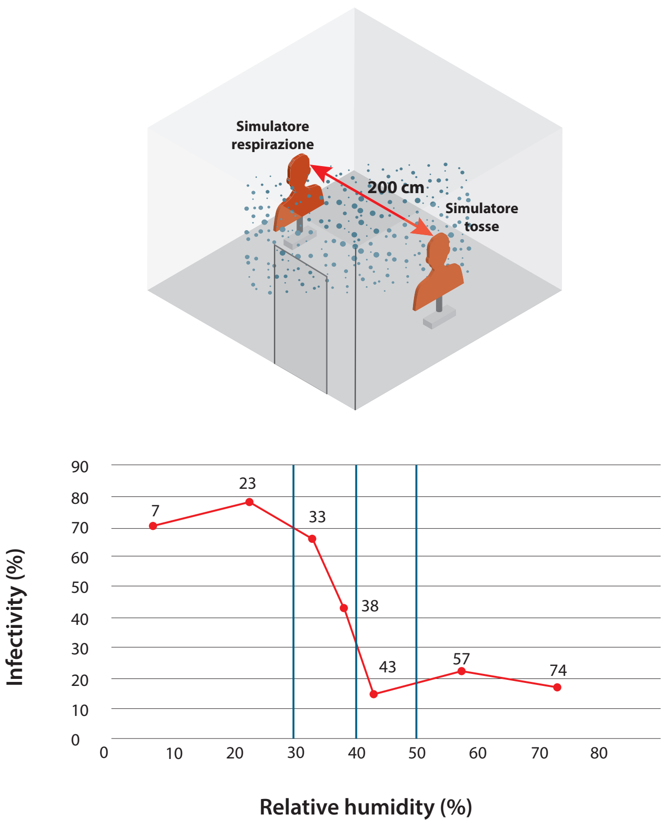


Figure 4-5 - The infectiousness and transmission capacity of the influenza virus drops when relative humidity is between 40 and 70%

Infectivity dropped from 80 to 20% once relative humidity was between 40 and 70%! This is due to the fact that the influenza virus can no longer remain suspended for a prolonged period of time and to the reduced lifespan of many airborne bacteria and viruses in this relative humidity range.

In addition to hindering the growth of microbes and bacteria, suitable humidity monitoring has the effect of drastically reducing their transmission rate and is absolutely essential in environments such as hospitals, where pathogens and exposed patients particularly sensitive to infections coexist.

Humidity and natural defences

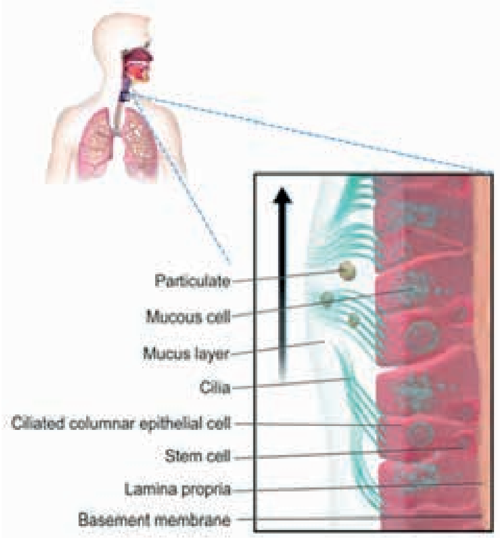


Figure 6 - The mucociliary clearance process enables the trapping and elimination of pathogens that penetrate the respiratory system, but its functioning is subordinated to a suitable relative humidity level

Airborne infections are contracted by inhaling bacteria which pass through the respiratory system and deposit on airway walls or in pulmonary alveoli causing pneumonia or blood infections.
Our body's last defence against these aggressions is made up of the respiratory system walls: from the nose to the trachea and bronchi, a small layer of mucus is secreted that humidifies and warms incoming air and traps the bacteria. This layer of mucus is continuously pushed upwards by the rhythmic movement of numerous epithelial cilia located on the walls of the respiratory system. The mucus then reaches the oral cavity and the bacteria is swallowed and rendered harmless by stomach acids. therefore becoming part of the intestinal microbiome without causing damage.

The process, called **mucociliary clearance** is of fundamental importance for our health as, in normal conditions, it blocks most of the pathogens we breathe in, however its functioning is strongly influenced by relative air humidity. Indeed, if relative humidity drops below 40%, the mucus layer dehydrates and the cilia slow down until they stop, allowing viruses and bacteria to penetrate and infect the cells [1].

We have seen various reasons why managing humidity plays a fundamental role in preventing many hospital infections.
A relative humidity between 40 and 60% inhibits the growth of bacterial colonies and moulds but, most of all, drastically reduces their transmission and helps our natural defences combat them.

Economic benefits

The economic consequences of humidity management in hospitals are difficult to estimate, considering the indirect nature of their effect. Nonetheless, considering the data discussed above and the enormous costs associated with nosocomial infections, it is understandable how the benefits on the balance sheets of healthcare facilities can be relevant.

Each year, in Italy, between 5 and 8% of hospitalised patients contracts an infection, for a total of approximately 450-700 thousand infections a year, 1% of which results in death. The main costs for the Italian healthcare system, for example, are caused by prolonged hospitalisation and amount to approximately €1 billion, i.e. 0.8% of the GDP, to which must be added the legal costs generated by patient disputes [4].

Urinary system infections, followed by the infection of surgical wounds, pneumonia and sepsis represent 80% of the causes of nosocomial infections and cases of pneumonia have been increasing considerably over the past few years.

The studies mentioned above show how proper humidity management could significantly reduce the number of airborne infections (between **10 and 33% of the total**) and therefore diminish the enormous social cost.

2. Humidification to guarantee the correct functioning of machinery

Air humidity can be a tool to protect electronic equipment against the damage caused by electrostatic discharge. [5] [6]

Electrostatic discharge, also referred to as **ESD**, is a phenomenon that occurs when differently-charged objects are brought close together. In the right conditions (quantity, distance, characteristics of the insulator that separates them, usually air) they manage to overcome resistance and pass from one body to the next generating an electrostatic discharge.

A concrete example in a hospital can be that of an analysis machine operator wearing rubber shoes. By walking on a plastic insulating surface such as a vinyl floor, rubber shoes tend to lose a certain quantity of electrons and thus become positively charged while the floor becomes negatively charged. This behaviour is described in the triboelectric series, which lists some insulating materials showing those which have a greater tendency to lose electrons and those with a greater tendency to gain electrons.

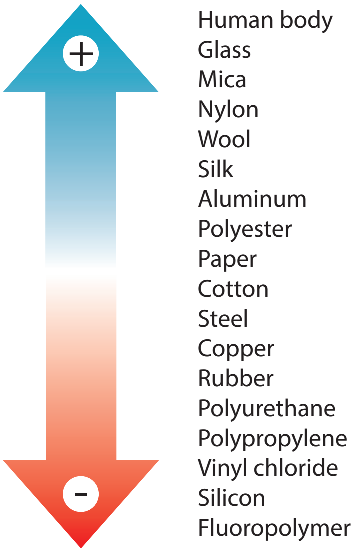


Figure 7 - Triboelectric series: in the example, rubber shoes release electrons to the vinyl floor

The positively-charged operator shoes provoke a superficial redistribution of the charges in the human body, as skin is a conductor. While maintaining an overall neutrality, the feet and the lower part of the body will be charged negatively, while the hands and the upper part of the body will be charged positively. According to the same induction principle, when the operator approaches the analysis machine with his hands positively charged, the charges on the metal surface will redistribute so that the negative ones are nearer to the operator.

At that moment, it may occur that:

- The electrostatic field generated by the static charge generates potential differences inside the equipment circuits that might damaged.
- Electric discharge between the fingers and the machine. The voltage can vary greatly, up to tens of thousands of Volts, **but even a voltage lower than 3500V**, which is **not** even **felt** by the person, can cause serious damage to the equipment!

The damage could include the destruction of some components, the turning off of the machine, wrong measurements, the cancellation of saved data and the accumulation of static electricity on X-ray films and might in any case irreversibly compromise the functioning of expensive machinery.

Once again, humidity management can be a suitable tool to solve these problems, as it influences the capability of our skin and of objects in general to accumulate electrostatic charges. Water helps lower air resistance when a current passes, impeding the accumulation of charges to dangerous values in favour of a gradual dispersion towards areas with a lower potential. The formation of a thin layer of water on the object surfaces also helps to spread the charges by reducing their concentration to a certain area.

Considering the delicate function played by most of the equipment in hospitals, it is important to prevent the problems caused by dry air. To avoid electrostatic charge problems, it is recommended to maintain relative humidity above 35%, taking care not to neglect other anti-ESD precautions, especially those concerning the machine's construction.

Relative Humidity
> 35 %

3. Humidifying to ensure the well-being of room occupants

The main reasons why humidity management in hospital is essential are the reduction of the infectiousness and transmission of bacteria and the protection of the equipment.

Humidification is also very important for the well-being and comfort of those living and working in the hospital as well as impeding the onset of new pathologies related to dry air.

Humidity and comfort conditions

Comfort is defined in different ways, all of which attributable to a sensation of physical and mental well-being a person experiences in a certain environment. The following contribute to a general sensation of well-being:

- Thermal comfort, measured in terms of temperature, relative humidity, air speed.
- Air quality, measured in terms of fresh air percentage, CO_2 concentration, VOC (Volatile Organic Compounds) and micro-organism concentration.
- Noise level.

According to standard EN15251, the level of thermal comfort in hospitals (category II) is only acceptable if the PPD (Percentage of Persons Dissatisfied) index is below 10%. In addition, there are various national and international standards (ref. Chapter 3) regulating the air temperature, humidity and quality ranges to be reached in the rooms.

Air temperature is the parameter we can most easily identify as the cause of discomfort, but humidity also plays a considerable role
as it alters our perception of air temperature and affects skin transpiration as well as our internal energy balance.

A suitable level of relative humidity prevents excessive skin, eye and respiratory tract dryness and enables us to breath and perspire more easily. This way, we can avoid subjecting our thermoregulation system to excessive effort that may cause discomfort.

Managing humidity correctly also makes it possible to reduce any dust particles in the air by making them adhere to the walls. In a dry environment, they would remain suspended for longer, accentuating the feeling of dryness and discomfort.

In addition, if dry air conditions protract over time, people spending time regularly in the building can develop a series of related symptoms, so considerable as to define a real pathology, i.e. the Sick Building Syndrome. The effect of all these issues is in any case an air quality that affects the health of people spending time in these environments.

Sick building syndrome

The Sick Building Syndrome (SBS) affects those people in a building experiencing health problems and continued discomfort that cannot be linked to specific causes or diseases.

Often, the causes of this condition can be linked to defects or a wrong usage of the air handling system, the lack of adequate fresh-air intake, volatile organic compounds (VOC), mould and other material and substances releasing pollutants.

Tests showed how SBS symptoms are caused or worsened by low relative humidity conditions. These include tear film deterioration, eye dryness, irritation of the nose and throat, asthma, skin dryness, headache, fatigue and irritability.

Low humidity conditions can cause a 3-7% reduction in the performance of subjects carrying out office tasks such as reading, document editing and calculus. When factors such as high temperature and air pollution are added to low humidity conditions, these symptoms worsen [7].

The optimal humidity range was calculated at 40% < RH < 60%, which coincides that the level to be obtained so as to reduce the chance of hospital infection (40% < RH < 60%) and overlaps with the levels needed to reduce the risk of electrostatic discharge (RH > 35%) and mould proliferation (RH < 80%).

Considering all the effects that relative humidity has on the human body and hospital operativeness, we can say that the desired range for this purpose and for the sake of comfort in general is precisely between 40 and 60%.
Considering the desired conditions, an obvious question arises. Are these conditions complied with and are there factors that alter them and therefore make constant humidity management necessary?

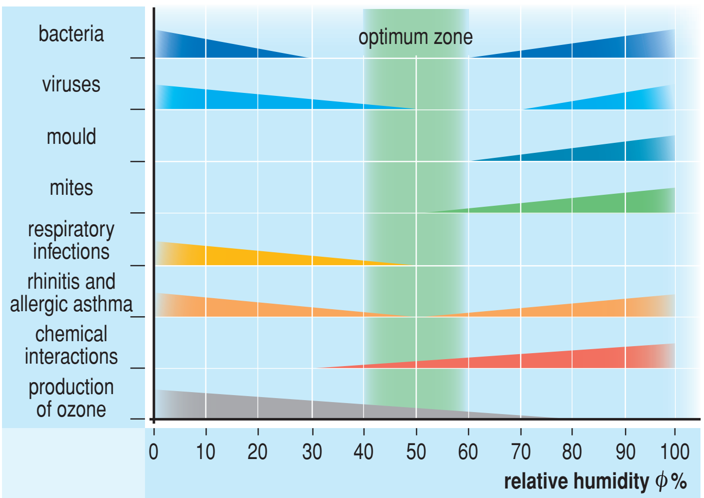
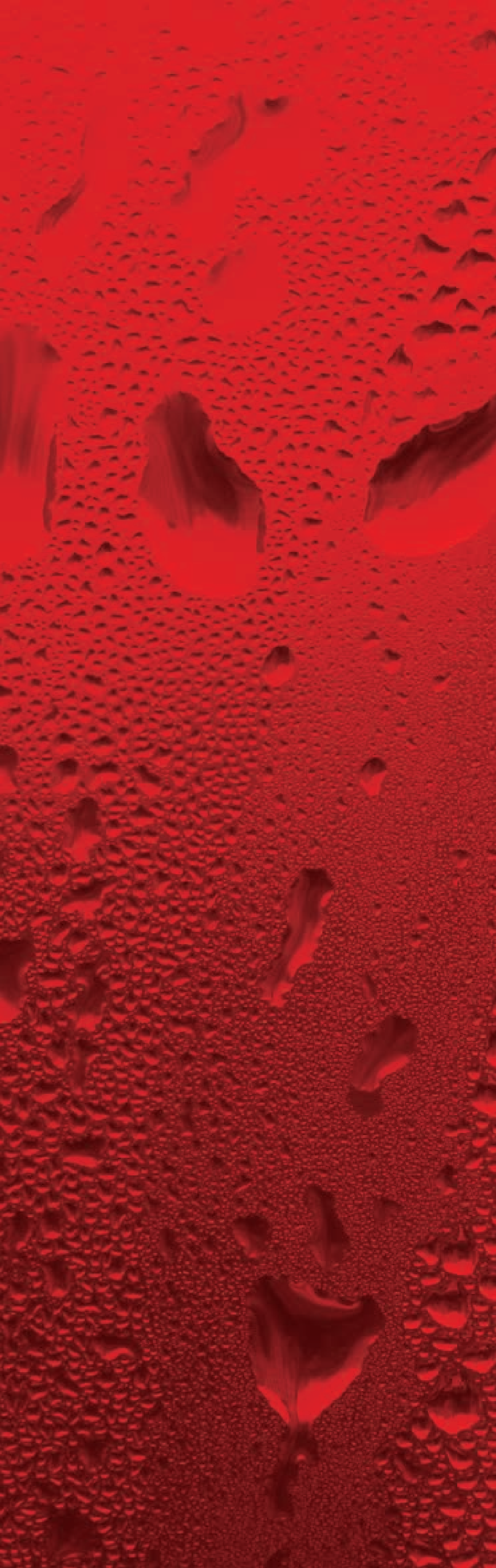


Figura 8 -Optimal relative humidity range for human comfort and health



What affects relative humidity optimal conditions?

Since we have understood the indispensable benefits of hospital humidification and therefore the relative humidity setpoint to be obtained, we can try to understand if and why the rooms constantly has different conditions and whether a humidification system is necessary.

To achieve recommended air quality levels in hospital structures, it is necessary to dilute indoor air, as it contains polluting substances produced by people and materials or anaesthetic gases used during operations that cannot be filtered. It is therefore necessary to replace indoor air with large quantities of **fresh air** from outside. Before being introduced into a room, however, it must be brought to an acceptable temperature interval, typically between 20 and 24°C.

For example, let us imagine a winter scenario and, for the sake of simplicity, dealing exclusively with fresh air from the outside, which would therefore be very cold and humid (point A, temperature = -5°C, relative humidity = 80%). The air would be heated up by a warm coil in one of the hospital's air handling unit, where temperature increases and specific humidity (mass of water vapour in a unit of air) remains constant (point B, temperature = 22°C, relative humidity = **12%**).

The relative humidity of the warm air (ratio of the amount of water vapour in the air to the maximum amount that the air could hold) is instead lower. It went from 80 to 12% without taking water out!
This is because the air, while heating up, increased its maximum capacity to "hold" in suspension water droplets that form humidity and so relative humidity, which indicates the maximum amount of water steam that air can hold, decreases.

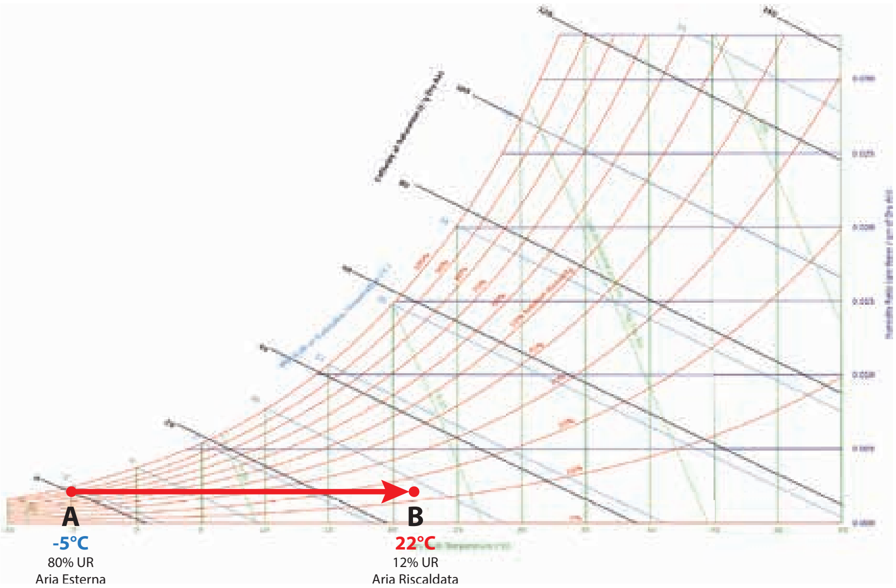


Figure 9 - The psychrometric diagram shows why warming air makes it too dry for hospital applications

Considering the importance of maintaining a suitable level of relative humidity, a humidification system that keeps relative humidity (and temperature) within the correct range is essential. The system can perform either adiabatic humidification (option 1) by spraying fine water mist into the air or isothermal humidification (option 2) by boiling water and producing steam directly.

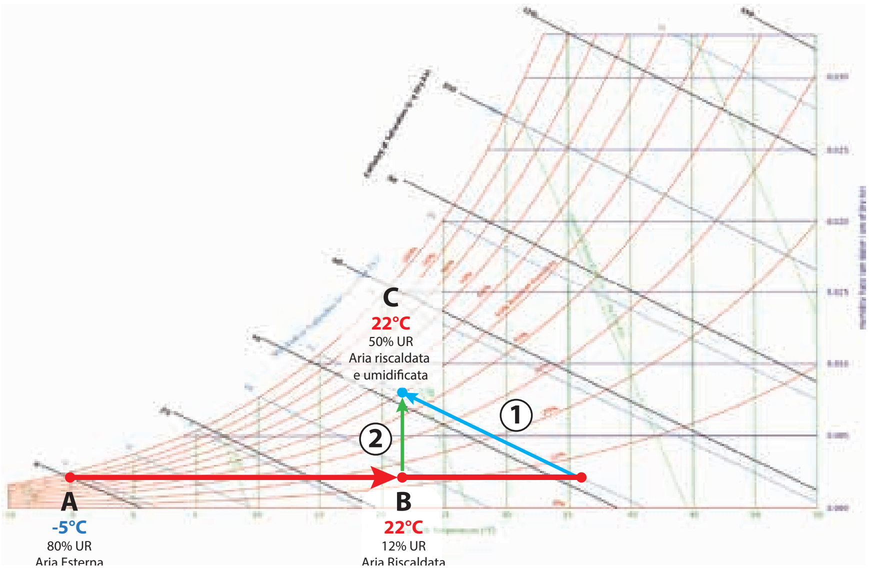


Figure 10 - After heating it, air must be humidified to reach the optimal condition of ≈ 22°C, 50% RH

Regardless of the technology chosen (described in detail in chapter 4), the humidification system will most likely function more in winter, when the heating system dries up the air.

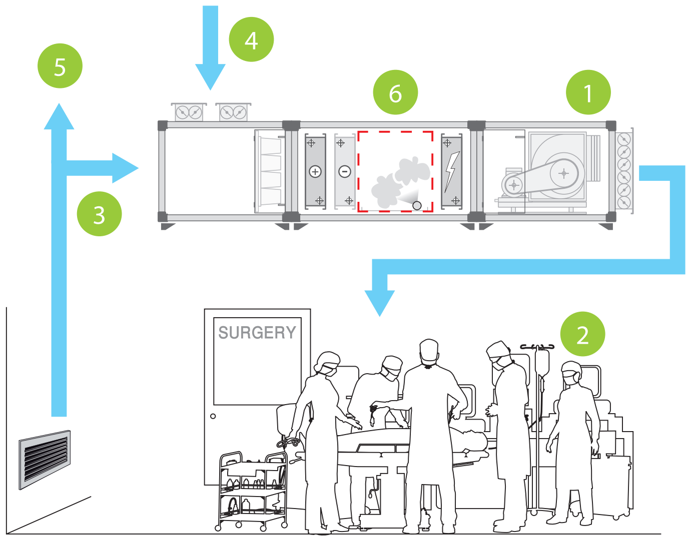
Hospital humidification systems

Hospital humidification systems usually humidify fresh air in the ducts rather than directly in the room but, aside from this, their main components are not dissimilar from those for other applications.

However, considering the importance of the processes carried out in these facilities, specific manufacturing measures must be taken to guarantee the hygiene and reliability of installation.

There are different technologies suitable to humidify hospital rooms but, whatever the chosen one, the systems are always made up of the following elements:

- **humidifier**, of the adiabatic (nebulized water production) or isothermal (steam production) type;
- a **distribution system** for the humidity produced. Hospitals often take outside air, treat it and release it indoors through ventilation ducts. Humidifier distribution systems will therefore be placed inside the ducts after heating batteries. The systems are connected to the humidifier and they can be made up of pierced manifolds with small nozzles that atomise pressurised water or larger pierced pipes that release the steam directly into the ducts. In other cases, the humidifier is installed directly in the ducts;
- a **drop separator**, employed only with adiabatic humidifier, is placed in the duct at the end of the humidification section. It traps any excessive humidity not absorbed by the water and prevents water stagnation;
- an incoming **water treatment system** for the feedwater. It is not always compulsory but it is strongly recommended for hospital applications.



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4. Isothermal humidifiers

Isothermal humidifiers make the water boil, so it turns into steam which is then released into the rooms. The energy for the change of state - approximately 750 W in total per litre of evaporated water - is supplied by the humidifier itself, supplied electrically or from other sources (methane or GPL). The system is defined as isothermal because the air is humidified and does not experience considerable changes in temperature.

Isothermal humidifiers are rather simple to install, they guarantee the hygienic safety of steam and can be used both for direct and in-duct distribution within an air handling unit. They are also suitable for the production of small quantities of steam.

The main limitation of steam technologies is their high energy consumption and related operative costs, which can be prohibitive in case of high humidification loads.

There are three main types of isothermal humidifiers:

- immersed electrode;
- heater;
- gas-fired.

Immersed electrode humidifiers

It's the simplest and generally the most economical solution. Two electrodes use water as a resistive element and heats it until it boils. The main limitations are its less than exceptional precision (it rarely exceeds ±5% RH) and its production modulation range, which only starts at a certain value of the rated capacity.

Consider also that, as this humidifier does not function with purified water, maintenance and cylinder replacement operations must be carried out more frequently the higher the salt content of the water.

Heater humidifiers

Resistive electric elements are submerged in water and heated to make it boil. Good-quality heater humidifiers are very accurate (±1%) and operate on the entire rated capacity range thanks to the possibility of regulating the temperature of the elements. They function with both mains and treated water.

Gas-fired humidifiers

Their functioning is similar to that of heater humidifiers. Methane gas or GPL are burned inside a heat exchanger submerged in water. The production is regulated by adjusting the gas supply. The main advantage is the lower cost of the power supply compared to electricity, so this solution is more economical where gas has a lower price. They function with both mains and treated water.

5. Adiabatic humidifiers

Adiabatic humidifiers cause the direct evaporation of water into the air without the need for outside power. The heat necessary for vaporisation is supplied by the humidified air cooling down.

These devices create a large interface surface between air and water, which evaporates spontaneously. The main advantage is the extremely low power consumption: the only power required is that for atomisation of the water into small drops with a diameter of a few microns.

In winter, the heating coil will have to pre-heat air more with respect to steam humidification to compensate the cooling effect of evaporation, but total consumption remains low, among the best for the various technologies available. In the summer, the air cooling effect can be used to save more money should you need to cool and humidify air at the same time.

The most popular adiabatic technologies are:

- high-pressure atomisers;
- ultrasonic atomisers;
- wetted media humidifiers.

High-pressure atomisers

These humidifiers are equipped with a pump that can make water reach a pressure that can even exceed 70 bar. Water is sprayed through a in-duct distribution system equipped with very small nozzles which atomise the water to be absorbed into the air.

These units can be very accurate (±2%) and have very high capacities with low power consumption (<4 W per litre of evaporated water). Water is not recycled, making this a hygienically safe solution.

Ultrasonic atomiser

Ultrasonic humidifiers atomise water using the high-frequency vibrations of a transducer. Results are similar to pressurised-water humidifiers but water drops are smaller.

The best ultrasonic humidifiers reach exceptional levels of precision (±1%) and operate on the entire rated capacity range. These humidifiers are ideal for both direct and in-duct distribution thanks to their great absorption efficiency and are suitable for both small and medium-sized installations.

It is a rather evolved technology that generally requires a more substantial initial investment compared to other smaller humidifiers. However, the high performance level, low energy consumption and practically non-existing maintenance required enable a swift return of the investment, especially in case of retrofit installations to replace steam systems.

Wetted media humidifiers

These humidifiers are made up of a media of honeycomb material or corrugated layers that is continuously soaked by water. The air passing through the media takes part of the water with it.

Despite the problems it may cause, this technology is still rather widespread as it is one of the more economical solutions for higher volumes and is easy to install. Nevertheless, it presents defects that, while tolerable in other applications, are incompatible with a hospital environment:

- the level of precision is mediocre (generally ±10%);
- due to the low absorption efficiency, it needs to recirculate water not to waste it. This in turn requires using chemical biocides to prevent the formation of bacterial colonies;
- it causes a considerable drop in pressure which increases the amount of energy used by the ventilation system even in summer, when humidification is not needed. This of course leads to high additional costs, especially considering the high air flow-rates used in hospital AHUs.

Considering the last two points, operating costs are higher than the most efficient adiabatic systems and, in the medium and long term, they would match the higher initial investment needed for the latter.

6. Requirements of the humidification system

It is important that all humidification system components, and humidifiers in particular, comply with specific requirements so as to be suitable for use in critical and delicate environments such as hospitals. The following are essential characteristics:

- Hygiene
- Reliability

Secondly:

- Energy saving
- Connectivity

Hygiene

The humidification system must be designed so as not to provoke the indoor accumulation and diffusion of bacteria and harmful elements.

This is particularly important in hospitals, where patients are weak and exposed to the risk of new infections.

For example, specific precautions must be taken against the Legionella bacteria, which have a very high mortality rate and has caused many deaths connected to nosocomial epidemics in the past.

This is why isothermal humidifiers are historically more widespread in hospitals, as water is boiled at 100°C to produce steam, guaranteeing aseptic conditions and therefore a hygienic system.

Their use is at times required by law in some hospital areas such as operating rooms, as to prevent the humidification system from being the cause of the diffusion of pathogens such as Legionella.

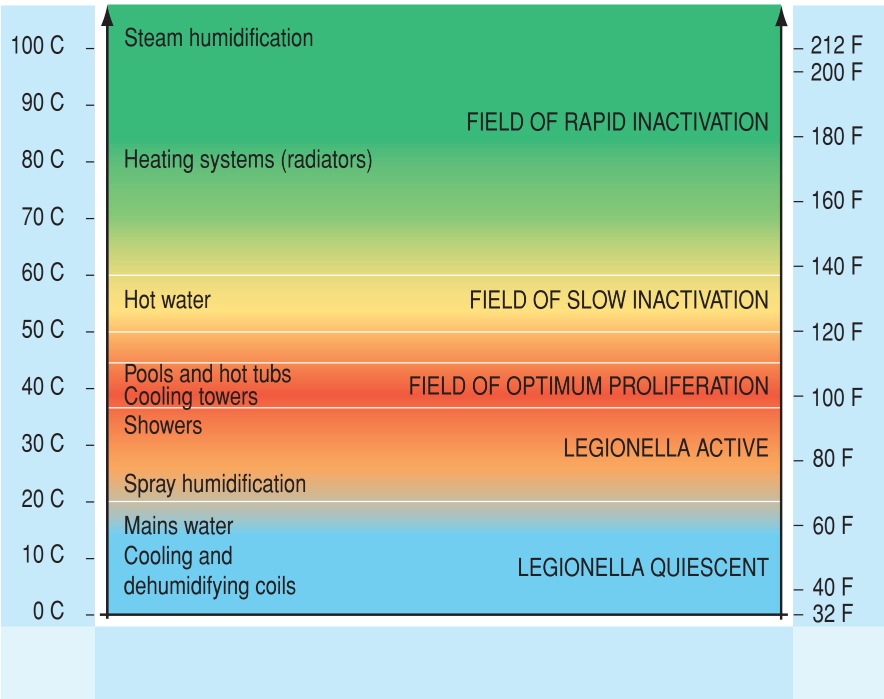


Fig. 11 - The diagram explains the behaviour of the Legionella bacteria at various temperatures between 0 and 100°C

The Legionella bacteria is in fact instantly deactivated when the temperature exceeds 70°C, therefore being completely eliminated by isothermal humidifiers [8].

Certain types of adiabatic humidifiers, such as high-pressure and ultrasonic ones, can also be used in hospital applications, as long as they are manufactured in such a way as to be hygienically safe.
For example, humidifiers should prevent water stagnation by discharging it during periods of inactivity. In addition, they should be subjected to periodical flushing to avoid generating a favourable environment for the formation and growth of bacterial colonies.

In addition, the quality of input water must also be monitored, as any excess mineral salts and micro-organisms may spread into the environment if they are not filtered. Using purified water produced with reverse osmosis systems is therefore recommended. The technology was developed commercially and guarantees excellent filtration performances.

Another advantage is provided if humidifiers are built using corrosion-resistant material that prevents the accumulation of dirt such as stainless steel.

UV-ray lamp treatments should also be carried out to eliminate any bacteria that survived reverse osmosis treatments. Alternatively, chemical biocides could be used. These, however, are rather expensive and require special provisions to dispose of waste water as well as frequent bacterial load analyses. In addition, in case of a failure in the biocide management and distribution system, humidifiers might continue to function with hygienically impure water: it therefore is **not** an **intrinsically safe** solution and anyway unsuitable for hospital applications.

Further safety can be guaranteed by limit probes. They are sensors that, placed in ducts or in the room, detect when humidity exceeds a set threshold. In this case, production is stopped preventing condensation, as it may pose significant hygienic risks in case of stagnant water accumulation. The most evolved models support a modulating reading of the probe, so the production diminishes progressively as the threshold level is reached, thus avoiding sudden interruptions that may have undesired effects.

To prevent condensation, some humidifiers are equipped with a remote ON/OFF function, which blocks humidity production should the duct ventilation system not function.

Finally, the presence of certifications issued by specialised bodies must also be checked, such as the German VDI 6022, as they are proof of the fact that the manufacturer has adopted solutions that safeguard the hygiene of the system.

Reliability

Hospitals are facilities of primary importance that need to be reliable also in case of malfunctions, maintenance or special weather conditions. In winter, an hourly air change without humidification is enough to drop humidity levels below the alarm threshold. The humidification system must therefore be reliable and keep machine down-times to the minimum to guarantee absolute service continuity.

A first suggestion is to choose systems that minimise the need of down-time to carry out maintenance operations. In general, the humidifiers requiring less maintenance are those operating with purified water, as there is less limestone and therefore cleaning and/or periodical replacements are not needed as much. This aspect penalises some humidification technologies such as the immersed electrode one, as they cannot function with purified water and, depending on quality, may require frequent interventions to replace/clean the cylinders.

Higher readability means shorter idle-time, during which the machine is active but is not actually capable of dealing with the humidity load. In case of isothermal humidifiers, solutions that pre-heat the water in the cylinder and reduce the frequency of water flushes to avoid limescale are preferable.

Humidifiers equipped with rotation and redundancy functions are strongly recommended. Rotation enables the alternation of humidifiers so as to maintain them all in operation and extend the interval between maintenance. Redundancy enables operations to be carried out continuously. In case of machine down-time due to maintenance or malfunctioning, the production of steam is not interrupted as other humidifiers compensate for it.

A humidification system with both these characteristics (functioning with purified water and with rotation/redundancy functions) is the ideal solution to ensure reliability - the production of humidity is not interrupted, even during maintenance.

Energy saving

Installing efficient systems that use less energy has the double benefit of saving on operating costs and complying with the most recent regulations in terms of air conditioning. Some technologies and humidifiers available on the market are equipped with special features which justify a higher investment by providing higher savings in the long run.

Isothermal humidifiers are generally disadvantaged compared to other technologies in terms of energy consumption as, to function, they need to boil water and therefore need approximately 750 W per litre of evaporated water/hour. Heater or immersed electrode humidifiers supply power through electricity and therefore have high operating costs for high capacities.

Gas-fired humidifiers use the same energy but their fuel costs less, so they are definitely more competitive for the heavy-duty sizes required by hospital AHUs.

Adiabatic humidifiers are instead better from the point of view of consumption, as the power needed to supply high-pressure atomizer pumps (< 4 W) and to vibrate ultrasonic humidifier transducers (< 80 W) is extremely low. Despite the little power needed to supply low-pressure pumps, wetted media humidifiers significantly increase the unit's fan power consumption with a permanent increase on load losses.

Should you want to take advantage of the cooling effect of evaporation in summer months, then adiabatic humidifiers are the perfect option. This type of application guarantees the best performances in warm dry environments, as it humidifies and cools down air while at the same time maximising energy saving. The cooling effect is of 0.7 kW for each litre of evaporated water, with insignificant power consumption.

By humidifying and cooling return air before it passes through a recovery exchanger, cooler air can be obtained in summer months even before recurring to air conditioning systems, thus reducing energy consumption (indirect evaporative cooling).

Connectivity

Connectivity functions are not strictly necessary, but they are preferable and are becoming increasingly important due to the growing need to manage, monitor and collect information in complex systems with different set points such as hospitals.

This is why it is more and more common to find HVAC systems managed by a BMS (Building Management System) that also monitors the humidification system, thus providing a centralised multi-site management. In this context, it is essential that humidifiers integrate the most popular communication protocols such as Modbus and BACnet.

Some state-of-the-art humidifiers are also equipped with an integrated web server. It is a system that enables the management, supervision and monitoring of the entire humidification system on a local network directly from PC or tablet. If connected to a suitable supervision system, it can also be managed remotely, making it easier to monitor the multiple units installed in hospital facilities.

Hygiene	Reliability	Energy saving	Connectivity
• steam humidification • no water stagnation • periodic flushing • purified water • corrosion-resistant material • UV-ray treatment • limit probe • consensus from AHU fan • hygiene certifications	• rotation and redundancy functions • less down-time for maintenance • purified water • water pre-heating and less frequent dilution drainage	• adiabatic humidification • evaporative cooling • indirect evaporative cooling • lower operating costs for gas-fired humidifiers	• integrated communication protocols (Modbus, BACnet) • compatible with BMS and remote management • integrated web server

7. Systems for steam/mist distribution

Humidification load distribution systems for hospital application are practically always located in-duct and made up of different pierced manifolds depending on whether they are supplied with pressurised water or steam.

Their effectiveness depends on the absorption efficiency, i.e. a very important parameter that measures the quantity of water actually absorbed by the air compared to the total duct input. Non-absorbed mist or steam that re-condenses upon contact with surfaces constitutes both a waste of energy and a hazard for duct hygiene.

Pressurized water distribution systems should be made of stainless steel and of tailored for duct dimensions. Nozzles should be rather small, numerous and well spaced so as to moisten most of the section without having to destine a long part of the duct to absorption.

Steam distribution systems typically have higher absorption capacities, but they cause the re-condensing of steam when it enters into contact with the distributor's cool metal surfaces. To limit this phenomenon, some distributors are equipped with condensate separators before the steam lances, nozzles drawing steam from the centre of the lance, insulation layers or air cushions protecting the external surface from excessive drops in temperature.

Another part of the humidity distribution system is the drop separator, which is only used with adiabatic humidifiers. This should also be made of stainless steel for hospital application and designed so that panels are easy to extract and clean during periodical maintenance operations.

The duct must have a tilted collection tank with a drain to prevent water from stagnating. In addition, a series of solutions can be used to make AHUs "sanitisable": frames and panels can be built so as to prevent infiltrations and insulate ducts both thermally and acoustically. Special surface antibacterial treatments are also available.

8. Water treatment systems

Water treatment systems improve input water quality to enhance humidifier functioning and, most of all, to improve final air quality. This is why, in hospitals, water treatment systems must always be associated with either adiabatic or some types of isothermal humidifiers.

The main treatments used in humidification applications are softening and reverse osmosis.

Softening

Softening is a treatment that reduces temporary hardness but does not purify water: it simply replaces Calcium and Magnesium scaling salts with Sodium. This reduces limescale formation in isothermal humidifiers operating with high-temperature water but does not reduce salt content. The same quantity of dissolved salt is input into air regardless of whether softened or non-softened water is used, thus affecting air quality, people's comfort and the good functioning of the processes and of the humidifier itself.

In addition, softened water leads to the formation of foam and a faster corrosion of the heating elements in isothermal humidifiers. The only instance in which softening is suitable is to supply immersed electrode humidifiers, as they need dissolved salts to function. For all other cases, demineralisation via reverse osmosis is recommended.

Reverse osmosis

Osmosis lowers water conductivity reducing dissolved salt content. It is a treatment that not only inhibits limescale formation inside the humidifiers, but that purifies water altogether. Reverse osmosis makes it possible for humidifiers to work at the best conditions and improve air quality to the benefit of people and machinery.

Some useful characteristics to look for in these systems are: ease of maintenance, presence of a treatment integrated with UV lamps to eliminate all bacteria and a high rejection ratio, indicating how much "clean" water is produced compared to the water used.

Humidifier choice criteria

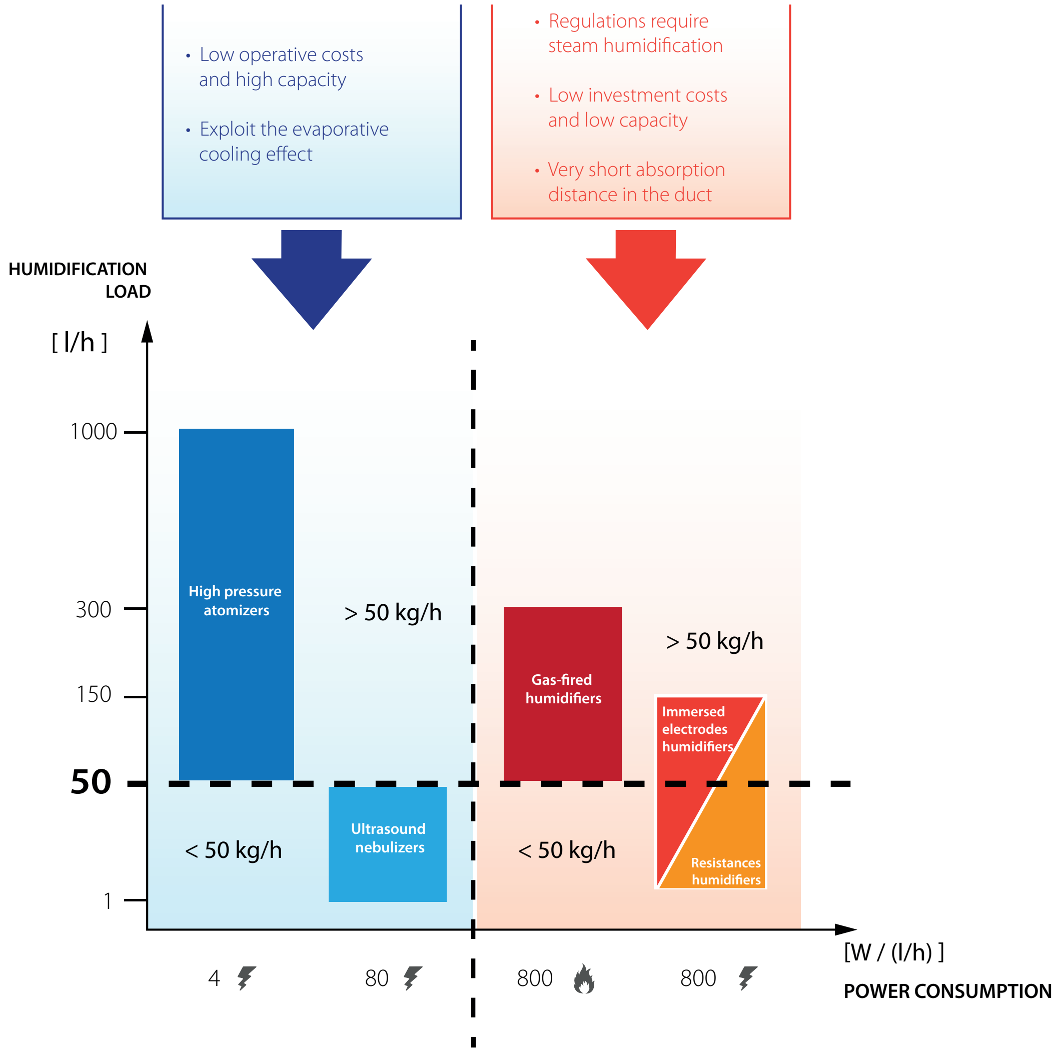
The best system to humidify different hospital areas depends on the characteristics of each installation, however a few considerations can be made as regards the technology to be chosen.

As we will see in the following chapter, standards often impose the use of steam humidifiers in specific hospital areas. Elsewhere, the choice can be based on the capacity required, room available in the duct, operating costs and investment costs.

In general, adiabatic humidifiers have very low operating costs, higher investment costs and require larger in-duct absorption distances. High-pressure atomisers have average per litre/hour costs which are more suitable for high capacity applications compared to ultrasonic atomisers. In addition, some models can humidify both supply air directly (winter season) and return air indirectly (summer season) with a single pump.

Isothermal humidifiers have lower investment costs but much higher operating costs, so they are preferable for small-medium capacities or when required by the standards. Gas-fired humidifiers are recommended for larger systems, as immersed electrode/heater humidifiers absorb electricity. The differences between the latter depend strongly on the model chosen, but we can say that heater humidifiers are easier to maintain and are more flexible in terms of supply water and modulation. They do require a higher initial investment though.

Regardless of the technology chosen, it is worth remembering to check that the solution considered is equipped with the manufacturing solutions examined in this chapter so as to comply with the hygiene and reliability needs required as well as with the energy saving and connectivity needs specific to hospital facilities.



Electric consumption

Natural gas consumption

Applicable standards

The characteristics of air handling and humidification systems are regulated both in Italy and abroad by a series or regional, national and international laws.

Managing the risk connected to the Legionella bacterium has become so important that it has its own dedicated legislation.

Air handling and, more specifically, humidification are strictly regulated by regional, national and international laws according to the type of hospital environment treated. For example, operating rooms require the strictest temperature-humidity and air quality standards while patient, visit, dressing, medical supplies rooms etc. require different conditions.

Many parameters are regulated, the main ones being:

- the temperature and relative humidity range acceptable
- the number of hourly air changes required while a certain area is in use

Other parameters include the cleanliness class, type and effectiveness of filters, decontamination time, type of air flow, type and location of air vents, air speed, maximum temperature difference between supply air and room, presence of anaesthetic gas, noise level.

Regulations often differ from country to country, but the most updated and stringent set out a range of temperature and humidity conditions in line with what described in this document.

The management of the risk regarding Legionella is instead established by dedicated legislation in each country, which determines aspects such as:

- manufacturing characteristics of the plant against the risk of Legionella.
- the elements increasing the risk of Legionella bacteria proliferation (water temperature 20÷50 °C, low flow rate pipes, systems that are not frequently used, characteristics of the supply water, rubber gaskets, etc...)
- when and on which systems to carry out assessments on the risk posed by Legionella
- sampling and analysis methods
- disinfection
- cleaning and periodical maintenance

9. Italian regulation

The official Italian laws establishing the requirements of air handling units in hospitals are the Presidential Decree 14/01/1997 (legge Bindi) and the more complete UN11425, referred to by the former.

Other reference texts are ISPESL's "Linee guida per la definizione degli standard di sicurezza e di igiene ambientale dei reparti operatori" (Guidelines for the definition of safety and environmental hygiene standards for operating wards) of 2009 and ARESS' "Misure igienistiche e requisiti tecnico-gestionali degli impianti di climatizzazione a contaminazione controllata nelle sale operatorie" (Hygiene measures and technical-management requirements of controlled-cleanliness air-conditioning systems in operating rooms) of 2010.

UNI 11425 establishes that the only type of humidifiers suitable for systems supplying operating wards are the isothermal or steam ones, thus limiting the use of the adiabatic technology to other hospital environments.

Here are the main indications set out by the Italian regulations.

<table>
<tr><th rowspan="2">Rooms</th><th colspan="2">Temperature [°C]</th><th colspan="2">R.H. [%]</th><th rowspan="2">Overpressure compared to outside [Pa] (1)</th><th rowspan="2">Outside air [vol/h]</th><th rowspan="2">Recirculation air [-]</th><th rowspan="2">Cleanliness classes in accordance with UNI EN ISO 14644-1</th><th rowspan="2">Final filtering level</th><th rowspan="2">Noise pressure level</th></tr>
<tr><th>Winter</th><th>Summer</th><th>Winter</th><th>Summer</th></tr>
<tr><td>Operating rooms with very high air quality</td><td rowspan="3">≥ 20</td><td rowspan="3">≤ 24</td><td rowspan="3">≥ 40</td><td rowspan="3">≤ 60</td><td>15 (1)</td><td>15</td><td>YES (2)</td><td>ISO5</td><td>H14</td><td>45 (3)</td></tr>
<tr><td>Operating rooms with high air quality</td><td>15 (1)</td><td>15</td><td>YES (2)</td><td>ISO7</td><td>H14</td><td>45 (3)</td></tr>
<tr><td>Operating rooms with standard air quality</td><td>15 (1)</td><td>15</td><td>- (4)</td><td>ISO8</td><td>H14</td><td>45 (3)</td></tr>
<tr><td>Sterile storage</td><td rowspan="8">≥ 22</td><td rowspan="8">≤ 26</td><td rowspan="8">≥ 40</td><td rowspan="8">≤ 60</td><td>15</td><td>≥ 2 (5)</td><td>- (4)</td><td>-</td><td>H14</td><td>45</td></tr>
<tr><td>Preparation of patients undergoing surgery</td><td>10</td><td>≥ 2 (5)</td><td>- (4)</td><td>-</td><td>≥ H12</td><td>-</td></tr>
<tr><td>Staff preparation</td><td>10</td><td>≥ 2 (5)</td><td>- (4)</td><td>-</td><td>≥ H12</td><td>-</td></tr>
<tr><td>Waking up patients who have undergone surgery</td><td>10</td><td>≥ 2 (5)</td><td>- (4)</td><td>-</td><td>≥ H12</td><td>-</td></tr>
<tr><td>Clean / sterile corridor</td><td>10</td><td>≥ 2 (5)</td><td>- (4)</td><td>-</td><td>≥ H12</td><td>-</td></tr>
<tr><td>Spaces for filters used for patients undergoing surgery</td><td>5</td><td>≥ 2 (5)</td><td>- (4)</td><td>-</td><td>≥ F9</td><td>-</td></tr>
<tr><td>Spaces for filters used for staff</td><td>5</td><td>≥ 2 (5)</td><td>- (4)</td><td>-</td><td>≥ F9</td><td>-</td></tr>
<tr><td>Sub-sterilization</td><td>10</td><td>≥ 2 (5)</td><td>- (4)</td><td>-</td><td>≥ H12</td><td>-</td></tr>
<tr><td>clean storage</td><td rowspan="2">≥ 18</td><td rowspan="2">≤ 26</td><td rowspan="2">≥ 40</td><td rowspan="2">≤ 60</td><td>10</td><td>≥ 2 (5)</td><td>- (4)</td><td>-</td><td>≥ H12</td><td>-</td></tr>
<tr><td>dirty storage</td><td>5</td><td>≥ 2 (5)</td><td>NO</td><td>-</td><td>≥ F9</td><td>-</td></tr>
<tr><td></td><td colspan="4">values required by Presidential Decree 14/01/1997</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Note: data supplied by AiCARR

(1) The pressure in operating rooms used for infected patient is lower compared to adjacent rooms.

(2) Please refer to the examples in annex D.

(3) In the event of renovation works where it is necessary to create class IOS5 operating rooms using room recirculation systems, the max noise level that can be reached is 48 dB (A) and the project must contain the reason for the decision.

(4) Depending on how clean the air needs to be, as well as the monitoring.

(5) Minimum value if there are no other values that, set in relation to the specific crowding needs, sources of pollutants and based on a risk analysis.

The Ministry of Health Guidelines for the prevention and monitoring of Legionellosis (May 2015) set out all the measures and provisions to prevent the proliferation of Legionella. They apply to the entire ventilation and water systems and entail periodical assessments and analyses by skilled personnel to decide the corrective measures to implement if needed.

As regards humidification, this regulation **prohibits** the use of systems that cause **water stagnation** and recommends against those that recirculate within the air handling unit. In adiabatic humidifiers, incoming water quality should be periodically checked according to the results of the Legionellosis risk assessment and must never exceed bacterial load threshold levels. This recommendation has legal force and would exclude the possibility of using wetted media humidifiers with recirculation in practically all air handling units, not only those for hospital application.

There are also some regional regulations such as the "Raccomandazioni [...] per le strutture sanitarie" (Recommendations [...] for health facilities) of Regione Piemonte, Regional Decree 1115 21/07/2008 of Regione Emilia Romagna and "Linee guida per la prevenzione e controllo della Legionellosi" (Guidelines for the prevention and monitoring of Legionellosis) (March 2009) of Regione Lombardia. We therefore recommend referring to both types of regulations - regional and national - and complying with the more stringent ones.

10. International regulations

		UNI 11425:2011	ASHRAE Std 170 2013	DIN 1946-4
		ITALY	UNITED STATES	GERMANY
Temperature-humidity conditions	Supply air temperature, relative humidity	Winter ≥20°C, RH≥40%; Sumer ≤24°C, RH≤60%	20÷24°C, Adjustable, RH 40÷60%	19÷26°C, Adjustable, HR as per DIN 13779
	Δt max between supply T and room T	-0,5<ΔT<-2°C	Not specified	Not specified
Cleanliness class	ISO class required	3 cleanliness classes: ISO5, ISO7, ISO8	Not specified	Classification according to RKI: classes Ia,Ib,II
	Measurement of contamination	Six-monthly monitoring of cleanliness class (ISO 14644-3)	Not specified	Bacteriological and particulate counts
Operating room minimum area		Not specified	Not specified	Not specified
Air change and recirculation	Recirculation allowed?	Yes, with air form the same operating room	Yes	Yes but from same group of rooms
	Hourly air changes	15 vol/h	between 6 and 20 vol/h	1200 m3/h outside air
Filters	Filter requirements	3 filtering levels: standard(H12), high(H13), very high(H13/H14)	Transplants and orthopaedics (7,8,17); operating rooms (8 and 14) (STD classes to ASHRAE 52.2-1999)	1st stage F5 (F7 recommended), 2nd F9, 3rd H13 within 0.5 m of the room
	Filter positions	Absolute filters located inside the operating room	Upstream of AHU and second stage downstream of AHU, absolute filters in operating rooms	1st stage upstream of AHU, 2nd on supply, 3rd on supply
specifications on decontamination time		ISO 14644-3	Not specified	Not specified
Types of air flow	Recommended flow	Turbulent or mixed unidirectional airflow	Downward unidirectional airflow, intake grills at bottom	Unidirectional airflow for type A rooms, unidirectional or mixed flow for type B rooms
	Dedicated units required	Not specified	Not specified	Not specified
Air velocity	Max turbulence allowed in operating room	Not specified	Not specified	Not specified
	Limit air velocity in operating room	Not specified	Not specified	Not specified
	Air velocity at outlets/ diffusers	So as to not disturb unidirectional airflow	Recommended 0.15 m/s after filter	Minimum 0.23 m/s after filter
Subdivision of zones	Sub-division of operating rooms	Physical sub-division of rooms according to function	Not specified	Reference to table 2 of the standard
	Identification of zones with different contamination classes	Zones with different contamination according to asepsis	Not specified	Class I zone, high bacteria control requirements (operating rooms)
	Method for controlling cleanliness	Press. diff. ≥10 Pa in operating room block and 15 to 20 Pa in operating room	Overpressure of 2.5 Pa with doors closed	Air flow between rooms cross pattern to establish direction of flow
Position of air openings	Supply	Not specified	on ceiling, unidirectional	Not specified
	Return	Not specified	At least 2 openings near ground (75 mm from floor)	At top (recirculation) and bottom (exhaust)
Anaesthetic gases	Operating room concentration limits	N_2O: <100 ppm built before '89, <50 ppm renovated before '89, <25 ppm built after '89, <2ppm new rooms	Not specified	N_2O= 25 ppm; halogenated =2 ppm ceiling (NIOSH values)
Minimum flow-rate in standby		15 vol/h	Not specified	in standby min 2 m/s in ducts before HEPA filters
Maximum noise level allowed		"<45 dB in operating room (if ISO 5 <48 dB)"	Not specified	48dB(A)

Note: data supplied by AiCARR

NF S 90 351	SWKI 99-3F	ONORM H 6020-1	GOST R 52539/2006
FRANCE	SWITZERLAND	AUSTRIA	RUSSIA
19÷26°C, RH 45÷65%	18÷24°C, Adjustable, RH 30÷50%	22÷26°C±1°C, Adjustable, RH 40÷60%	18÷24±1°C, min HR value 30% with 22°C
Not specified	ΔT max 1°C, max air supply T deviation ±1°C	Not specified	Not specified
ISO5 B10 (zone4), ISO7 B10 (zone3), ISO8 B100 (zone2)	Classification not required	4 purity classes: A and B=ISO5, C=ISO7, D=ISO8	Risk divided into 5 levels, highest risk rooms ISO5
ISO classes, kinetic decontamination classes, bacteriological classes (CFU/m3)	Particulate counts with sample source (CFU/m3 classification is not useful)	CFU/m3 limits for indoor air and rooms of various classes: I, II, III, IV, class I	Particulate counts with measurement 30 cm from operating table
Not specified	Not specified	Not specified	Not specified
Yes but from same group of rooms	Yes	Yes, with air filtered using absolute filters	Yes, with air form the same operating room
6 vol/h	Outside air 100m3/(h*pers);	Outside air flow-rate 20 m3/h per m2 of surface areas	100 m3/h p.p.; >12 vol/h operating rooms
1st stage F6 (outside air), 2nd stage F7, 3rd stage H13, min F5 for grills	1st stage F5 (outside air), 2nd stage F9, 3rd stage H13	"For classes I and 3 II; F7,F8,H13; extraction F6"	3 filtering levels: F7,F9, H14 (this one directly into the room)
1st stage upstream of AHU, 2nd upstream of humidif., 3rd entrance to controlled area	1st stage upstream of AHU, 2nd on supply, 3rd on supply	1st stage upstream of AHU, 2nd on supply, 3rd on supply	1st stage upstream of AHU, 2nd on supply, 3rd on supply
Time to reduce concentration by 90% for the various zones	Not specified	Not specified	Not specified
Unidirectional airflow in zone 4, mixed in zone 3, turbulent for others	Unidirectional airflow above the occupied area	Class I: supply airflow with low turbulence	Unidirectional airflow for most critical applications, not unidirectional for others
Not specified	Not specified	Yes, in class I and II rooms	Not specified
Not specified	Max 10% at 1.5 m in height	Not specified	Not specified
Not specified	Not specified	0.45 m/s for classes I and II	Not specified
Air vel. near cool coil <3m/s	Supply 0.24 m/s, average 0.2 m/s	Not specified	"Between 0.24 and 0.30 m/s"
Not specified	Not specified	Not specified	Not specified
4 zones, not necessarily physically separated into operating rooms and service rooms	Zones with different contamination, not necessarily physically separated	Physical separation of the various rooms	Physical separation of the various rooms
Air vel. >0.2 m/s or alternatively pressure >15 to 20 Pa	Dynamic protection of zones with downward vertical airflow	DP>30 Pa with extraction system off, dampers to close ducts	DP>10 Pa between adjacent rooms, continuous control of overpressure
Not specified	filtering ceiling, area >9 m2	Not specified	Unidir. ceiling diffusers >9 m2
Not specified	Uniform division of openings on ceiling/wall	Top and bottom, extracted air 75% bottom, 25% top	>50% from return at top (ceiling and walls)
Not specified	Not specified	Not specified	Not specified
Minimum 6 timesl/h air change	Not specified	System off when not used, restart 30 min before	Not specified
Not specified	48 dB(A) at 1.75m from floor	45 dB(A) in operating room, 35 dB(A) in sterile storage and others rooms	Not specified

These parameters establish the setpoints and characteristics of the ventilation system, but often also international regulations, like Italian ones, set out limitations regarding the type of humidifier to use in specific rooms. Operating rooms are the most strictly regulated and standards usually prescribe their supply via dedicated air handling units with an isothermal humidification system.

US regulation ASHRAE 170-2013 was recently updated with an addendum [9] permitting the use of high-pressure adiabatic humidifiers in operating rooms, provided that measures are taken to ensure a hygienic installation. These include reverse osmosis systems with UV lamps for water treatment, the use of drop separators and limit probes, no water recirculation and a consensus for the activation of the humidifier subordinated to that of the duct fan. Many characteristics we had previously identified as positive for hygienic installation are therefore also requirements established by the standards.

Some of the main international regulations on Legionella risk management are:

Country	Reference standards
FRANCE	Circulare 08/12/2015; Circulare 493 28/10/2015; Circulare 323 11/07/2005;
SPAIN	Real Decreto 865/2003;
UNITED KINGDOM	L8: Legionnaires' disease. The control of legionella bacteria in water systems (2013);
GERMANY	VDI 6022-3 (2002); Bericht Legionellen und Legionellose (05/2005);
SWITZERLAND	Legionella e Legionellosi (03/2009);
EUROPE	REHVA Legionella prevention: practical guide for design, installation, operation and maintenance to minimize the risk;
UNITED STATES	ANSI/ASHRAE Standard 188-2015 Legionellosis: risk management for building water systems; Guideline 12-2000: Minimizing the risk of Legionellosis associated with building water systems;

Source: AICARR

11. Conclusions

Humidification is an aspect more important than one would think for the operativeness of a hospital facility due to its great impact on the:

- development of pathogens and transmission of patient infections;
- protection of medical machinery against electrostatic discharges;
- well-being and performance of patients and medical staff.

Numerous studies show that the optimal relative humidity range is between 40 and 60% and the standards regulating the installation of ventilation and humidification systems in hospitals instruct the maintaining of similar values.

This is why humidification systems are compulsory in hospitals and the various components must be selected so as to be suitable for application needs regarding hygiene, reliability and connectivity. When possible, choose adiabatic or high-performance isothermal humidifiers as they combine humidification needs with the energy saving objectives to be reached in energy-consuming facilities such as hospitals.

This choice has a relevant effect on both the medical condition of patients and the related expenses for the entire community.

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Notes

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Headquarters ITALY

CAREL INDUSTRIES Hqs.
Via dell'Industria, 11
35020 Brugine - Padova (Italy)
Tel. (+39) 0499 716611 - Fax (+39) 0499 716600
carel@carel.com

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