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Eurovent 17/14 - 2025

Moisture recovery in ventilation and air-conditioning systems

First Edition

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Document history

This Eurovent Industry Recommendation / Code of Good Practice supersedes all of its previous editions, which automatically become obsolete with the publication of this document.

Modifications

This Eurovent publication was modified as against previous editions in the following manner:

Modifications as against	Key changes
1st edition	Current document

Preface

In a nutshell

The recommendation discusses the application of moisture recovery from extract air in general ventilation and combined ventilation and air conditioning systems. It provides a comprehensive overview of available heat and moisture recovery technologies, sets out principles for their correct application and explains the benefits of moisture recovery in terms of energy and cost savings, as well as improved IEQ. The document is addressed to investors and HVAC professionals involved in the design of ventilation and combined ventilation and air-conditioning systems.

Authors

This document was published by Eurovent and was prepared in a joint effort by participants of the Product Group 'Energy Recovery Components' (PG-ERC), which represents a vast majority of all manufacturers of these products active on the EMEA market. Particularly important contribution has been provided (in alphabetical order of the last name) by Yakub Bawa, Peter Bräutigam, Simone Dugaria, Pedro Lapa, Paolo Liberati, Frank Lichtner, Rikard Lindbom, Thomas Richter and Igor Sikonczyk.

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Important remarks

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List of abbreviations used

AHU	Air Handling Unit
EATR	Exhaust Air Transfer Ratio expressed in % (ratio between the exhaust air amount in supply air and supply air mass flow), as defined in EN 308:2022
ECC	Eurovent Certita Certification
EHA	Exhaust Air (airflow leaving the extract air treatment system and discharged to the atmosphere). Alternatively, the term *Exhaust air outlet* is used
ERC	Energy Recovery Component
ETA	Extract Air (airflow leaving the treated room and entering the air treatment system). Alternatively, the term *Exhaust air inlet* is used
HRS	Heat recovery system
IDA	Indoor air
OACF	Outdoor Air Correction Factor (ratio between ODA and SUP mass flow rates), as defined in EN 308:2022.
ODA	Outdoor Air (airflow entering the system from outdoors before heat recovery) Alternatively, the term *Supply air inlet* is used
PHE	Plate Heat Exchanger
RHE	Rotary Heat Exchanger
SUP	Supply Air (airflow entering the treated room after heat recovery) Alternatively, the term *Supply air outlet* is used
VOC	Volatile organic compounds

List of symbols used

η_t	Temperature efficiency of energy recovery as defined in EN 308:2022, %
η_x	Efficiency of moisture recovery as defined in EN 308:2022, %
t	Air temperature, °C
x	Moisture content in air, g/kg

1 Introduction

While recovery of sensible heat in ventilation and air-conditioning systems has long been a mandatory standard, the technologies for combined sensible and latent (moisture) heat recovery, which have been available on the market for many years, are increasingly being applied.

This is because heat exchangers capable of recovering sensible heat and moisture, also known as enthalpy exchangers, significantly contribute to improving indoor environmental quality and additional energy savings in applications that require indoor humidity control.

Heat exchangers are broadly used in ventilation and air-conditioning systems as components of HVAC devices (residential ventilation units, air handling units, roof-top units etc.) as well as stand-alone system elements. They are also used in industrial plants.

This recommendation presents a comprehensive overview of moisture recovery technologies, discusses their applications, and provides guidelines for proper selection, as well as for estimating the benefits of moisture recovery.

2 Why do we need moisture recovery?

2.1 Humidity is crucial for indoor comfort and human well-being

Relative humidity is one of the key elements of the indoor environmental quality (IEQ) and its essential part - indoor air quality (IAQ). It has a key impact on thermal comfort and health. It is also of importance for the durability of building structures. Thermal comfort means conditions, which are basically determined by a combination of temperature and relative humidity, that are perceived by people as satisfactory. Thermal comfort, which involves maintaining relative humidity within the right range, is essential for well-being and high productivity. Regarding health issues, too low indoor humidity is associated with the risk of effects such as irritation of the eyes, nose and throat, as well as dryness of the mucous membranes and skin. In turn, excess humidity can lead to microbial growth that provokes respiratory diseases or allergies. Further, humidity has an impact on viral survival [1].

Although there is no single universally recognised international standard for indoor humidity values, for buildings intended for human occupancy, the following criteria are generally acknowledged:

- For thermal comfort, relative humidity within the range of 40 – 60%
- For health reasons: relative humidity above 30%

In many climates, maintaining the right indoor humidity level year-round requires air conditioning or ventilation systems, which may consume significant amounts of energy. Applying proper heat and moisture recovery exchangers in these systems significantly contributes to improving IEQ and reducing energy consumption.

2.2 Impact of moisture recovery on IEQ in residential buildings

The vast majority of residential buildings are not equipped with indoor humidity control but do have balanced (supply and exhaust) mechanical ventilation systems. In the winter season, particularly in cold climates, the moisture content in outdoor air is very low. This dry outdoor air is supplied indoors by ventilation systems, resulting in low indoor humidity in winter, even below 20%. In buildings, however, there are various sources of moisture emissions, which in addition to people themselves, include cooking, dishwashing, showering, cleaning and plants. The generated moisture is extracted from the building by exhaust ventilation air.

By incorporating in the ventilation system an exchanger that recovers moisture from extract air and transfers it to the outdoor air supplied to the building, the indoor air humidity may be maintained at a correct level, and the problem of drying out the rooms by outdoor air can be mitigated.

According to the Norwegian study [1] that analysed the impact of moisture recovery on indoor humidity level over the heating season in a single-family residential house in Oslo, Norway, with typical moisture generation, applying a heat exchanger with a moisture recovery efficiency in the range of 50-60% in the ventilation system ensured that the period with unacceptable (too low or too high) indoor humidity levels was minimized. For the moisture recovery efficiency of 60%, the time fraction during the heating seasons with too low indoor relative humidity (below 25%) was only 1%, while for a system without moisture recovery, it exceeded 25% of the heating season period.

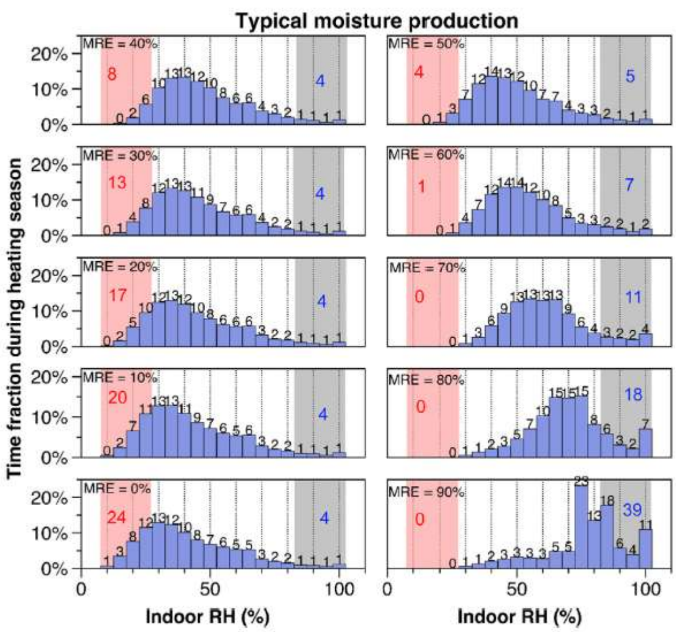

Figure 1. Time fraction of indoor relative humidity in analysed residential home in heating season for different moisture recovery efficiency (MRE). Red area = too dry, grey area = too humid [1]

Thus, applying in the system a ventilation unit with an exchanger that recovers moisture in addition to heat, enables to maintain adequate humidity in the rooms during the heating period without any additional energy for humidification. However, although this solution considerably improves indoor comfort and well-being, it does not enable to control the humidity level.

2.3 Impact of moisture recovery on energy saving and IEQ in non-residential buildings

Contrary to residential buildings, in many non-residential buildings, such as hospitals, hotels, cinemas, museums, office and conference buildings etc, the indoor comfort needs to be controlled within set values.

This means that in summer, the air supplied to the building must be cooled, and in winter, heated. In some applications, control of the moisture content in the supply and indoor air is also required.

Summer

The amount of energy needed to cool the outside air depends not only on the temperature difference, but also on the moisture content, or in other words relative humidity, of the outside air. The lower the moisture content in the outdoor air, the lower the power demand to cool it to a desired temperature. Outdoor moisture content in summer, especially in hot and humid climates (e.g., in the Mediterranean region of Europe) is much higher than in cooled indoor spaces. Thus, applying in such cases moisture recovery exchangers in ventilation and air-conditioning systems allows to reduce the moisture content of the air to be cooled, and consequently limit energy consumption for cooling. Depending on climate and operating conditions, savings in annual consumption of energy for cooling can be considerable due to moisture recovery. For more information see section 5.1.

Winter

In turn, during winter in colder climates (the northern part of Europe), the moisture content of outdoor air is usually much lower than indoors. Thus, in buildings which require indoor humidity control, the supplied air needs to be humidified. Depending on the technology used, the energy demand for humidification may be very high. The most energy-consuming technology is electric steam humidification. However, this technology, due to ease of implementation, is often used in small-sized systems.

By using moisture recovery, the moisture content of the air to be humidified can be considerably increased, leading, as with cooling, to a significant reduction in energy consumption. In some cases, moisture recovery can eliminate the need for humidification completely. Either way, moisture recovery in cold climates always improves IEQ, regardless of whether indoor comfort parameters are controlled or not.

Energy savings resulting from moisture recovery are discussed in more detail in section 5.2.

2.4 Impact of moisture recovery on freezing of heat exchangers

To reduce energy for heating, ventilation air supplied to the building in winter ventilation systems are equipped with exchangers for heat recovery, typically installed as a component in ventilation units. Besides the obvious reasons, this is required by the building codes of many countries. Furthermore, in the EU, all bidirectional ventilation units must be mandatorily equipped with sensible (without moisture) heat recovery of the minimum required efficiency is specified in the relevant Ecodesign Regulation[1]. Exchangers for sensible heat recovery, in particular the recuperative plate exchangers, are prone to freezing at low outdoor temperatures. This is because the moisture contained it the warm extract air condenses when the air is cooled in the exchanger. If the temperature of the outdoor air flowing on the other side of the exchanger is below or sub-zero, the condensed moisture freezes and malfunctions the exchanger, i.e., reduces air flow and efficiency, and in the worst-case scenario may result in physical damage. This means, particularly in cold climates, the heat recovery is reduced, and energy use for heating is increased.

The freezing-temperature limit for exchangers recovering both sensible heat and moisture is clearly lower compared to recuperative exchangers that recover only sensible heat. Under typical operating conditions, it is well below the outdoor temperature of -10°C, which in practice means that freezing does not occur at all, or its period is negligible. The difference between the two types of exchangers is depicted in Figure 2.

[1] Regulation (EU) 1253/2014

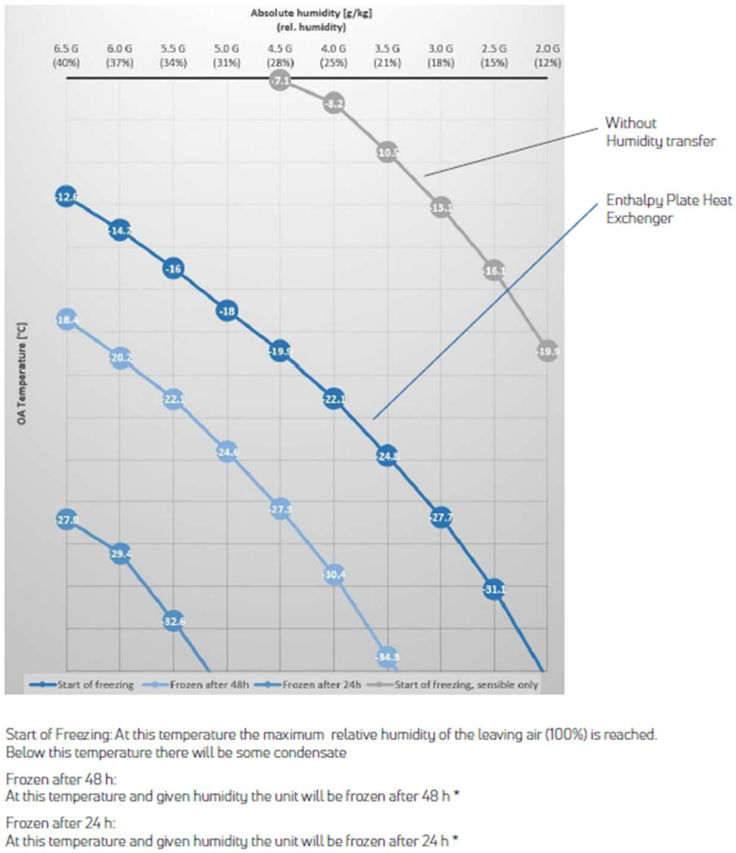

*Figure 2. Freezing of heat recovery exchangers with and without humidity transfer. *) Frozen in the diagram means that half of the condensate freezes and is clogged by ice one third of the unit ©Polybloc*

At outside air temperatures of approx. below - 5 °C, a freezing process begins in the cold corner area of standard plate exchangers in the exhaust air duct. The freezing process is a transient process that usually lasts several hours and is accompanied by an increasing pressure loss on the exhaust air side.

Since in enthalpy exchangers the air on the exhaust air side is increasingly dehumidified in the direction of the cold corner, the icing process only occurs at lower temperatures. As a rule of thumb, a shift of about - 6 Kelvin can be expected.

2.5 Humidity is fundamental to many industrial processes and storage of goods

In addition to ventilation and air-conditioning systems in buildings for human occupancy, there are numerous industrial buildings and processes that require precise air humidity control. In many of these applications, using heat exchangers for heat and moisture recovery in systems for air treatment provides for considerable energy savings.

3 Technologies and their principles

Three main types of exchangers for heat recovery include:

- Plate exchangers,

- Rotary exchangers
- Alternate storage systems

All these types are available in a version for sensible heat and moisture recovery and a standard version intended principally for sensible heat recovery. Principally intended, because standard rotary exchangers and alternate storage systems (with a matrix made of aluminium without additional treatment) have a limited ability of moisture recovery in winter, and standard (aluminium) plate exchangers have the capability of latent heat recovery by condensation at humid extract air and low outdoor temperatures.

The differences in technology of heat and moisture recovery exchangers, compared to standard exchangers and are outlined in the following sections.

3.1 Enthalpy plate exchanger

In standard plate heat exchangers with, for example, aluminium or PET as plate material, only sensible heat is transferred from the exhaust air to the supply air (winter conditions). In enthalpy plate heat exchangers, the plate material is a membrane which allows diffusion of water vapour between the exhaust and supply air sides. The water vapour diffusion represents the desired moisture transfer and the driving force here is the local difference in water vapour partial pressure between the exhaust and supply air side. The local difference in absolute humidity is a very good indicator of the local water vapor partial pressure.

To allow water vapor diffusion, the membranes are usually microporous polymer membranes as a supporting structure with a thin hydrophilic coating on one side of the membrane.

The most important requirements for moisture transmitting membranes are as follows:

- Hygienic requirements, e.g. as specified in VDI 6022
    - including EN ISO 846 procedure A and C
    - including testing on release of volatile organic compounds (VOC)
- High air tightness – the complete enthalpy exchanger must meet the EUROVENT leakage limit
- Resistant to viral transmission,
- High odour tightness,
- If the four above criteria are met, then a potential transfer of VOCs and aerosols is also considered non-critical,
- Sufficient fire protection class,
- Long service life - no degradation caused by moisture.

Some non-European manufacturers often use paper-based membranes in enthalpy exchangers. There is no reliable information on the hygiene and long-term behaviour of these membranes. However, it is understood that even minor coating damage related to production puts the paper membrane at a clear hygienic disadvantage compared to the membrane with a polymeric support structure commonly used in Europe.

3.2 Rotary heat exchangers

In standard condensation rotary exchangers, the rotor is typically made of aluminium. For humidity transfer, it is coated with special materials or treated. The coating materials and treatments used, and their properties are outlined in the section below.

3.2.1 Coating materials

Moisture-transferring coatings consist largely of powdered adsorbents and suitable binders. Adsorbents, also known as sorption materials, are solid materials with a tremendous internal surface area per unit of mass. The ability of an adsorbent to attract moisture depends on the difference in vapour pressure between its surface and the air.
Several solid adsorbents can be manufactured to precise tolerances, with pore diameters that can be closely controlled. This means they can be tailored to adsorb molecules of a specific diameter. Water, for example and of particular interest in the field of ventilation and air-conditioning systems, has an effective molecular diameter of 0.32 nm. A molecular sieve adsorbent with an average pore diameter of 0.40 nm (= 4 Ångström) adsorbs water but has almost no capacity for larger molecules, such as organic solvents. This selective adsorption characteristic is useful in many applications. Common Adsorbents are:

Silica gel
Silica gels are amorphous solid structures formed by condensing soluble silicates from solutions of water or other solvents. Advantages include relatively low cost and relative simplicity of structural customizing. They are available as large as spherical beads about 5 mm in diameter or as small as grains of a fine powder. The pore sizes vary from 1 nm to several hundred nm (10 to several thousand Ångström).

Zeolites and Molecular sieves
Synthetic zeolites, also called molecular sieves, are crystalline aluminosilicates manufactured in a thermal process. Controlling the process temperature and the composition of the ingredient materials allows close control of the structure and surface characteristics of the adsorbent. At a somewhat higher cost, this provides a much more uniform product than naturally occurring zeolites. The pore sizes vary from 0.3 nm to 1.0 nm (3 to 10 Ångström) or larger.

Treatments
Possible treatments for humidity supporting material are oxidizing or anodizing the aluminium base material. This creates a hygroscopic layer that can hold and distribute condensing water on the surface and has a low level of adsorption capacity.

3.2.2 Recommendations for selecting the right design

This section provides general guidance on selecting the appropriate type of exchanger rotor depending on the intended application.

Condensation wheel

- Sensible heat transfer all year round.
- Moisture transfer in winter is possible due to condensation (unstable process; it only occurs when there is condensation).

Hygroscopic and hybrid wheels

- Target season: spring, autumn, winter. Typical moisture efficiency: $30\% < \eta_x < 50\%$
- Winter operation: reduced demand and energy use for humidification.

Sorption wheel

- Stable and high moisture transfer all year round.
- Target season: summer.

- Summer operation: reduced demand and energy use for cooling.
- Winter operation: reduced demand and energy use for humidification.
- For potential reduction in capacity demand and energy use see Section 5.

3.3 Alternate storage systems

In alternate storage systems, two physically separate packages of metal sheets serve as heat accumulators. One bundle of sheets is heated in the exhaust air flow, while the other transfers its heat to the incoming outside air. The exhaust and outside air streams are switched over periodically.

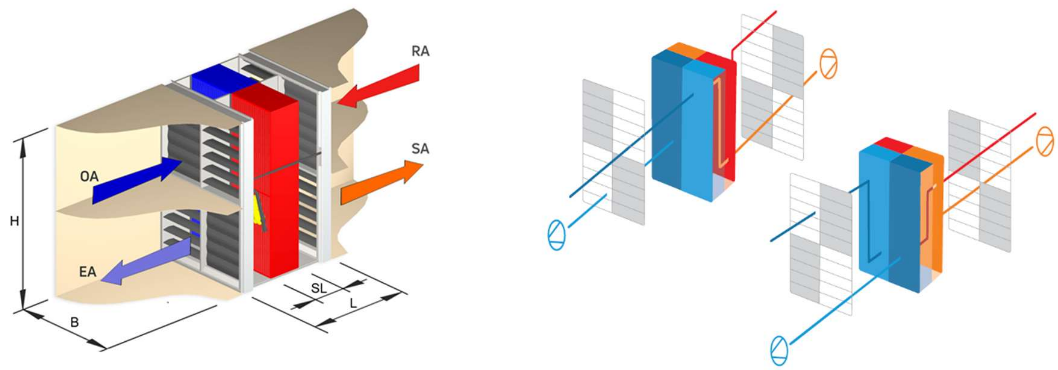

Figure 3. Design and operation principle of alternate storage systems. ©Polybloc

Comparable to rotors, a noticeable moisture transfer is already achieved under condensing conditions. These systems are also available with sorption coating which significantly increases moisture transfer (even in condensing conditions).

4 Heat exchanger types

This chapter provides a detailed description of various heat and moisture recovery exchanger types, including specifications of available product ranges and typical performance, as well as useful information on aspects such as maintenance, inspection and special considerations specific to the exchanger type.

4.1 Enthalpy plate exchangers

4.1.1 Physical sizes and air flow range

Both enthalpy counterflow and crossflow technologies are available on the market. Most manufacturers focus on the residential market (airflows of less than 1000 m³/h), while only a few have a range that can cope with the higher airflows typical of commercial applications. Some producers offer both technologies. Most manufacturers have a range size with a diagonal A (see Figure 5) that does not exceed 700mm. This figure shows that the preferred technology is counterflow, which can achieve higher efficiencies.

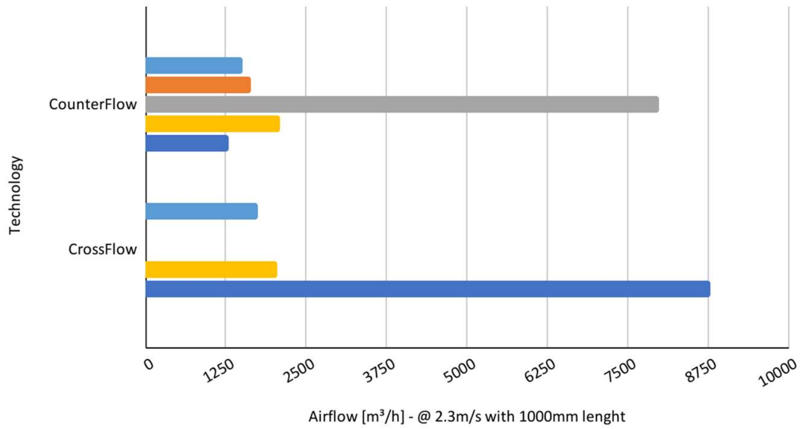

Figure 4. Airflow range for different enthalpy plate exchangers of various manufactures (marked by colours). ©Recuperator

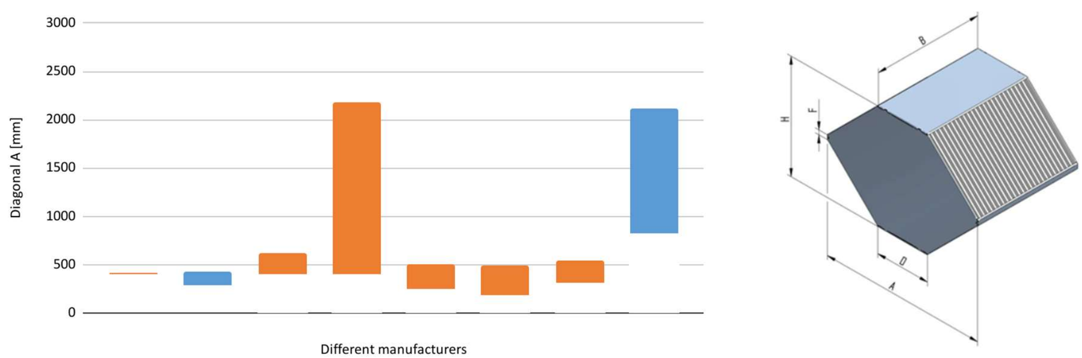

Figure 5. Range of sizes for different manufacturers (blue = crossflow, orange = counterflow). ©Recuperator

4.1.2 Typical efficiency

The characteristics of the membrane and the technology of the heat recovery component have a significant impact on the moisture exchange. In winter, temperature efficiency can reach 80% and humidity efficiency up to 60%. In some cases, efficiency can be lower with cross-flow technology for both sensible and latent heat. In summer, the efficiency of sensible and latent heat exchange can drop by a few percentage points.

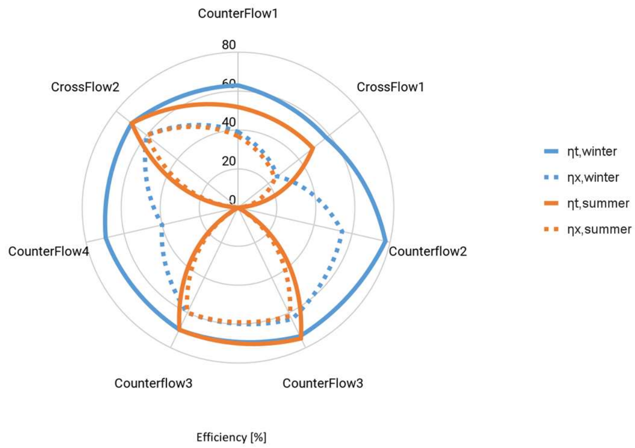

Figure 6. Sensible and latent efficiency for different manufacturers. ©Recuperator

4.1.3 Special characteristics

The housing can be made of plastic, galvanized steel or aluminium. The core of the enthalpy heat recovery component is made up of various materials. The spacers are usually made of plastic and the membrane is often made of polymer. The membrane could be made of paper, but this is limited to certain applications and dimensions for hygienic and flammability reasons. The membrane can also be thermoformed to achieve sufficient mechanical strength without the need for spacers. Hygienic certification could be a requirement for this type of unit.

All the units proposed on the market are washable. Maintenance is important to maintain the latent efficiency. Normally, cleaning can be done with warm water and a soft detergent. Regular maintenance will guarantee the performance of the unit for years to come.

The maximum pressure difference allowed could reach over 1000 Pa and the maximum temperature allowed is around 60°C.

4.1.4 Different weather conditions

The ability of the membrane to transfer moisture from one airflow to the other without condensation limits the formation of frost. It has been measured that freezing starts at a temperature below -12°C, while a standard aluminium heat exchanger starts to freeze at -3°C. This temperature decreases as the humidity on the exhaust side decreases.

The performance of the enthalpy heat exchanger is sensitive to the temperature and humidity conditions of the supply air flow. In summer, the performance decreases slightly due to the smaller differences between the two airflows.

4.1.5 VOC and aerosol carry over

For the enthalpy plate heat exchanger, the EATR and OACF are 0% and 1 respectively due to the sealed technology. The plate assembly is designed to have almost zero leakage at 250 Pa. In addition, the membrane is constructed in such a way that the VOCs and aerosols are not transferred to the supply air flow, as the structure of the membrane does not allow the passage of molecules bigger than those of water vapor.

4.1.6 Performance control principle

The performance of the plate exchanger can be controlled using the bypass section, which is available on units often designed for commercial applications.

The units with a bypass section are often supplied with a damper. When the bypass damper section is opened, some of the supply air is bypassed and so the heat and moisture transfer is reduced. The damper can be controlled by an on-off or modulating actuator.

4.1.7 Possible issues to consider

To keep the performance over time, maintenance is important. This process avoids the formation of a layer of dust that could close the pores of the membrane.

The presence of the membrane limits the maximum pressure differential compared to the standard aluminium plate heat exchanger solution. This should be taken into account when determining the position of the fan.

The enthalpy plate heat exchanger is more expensive than the aluminium or plastic heat exchanger. This price is expected to decrease in the near future.

4.1.8 Cleaning and maintenance

Enthalpy membrane plate heat exchangers must be cleaned with caution. The heat exchanger should be checked regularly for dirt (once a year) and be cleaned, if necessary, in order to maintain its latent effectiveness. It is recommended to:

- not use a high-pressure cleaner as it could damage the membrane,
- not exceed the temperature of 60°C,
- clean the heat exchanger with tepid water up to 30°C and at a pressure approximately of 4 bar,
- maintain the distance between nozzle and exchanger surface not less than 50 cm,
- if necessary add a mild dishwashing liquid..

4.2 Rotary heat exchangers

4.2.1 Rotor material

Most common rotor matrix material for ventilation applications is aluminium.

4.2.2 Coating materials for humidity transfer

- Molecular sieves different types and pore sizes available, but most common are 3Å, 4Å (most common).
- Silica gel (seldom on the market).
- Oxide layer on the aluminium foil to support humidity transfer, mainly under condensation conditions, used in so called 'hygroscopic rotors' with lower humidity efficiency (not common on the market).

Sorption coated material can be used for all the rotor or only for the flat or corrugated layer of the rotor wheel (hybrid). This allows the selection of a suitable rotors for the respective humidity transfer requirement.

4.2.3 Physical sizes

- Wheel diameter: from 250 mm up to 6000 mm,
- Internal length of the wheel 100 to 300 mm, most common size is 200 mm.
- Structure of the matrix: wave heights between 1.3 and 3.0 mm are available.
- Rotor (rotation) speed between 10-15 rpm (sensible) and 12-25 rpm (sorption)

4.2.4 Air flow range

Face air velocity starting at 1 m/s up to 3 or 4 m/s depending on permissible pressure drop and the required efficiency.

4.2.5 Typical efficiency and pressure drop

At 2 m/s face air velocity.

- Temperature efficiency: 73% to 85%
- Humidity efficiency: 52% to 85% (for sorption rotors)
- Pressure drop: 100 to 250 Pa

4.2.6 Performance under different weather conditions

Condensation in winter conditions supports humidity transfer even with uncoated (sensible) rotor material. Humidity efficiency under summer (non-condensing) is typically lower than temperature efficiency.

While temperature efficiency can be considered constant regardless of weather conditions, humidity efficiency is dependent on parameters of outdoor and exhaust air, as well as the rotor type. The relation between humidity efficiency and air parameters can be expressed by the condensation potential, which is explained in Figure 7.

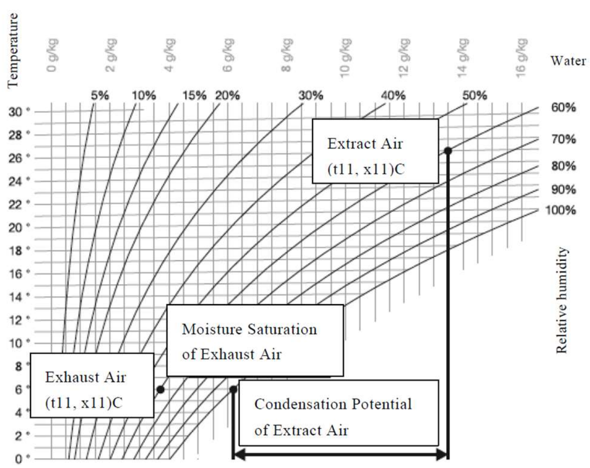

Figure 7. Condensation potential of extract air [3]

A study by Hoval [3] presents typical moisture recovery efficiency for different rotor types depending on condensation potential. Its results relate to the typical range of extract air parameters in common ventilation systems but not to hight extract temperatures in industrial applications.

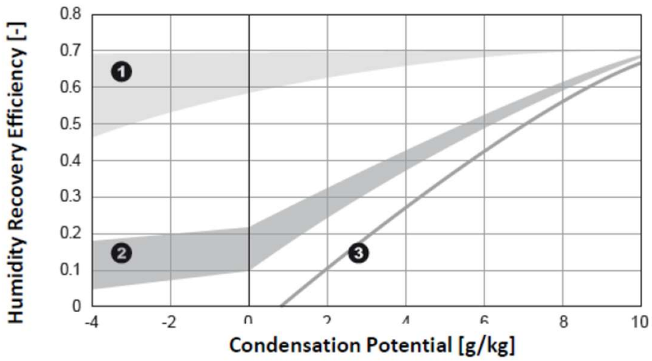

Figure 8. Comparison of humidity efficiency for different rotor types depending on condensation potential. 1 = sorption, 2 = hygroscopic, 3 = condensation rotor [3]

The study shows that under summer non-condensing conditions (negative condensation potential), the moisture efficiency remains high only for sorption rotors, while it decreases significantly for hygroscopic rotors and vanishes for standard condensation rotors. The study supports recommendations presented in section 3.2.2 and also highlights that cooling energy savings discussed in section 5.1 only apply to sorption rotors. According to the Eurovent certification definitions, the term 'sorption rotor' may only be used for rotors whose humidity efficiency is at least 70% of the temperature efficiency under the certified conditions, while the term 'hygroscopic rotor' may only be used for rotors whose humidity efficiency is at least 20% of the temperature efficiency under certified conditions. For more information on the Eurovent Certification see section 6.

4.2.7 VOC and aerosol carry over

EATR must be taken into account. With suitable pressure conditions and purge sector the EATR can be reduced to 0%. A study by an independent laboratory[2] also demonstrated that the behaviour of aerosols can be described using EATR. For VOCs beside the EATR effect, an ongoing study shows that the transfer is strongly influenced by the pore size of the sorbent.

4.2.8 Performance control principle

Control of temperature and humidity transfer is possible by reducing the wheel rotation speed.

4.2.9 Possible issues to consider

As indicated in section 4.2.7, suitable pressure conditions are fundamental for a correct and safe operation of rotary heat recovery. Besides carry over, other leakages can be minimised with optimised sealing systems and regular maintenance.

4.2.10 Cleaning and maintenance

Due to the counter flow principle of operation rotors are very insensitive to dirt. However, dry dust can be removed with hoover and / or compressed air, sticky contaminations with compressed warm water and cleaning additives according to the need and manufacturer's instructions.

Other maintenance recommended as part of the AHU inspection cycles include visual inspection and adjustment of moving parts, seals, drive and drive belt.

[2] Measurements of Aerosol Transfer by Rotary Heat Exchangers. Report HP-212193, Hochschule Luzern, 2022

4.3 Alternate storage system

4.3.1 Physical sizes

- Width: from 1100 mm up to 8000 mm
- Height: from 800 mm up to 8000 mm
- Internal total length from 1640 to 1740 mm, length of the storage block is 500 mm or 600 mm
- Structure of the matrix: wave heights between 2.0 and 2.5 mm are available.

4.3.2 Air flow range

Face air velocity starting at 1 m/s up to 3 or 4 m/s depending on permissible pressure drop and the required efficiency.

4.3.3 Typical efficiency and pressure drop

At 2 m/s face air velocity.

- Temperature efficiency: 85% to 92%
- Humidity efficiency: 72% to 85% (with sorption coating)
- Pressure drop: 200 to 250 Pa

4.3.4 VOC and aerosol carry over

EATR has to be considered as carry over is inevitable in this type of exchanger. With suitable pressure conditions and preferred fan arrangement (suction-suction) EATR can be limited to values of about 2.5 %.

4.3.5 Performance control principle

Control of temperature and humidity transfer is possible by the adjustable cycle time. The shorter the cycle time (within the setting options) the higher the energy recovery performance. The minimum cycle time is 20 s.

5 Impact of humidity recovery on capacity demand and energy consumption

In many applications where the indoor humidity needs to be controlled, under appropriate climate conditions and operating scenarios, moisture recovery can provide significant savings, both in terms of running costs (reduced energy consumption) and capital costs (reduced power requirements and system size).

Clearly, the greater the difference between the moisture content of outdoor and indoor air, the greater the benefits that can be achieved. Potential savings for two common air handling processes, i.e. cooling and steam humidification, depending on climate and actual operating conditions, are discussed in following sections.

5.1 Cooling of air in summer

5.1.1 Reduction in cooling power demand

In a typical HVAC system, the outdoor air is first cooled in a heat recovery exchanger and then by a cooling coil to the desired supplied temperature. The capacity of the cooling coil and chiller are usually sized according to the coil's inlet air parameters for the design outdoor conditions, allowing for an appropriate safety margin. If a standard 'sensible only' heat exchanger is applied, the moisture content of the air at the cooling coil inlet will be the same as of outdoor air. However, if the (controlled) indoor moisture content is considerably lower than the design outdoor moisture content, the use of a moisture recovery exchanger will lower the moisture content at the cooling coil inlet and reduce the capacity demand needed to achieve the desired supply temperature. This is illustrated in Figure 9.

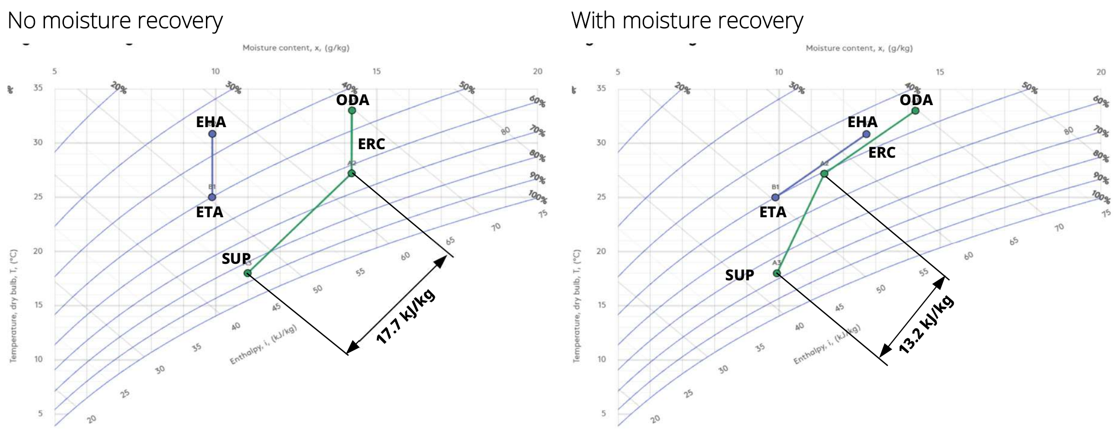

Figure 9. Comparison of required cooling coil capacity without (left) and with (right) moisture recovery. Diagrams plotted using www.mollier.swegon.com

Figure 9 refers to summer design conditions in Rome and compares the required cooling coil capacity with a standard rotary heat exchanger (η_t = 73%, η_x = 0) and a sorption rotary heat exchanger (η_t = 73%, η_x = 65%), further assuming a supply air (SUP) temperature of 18°C and the extract air (ETA) parameters of 25°C / 50%. In this case, by using a sorption rotor the required design capacity of the cooling coil can be reduced by 27 %.

Table 1 below presents a rough estimate of the potential reduction in the cooling coil capacity for different locations in Europe, due to using a sorption rotor with moisture recovery efficiency of 65% (η_t = 73%, η_x = 65%), instead of a condensation rotor of the same temperature efficiency but without moisture recovery (η_t = 73%, η_t = 0%). Potential savings are estimated for various SUP and ETA parameters.

Catania (IT) – Summer ODA[3]: 33.5°C/48%		
SUP	ETA = 25°C/50%	ETA = 23°/45%
22°C	-35%	-48%
20°C	-33%	-46%
18°C	-32%	-44%
16°C	-30%	-42%

Rome (IT) – Summer ODA[2]: 33°C/45%		
SUP	ETA = 25°C/50%	ETA = 23°/45%
22°C	-30%	-43%
20°C	-30%	-41%
18°C	-27%	-40%
16°C	-25%	-38%

[3] UNI 10339, Annex D

Barcelona (ES) – Summer ODA[4]: 30.3°C/52%		
SUP	ETA = 25°C/50%	ETA = 23°/45%
22°C	-31%	-44%
20°C	-29%	-42%
18°C	-27%	-41%
16°C	-26%	-39%

Madrid (ES) – Summer ODA[3]: 33.6°C/32%		
SUP	ETA = 25°C/50%	ETA = 23°/45%
22°C	-3%	-11%
20°C	-3%	-14%
18°C	-4%	-16%
16°C	-4%	-17%

North Germany – Summer ODA: 32°C/40%		
SUP	ETA = 25°C/50%	ETA = 23°/45%
22°C	-16%	-28%
20°C	-15%	-28%
18°C	-15%	-28%
16°C	-14%	-28%

Sweden – Summer ODA: 27°C/50%		
SUP	ETA = 25°C/50%	ETA = 23°/45%
22°C	-10%	-22%
20°C	-11%	-24%
18°C	-10%	-25%
16°C	-10%	-25%

Table 1. Estimate of the potential reduction in the cooling coil capacity for different locations in Europe and for various SUP and ETA parameters due to using a sorption rotor with moisture recovery efficiency of 65% (η_t = 73%, η_x = 65%), instead of a condensation rotor of the same temperature efficiency but without moisture recovery (η_t = 73%, η_x = 0). Source: own calculations.

The results presented in the tables, shows that the potential reduction in the capacity of cooling coils essentially depends on climate conditions. For this reason, an analysis of the benefits from using moisture recovery must be carried out on a case-by-case basis. In Europe, the greatest savings can be achieved in the warm and humid Mediterranean regions (e.g. Catania, Barcelona, Rome). In warm but dry climates (e.g. Madrid), they may not be as high as in coastal areas, while even in Nordic climates they may be worth considering.

It must be stressed that the estimated savings assume steady-state operating conditions, which is not usually the case in practice. A further conservative margin should therefore be taken into account when assessing the figures.

Nevertheless, it needs to be emphasised that moisture recovery may result in significant investment cost savings from reductions in:

- Cooling source power (typically the size of a chiller)
- Diameter of chilled water system pipes
- Volume of antifreeze agent in the pipe system
- Size of an AHU cooling coils
- AHU Fan power due to reduced air pressure on the cooling coil

[4] Guía técnica. Condiciones climáticas exteriores de Proyecto.

- Capacity (size) of cooling coils in terminal units (e.g. fan-coils).

5.1.2 Reduction in annual energy consumption for cooling

Lowered power demand for cooling obviously results in reduced energy consumption during the cooling season. To properly assess potential energy savings in systems with controlled indoor humidity, it is necessary to consider both the first stage cooling coil in the AHU (C1), and the second stage cooling coils in the terminal unit or AHU (C2). The first stage cooling coils processes the ventilation air to meet the required supply air temperature, which the second stage coil processes the indoor air to meet the set indoor moisture content depending on the outdoor air humidity. The analysis includes only ventilation airflow, although the flow rate through the second coil is higher (recirculation) as it also compensates internal heat and moisture gains. A scheme of the considered setup is presented in Figure 10 and the related processes are shown in Figure 11.

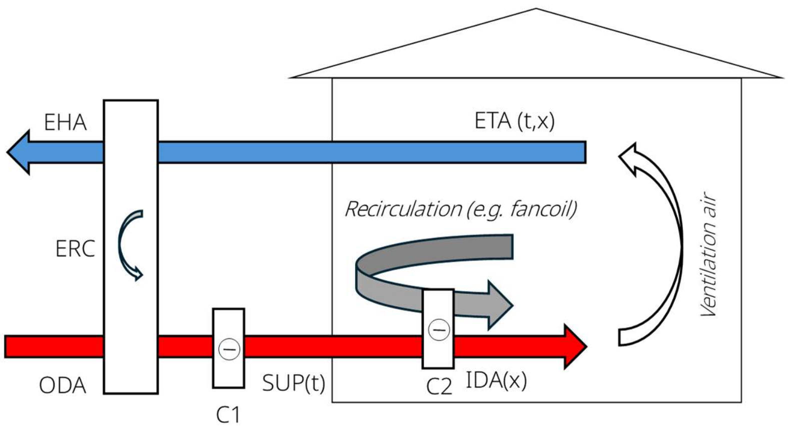

Figure 10. Scheme of the system considered for assessing cooling energy savings due to moisture recovery.

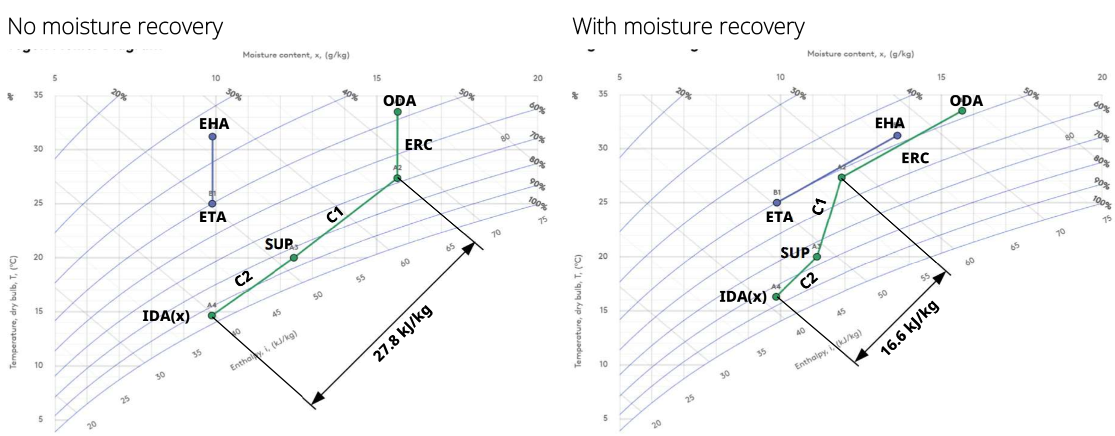

Figure 11. Air handling processes considered for assessing cooling energy savings due to moisture recovery. Design conditions for Catania. Left – without moisture recovery, Right - with moisture recovery. Diagrams plotted using www.mollier.swegon.com

Energy saving can be estimated based on degree-hour calculation for specific climate data, assumed supply and extract air parameters and operating times.

The order of magnitude of potential annual savings in consumption and costs of cooling energy due to moisture recovery is presented in Table 2 to Table 7. The tables compare energy use of a balanced systems with a standard rotary heat exchanger (no moisture recovery) and a temperature efficiency of 78%, and a system equipped with a sorption rotary exchanger with the same temperature efficiency and a moisture efficiency of 73%. Furthermore, for the sorption rotor option, energy consumption is shown separately depending on the moisture recovery control system - temperature-controlled and enthalpy-controlled, as this also has a significant impact (see section 5.1.4). Indicative annual energy consumption is shown in kWh/(m^3/s) so that it can be converted to actual flow rates. Values are provided for several example Mediterranean cities and for the following operating scenarios according to EN 16798-1:

Scenario 1 – operating time: Monday-Friday, 07:00 – 20:00h (e.g. schools or office buildings).

Scenario 2 – operating time: Monday-Sunday, 06:00 – 24:00h (e.g. restaurants and eating places).

Scenario 3 – operating time: 24/7 (e.g. hotels, residential buildings, hospitals).

Estimates have been calculated under the following additional assumptions:

Supply air temperature (constant):	20°C
Extract air temperature:	22°C for outdoor temperature up to 20°C. With outdoor temperatures higher than 20°C, the extract air temperature proportionally rises from 22°C to 25°C and maintains this value at an outdoor temperature of 25°C or higher
Extract air moisture content (constant)	10 g/kg
Cooling season:	May to October
Cooling generator efficiency (SEER)	3.5
Electricity cost	0.25 EUR/kWh

Estimated energy consumption was calculated based on the comprehensive methodology set out in Eurovent 6/19-1: Life Cycle Cost calculation for AHUs Part 1. Energy consumption [4].

Potential cost savings over the system lifetime were calculated as a present value (PV) for period (n) of 17 years and discount rate (r) of 3%, using the formula: $PV = \text{annual savings} \cdot ((1+r)^n - 1) / (r \cdot (1+r)^n)$

Scenario 1 - operating time: Monday-Friday, 07:00 – 20:00h

Annual consumption of cooling energy by rotor and control type.

	(1) Condensation rotor, temperature-controlled			(2) Sorption rotor, temperature-controlled			(3) Sorption rotor, enthalpy-controlled		
	C1	C2	Total	C1	C2	Total	C1	C2	Total
City	kWh/(m³/s)/a			kWh/(m³/s)/a			kWh/(m³/s)/a		
Athens	8,991	12,754	21,745	8,760	10,408	19,168	8,909	9,813	18,722
Barcelona	6,626	18,885	25,511	5,793	16,614	22,407	6,124	13,761	19,884
Catania	9,283	18,642	27,925	7,955	15,660	23,615	8,199	14,097	22,296
Lisbon	6,700	10,174	16,874	6,413	8,957	15,370	6,677	7,977	14,654
Marseille	5,948	12,210	18,159	5,874	10,562	16,435	6,096	9,055	15,151

Table 2. Comparison of energy consumption for Scenario 1

Potential reduction in annual cooling energy consumption and related energy cost savings over the system's lifetime (PV) due to application of enthalpy-controlled moisture recovery (3) compared to a non-moisture recovery and temperature-controlled system (1) presents the table below.

	(3) Sorption rotor, enthalpy-controlled		
	Reduction in energy use	Annual cooling energy savings	Lifetime cost savings
City	%	kWh/(m³/s)/a	EUR/(m³/s)/17Y
Athens	-14%	3,023	2,843 €
Barcelona	-22%	5,627	5,292 €
Catania	-20%	5,628	5,293 €
Lisbon	-13%	2,220	2,087 €
Marseille	-17%	3,008	2,828 €

Table 3. Estimated annual cooling energy and lifetime cost savings by location for scenario 1

Scenario 2 - operating time: Monday-Sunday, 06:00 – 24:00h

Annual consumption of cooling energy by rotor and control type.

	(1) Condensation rotor, temperature-controlled			(2) Sorption rotor, temperature-controlled			(3) Sorption rotor, enthalpy-controlled		
	C1	C2	Total	C1	C2	Total	C1	C2	Total
City	kWh/(m³/s)/a			kWh/(m³/s)/a			kWh/(m³/s)/a		
Athens	15,588	22,583	38,171	15,265	18,874	34,139	15,566	17,196	32,761
Barcelona	11,145	33,674	44,820	9,910	30,393	40,302	10,261	24,374	34,635
Catania	15,927	34,252	50,179	13,552	30,017	43,569	13,691	25,713	39,404
Lisbon	9,737	17,508	27,245	9,352	15,646	24,998	9,878	13,494	23,372
Marseille	9,879	21,331	31,211	9,622	18,976	28,598	10,086	15,855	25,941

Table 4. Comparison of energy consumption for Scenario 2

Potential reduction in annual cooling energy consumption and related energy cost savings over the system's lifetime (PV) due to application of enthalpy-controlled moisture recovery (3) compared to a non-moisture recovery and temperature-controlled system (1) presents the table below.

	(3) Sorption rotor, enthalpy-controlled		
	Reduction in energy use	Annual cooling energy savings	Lifetime cost savings
City	%	kWh/(m³/s)/a	EUR/(m³/s)/17Y
Athens	-14%	5,410	5,087 €
Barcelona	-23%	10,184	9,578 €
Catania	-21%	10,776	10,134 €
Lisbon	-14%	3,873	3,642 €
Marseille	-17%	5,269	4,956 €

Table 5. Estimated annual cooling energy and lifetime cost savings by location for scenario 2

Scenario 3 - operating time: 24/7

Annual consumption of cooling energy by rotor and control type.

	(1) Condensation rotor, temperature-controlled			(2) Sorption rotor, temperature-controlled			(3) Sorption rotor, enthalpy-controlled		
	C1	C2	Total	C1	C2	Total	C1	C2	Total
City	kWh/(m³/s)/a			kWh/(m³/s)/a			kWh/(m³/s)/a		
Athens	18,206	28,320	46,526	17,867	24,377	42,244	18,382	21,464	39,846
Barcelona	12,277	40,605	52,882	10,994	37,277	48,271	11,479	29,362	40,841
Catania	16,851	39,571	56,423	14,467	35,327	49,793	14,790	29,443	44,234
Lisbon	9,823	18,408	28,231	9,438	16,547	25,984	10,035	14,132	24,167
Marseille	10,549	25,107	35,656	10,292	22,750	33,042	10,925	18,717	29,642

Table 6. Comparison of energy consumption for Scenario 3

Potential reduction in annual cooling energy consumption and related energy cost savings over the system's lifetime (PV) due to application of enthalpy-controlled moisture recovery (3) compared to a non-moisture recovery and temperature-controlled system (1) presents the table below.

	(3) Sorption rotor, enthalpy-controlled		
	Reduction in energy use	Annual cooling energy savings	Lifetime cost savings
City	%	kWh/(m³/s)/a	EUR/(m³/s)/17Y
Athens	-14%	6,681	6,283 €
Barcelona	-23%	12,041	11,324 €
Catania	-22%	12,189	11,463 €
Lisbon	-14%	4,064	3,822 €
Marseille	-17%	6,014	5,656 €

Table 7. Estimated annual cooling energy and lifetime cost savings by location for scenario 3

5.1.3 Example of estimating financial benefits

This section shows the way to evaluate the financial viability of investments in moisture recovery. Using the operating scenarios and estimates presented is section 5.1.2, a balanced ventilation system serving a restaurant in Barcelona is considered. The design airflow rate of an air handling unit is 5,000 m^3/h (1.39 m^3/s). According to Table 5, by applying in the air handling unit a enthalpy-controlled sorption rotor (η_t = 78%, η_x = 73%) instead of a temperature-controlled condensation rotor (η_t = 78%, η_x = 0), the annual consumption of cooling energy can be reduced by 1.39 · 10,184 = 14,144 kWh/a. In terms of reducing electricity costs, assuming an electricity price of 0.25 EUR/kWh and a seasonal efficiency of a chiller (SEER) of 3.5, the annual saving is 0.25 · 14,144 / 3.5 = 1,010 EUR per year. On the other hand, sorption rotors feature a higher pressure drop than condensation rotors, which must be consider as additional cost. Assuming that in this case the additional pressure drop (on both sides) amounts to 20 Pa, total efficiency of a fan is 60% and it operates 6570h per year (scenario 2), the additional electricity consumption is $6570 \cdot 1.39 (20+20) \cdot 10^{-3} / 0.6 = 608$ kWh/a, which corresponds to additional electricity cost of 0.25 ·608 = 152 EUR per year.

Thus, the effective savings in running cost can be estimated at 1,010 – 152 = 858 EUR per year.

This figure, when compared with the increase in investment cost (which basically is the difference in the purchase cost of an AHU with the enthalpy-controlled sorption rotor and an AHU with the standard temperature-controlled rotor), provides a simple estimate of the payback time of the higher investment cost.

To complement the payback time information, in order to get a complete picture of the benefits over the lifetime of the system, the Present Value (PV) of the savings can be estimated using the following formula:

$$PV = \text{annual savings} \cdot ((1+r)^n - 1) / (r \cdot (1+r)^n)$$

The Present Value is the discounted sum of the difference in annual energy costs for a system with and without moisture recovery for a given lifetime of the air handling (n) unit and a discount rate (r).

Assuming the typical AHU lifespan of 17[5] years and discount rate of 3%, the Present Value of savings for the example in question amounts to:

$$PV = 858 \cdot ((1+0.03)^{17} - 1) / (0.03 \cdot (1+0.03)^{17}) = 11{,}297.00 \text{ EUR in 17 years.}$$

5.1.4 Control of moisture recovery in summer

The way of controlling the operation of the moisture-recovery heat exchangers has a crucial impact on cooling energy savings. While in winter operation it is correct to control the exchanger operation according to temperature, in summer with a small temperature difference but a large enthalpy difference between the ODA and ETA air, enthalpy control results in much higher savings. This is illustrated in Figure 12. Diagrams show the real conditions for Lisbon in late May.

The left-hand chart is for a temperature-controlled system. As the outdoor temperature (ODA) is lower than the extract air (ETA) temperature, the recovery exchanger will not be activated, and the outdoor air will be cooled first by the AHU coil (C1) and then by the terminal device coil (C2) to meet the set indoor humidity. For these particular conditions, the required enthalpy reduction by both cooling coils is 11.7 kJ/kg.

[5] The typical AHU lifetime assumed in the studies of Ecodesign requirements for ventilation units.

The right-hand chart illustrates the process for an enthalpy-controlled system. As the extract air enthalpy is lower than the outdoor enthalpy, the exchanger will be activated. Although the supply air temperature downstream the exchanger (22) will be higher than the outside temperature, the required enthalpy reduction by both coolers is 10.8 kJ/kg and lower than for the temperature-controlled system.

Given the large number of operating hours with conditions favourable to enthalpy-based control, the annual cooling energy savings from this control mode are considerable (see 5.1.2).

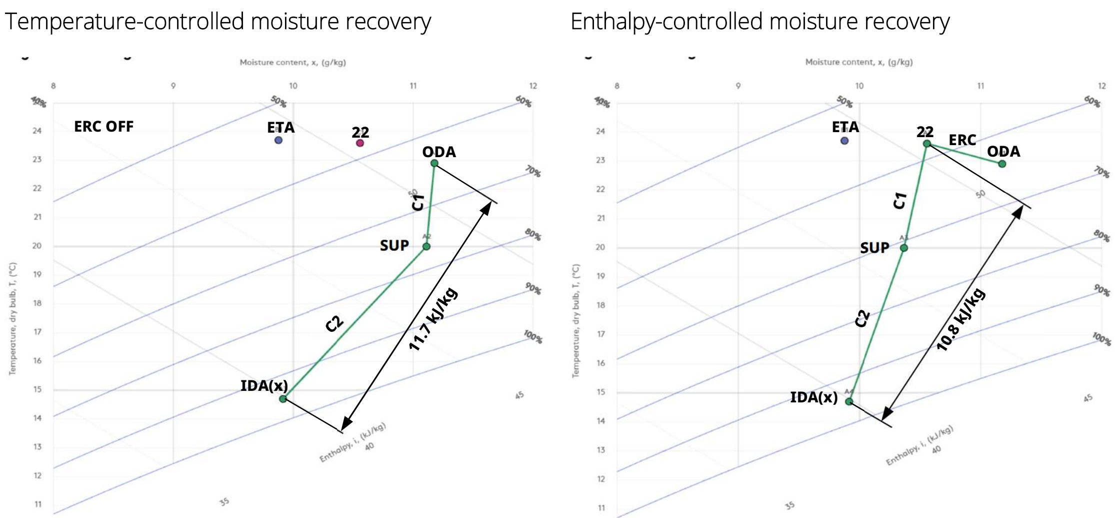

Figure 12. Air handling processes for temperature-controlled (left) and enthalpy-controlled (right) moisture recovery

5.2 Humidification of air in winter

Humidification of supply air may be necessary in comfort and industrial applications which require indoor air humidity control in winter, typically in cold and dry climates. Humidification, in particular electric steam humidification, is a very energy consuming process. Moisture recovery exchangers can significantly reduce the demand for humidification capacity and energy consumption, making use of moisture generated indoors. The magnitude of potential savings in the humidification capacity is presented in Figure 13. It compares the required capacity of a steam humidifier to reach a supply air relative humidity of 30%, in a system without moisture recovery and a system with a sorption rotor with a moisture recovery efficiency of 65%, assuming that internal gains result in the increase of indoor temperature and relative humidity to 22°C / 35%.

As illustrated in the graphs, the reduction in the humidification capacity may be considerable. Further, under some operating conditions, in particular at a higher moisture contend in outdoor and indoor air, the need for humidification could be eliminated by moisture recovery.

Without moisture recovery With moisture recovery

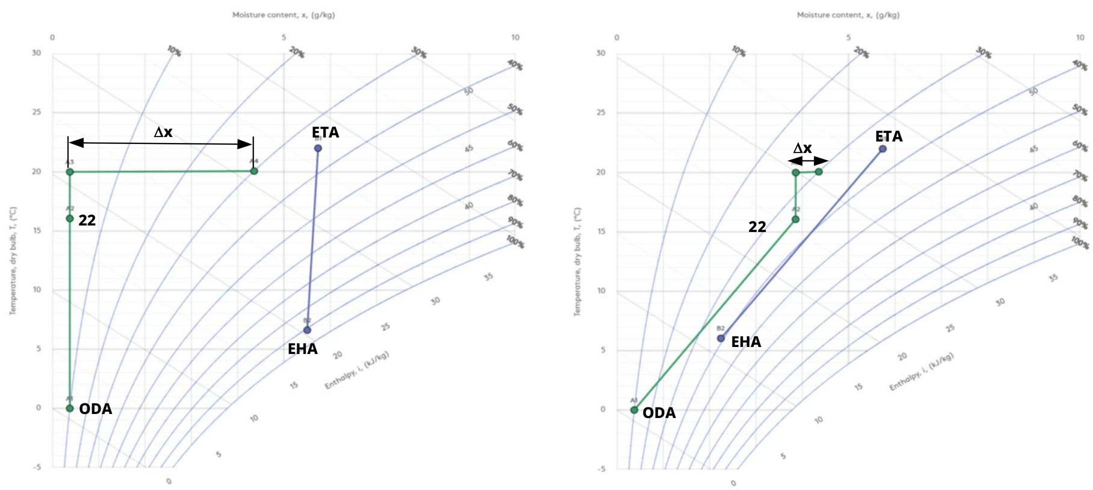

Figure 13. Comparison of a required steam humidifier capacity (Δx) without moisture recovery (left) and with moisture recovery (right) . Diagrams plotted using www.mollier.swegon.com

5.2.1 Reduction in annual energy consumption for electric steam humidification

Similar to cooling, the annual energy savings required for humidification can be estimated based on degree-hour calculations for specific climate data and assumed operation scenarios.

Comparisons of electricity consumption needed to humidify 1 m^3/s of supply air for a system with a sorption rotary heat exchanger (η_t = 73%, η_x = 65%) compared to a system with a heat exchanger of the same temperature efficiency but without moisture recovery, for the climates of Stockholm and Frankfurt, are shown in the tables below. The calculated values assume a balanced airflow rate and are presented for the same operating time scenarios as in section 5.1.2. Energy consumption is estimated for two different set points for the supply air (SUP) humidity: 25% and 30% at a constant temperature of 20°C and for different parameters of the extract air (ETA). The humidification season is from November until March (included). Calculations are based on the comprehensive methodology set out in Eurovent 6/19-1: Life Cycle Cost calculation for AHUs Part 1. Energy consumption [4].

Scenario 1 - operating time: Monday-Friday, 07:00 – 20:00h

Frankfurt	Annual electric energy for steam humidification, kWh/(m^3/s)/a			
	ETA: 22°C / 35%		22°C / 30%	
SUP set point	η_t = 73% η_x = 65%	η_t = 73% η_x = 0	η_t = 73% η_x = 65%	η_t = 73% η_x = 0
20°C / 25%	No demand	1,720	No demand	1,720
20°C / 30%	14	4,469	339	4,469

Stockholm	Annual electric energy for steam humidification, kWh/(m³/s)/a			
	ETA: 22°C / 35%		22°C / 30%	
SUP set point	η_t = 73% η_x = 65%	η_t = 73% η_x = 0	η_t = 73% η_x = 65%	η_t = 73% η_x = 0
20°C / 25%	No demand	3,189	17	3,189
20°C / 30%	102	5,932	1,011	5,932

Table 8. Potential electricity savings for humidification by location due to moisture recovery for scenario 1

Scenario 2 - operating time: Monday-Sunday, 06:00 – 24:00h

Frankfurt	Annual electric energy for steam humidification, kWh/(m³/s)/a			
	ETA: 22°C / 35%		22°C / 30%	
SUP set point	η_t = 73% η_x = 65%	η_t = 73% η_x = 0	η_t = 73% η_x = 65%	η_t = 73% η_x = 0
20°C / 25%	No demand	2,223	2	2,223
20°C / 30%	26	5,505	713	5,505

Stockholm	Annual electric energy for steam humidification, kWh/(m³/s)/a			
	ETA: 22°C / 35%		22°C / 30%	
SUP set point	η_t = 73% η_x = 65%	η_t = 73% η_x = 0	η_t = 73% η_x = 65%	η_t = 73% η_x = 0
20°C / 25%	No demand	6,260	37	6,260
20°C / 30%	216	11,487	1,977	11,487

Table 9. Potential electricity savings for humidification by location due to moisture recovery for scenario 2

Scenario 3 - operating time: 24/7

Frankfurt	Annual electric energy for steam humidification, kWh/(m³/s)/a			
	ETA: 22°C / 35%		22°C / 30%	
SUP set point	η_t = 73% η_x = 65%	η_t = 73% η_x = 0	η_t = 73% η_x = 65%	η_t = 73% η_x = 0
20°C / 25%	No demand	3,099	2	3,099
20°C / 30%	31	7,658	974	7,658

Stockholm	Annual electric energy for steam humidification, kWh/(m^3/s)/a			
	ETA: 22°C / 35%		22°C / 30%	
SUP set point	η_t = 73% η_x = 65%	η_t = 73% η_x = 0	η_t = 73% η_x = 65%	η_t = 73% η_x = 0
20°C / 25%	No demand	8,469	56	8,469
20°C / 30%	292	15,432	2,669	15,432

Table 10. electricity savings for humidification by location due to moisture recovery for scenario 3

It must be stressed that estimation results presented in Table 8 to Table 10 above assume constants steady-state operation, which is not the case in practice. Therefore, the theoretical conclusion of no demand for humidification in some cases, should not be interpreted as no need for installing a humidifier.

6 Certified performance of heat and moisture recovery

The credibility of the declared performance of heat and moisture recovery exchangers is fundamental to achieving the energy savings and improved indoor environmental quality discussed in this document.

For this reason, when planning the investment and designing the system, it is important to ensure that the performance of the products to be installed is independently verified and that the expected effects will be achieved.

There is no legal requirement to involve an independent third-party to verify performance of products, and manufacturers can simply self-declare it. This does not provide a high confidence level.

To increase the level of reliability, manufacturers can provide a sample test report from an ISO17025 accredited laboratory. However, this does not eliminate the risk of sample manipulation and does not provide confidence that reliable results apply to all products.

The highest level of confidence is ensured by the voluntary certification by independent ISO 17065 accredited bodies. The leading and worldwide acknowledged certification body for HVAC&R products in Eurovent Certita Certification (ECC).

Among many certification programs, ECC runs dedicated programs for:

- Rotary Heat Exchangers[6] - AARE
- Plate Heat Exchangers[7] - AAHE

Details of these programs and the exact scope of certified parameters can be found on their websites (see footnotes). General information about ECC and a public list of all certified products are available at www.eurovent-certification.com.

[6] https://www.eurovent-certification.com/en/third-party-certification/certification-programmes/aare
[7] https://www.eurovent-certification.com/en/third-party-certification/certification-programmes/aahe

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[4] Eurovent 6/19-1 - 2024 - Life Cycle Cost calculation for AHUs. Part 1. Energy consumption. Brussels: Eurovent, 2024 (https://www.eurovent.eu/publications/eurovent-6-19-1-2024-life-cycle-cost-calculation-for-ahus-part-1-energy-consumption/)

[5] EN 308:2022 - Heat exchangers - Test procedures for establishing performance of air to air heat recovery components.

[6] EN 16798-1:2019 - Energy performance of buildings - Ventilation for buildings - Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics

About Eurovent

Eurovent is the voice of the European HVACR industry, representing over 100 companies directly and more than 1.000 indirectly through our 16 national associations. The majority are small and medium-sized companies that manufacture indoor climate, process cooling, and cold chain technologies across more than 350 manufacturing sites in Europe. They generate a combined annual turnover of more than 30 billion EUR and employ over 150.000 Europeans in good quality tech jobs.

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