ROOFTOP UNITS

GUIDEBOOK

PREFACE

This Guidebook provides a comprehensive overview of the rooftop technology. It gives an insight into types, design, applications, operation, selection and maintenance of rooftop units. It is a must-read for designers, contractors and investors involved in the HVAC sector.

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Contents

List of abbreviations and symbols

AHU	Air Handling Unit
BMS	Building Management System
CAV	Constant Air Volume
CEN	The European Committee for Standardization
CO_2	Carbon Dioxide
DCV	Demand Controlled Ventilation
EMI	Eurovent Market Intelligence EU European Union
GWP	Global Warming Potential
HVACR	Heating, Ventilation, Air Conditioning and Refrigeration
IAQ	Indoor Air Quality
IEQ	Indoor Environmental Quality
PG-RT	Eurovent Product Group 'Rooftop Units'
PM	Particulate Matter
ppm	Parts per Million
RTU	Rooftop Unit
VAV	Variable Air Volume
VFD	Variable Frequency Drive
VOC	Volatile Organic Compound
VSD	Variable Speed Drive

List of definitions

Extract air (ETA)
Air leaving the air conditioned space and entering the unit; the extract air may be mixed with outdoor air as recirculated air, or it may enter a heat recovery device to enhance the efficiency of the unit

Exhaust air (EHA)
Air from the air conditioned space discharged outdoors, which may enter the outdoor heat exchanger beforehand

Outdoor air (ODA)
Air from the outdoor environment

Supply air (SUP)
Air leaving the indoor heat exchanger for entering the space that is to be air conditioned

1. Introduction

1.1 What are rooftop units for and why do we need them?

Nowadays, on average we spend 90% of our time indoors. At first, this figure may seem overstated, but when we realise how much time we spend at work, at school, in shops, in cafés, in restaurants, in cinemas, in theatres, in sports clubs and, finally, at home, the number adds up.

For this reason, we should expect a very good indoor climate in buildings, which in technical terminology is called Indoor Environmental Quality (IEQ).

IEQ has a fundamental impact on our health, wellbeing and productivity, which for example means high work performance and high learning effectiveness for children.

Providing high IEQ entails significant energy consumption, thus technologies delivering IEQ must ensure very high energy efficiency, low carbon dioxide (CO_2) emissions and be environmentally friendly. The rational investment cost of such technologies is also very important.

Two main elements of IEQ are the thermal comfort (adequate temperature and humidity) and Indoor Air Quality (IAQ). Ensuring high IAQ involves proper air renewal in the building and suitable air filtration, while maintaining appropriate thermal comfort indoors means providing energy for heating and cooling. More specifically, this energy is needed for:

- Conditioning the outdoor air supplied to the building.
  This process includes heating, cooling and where required, also humidification and/or dehumidification.
- Compensating the heat losses and heat gains of a building, in other words, the energy transferred through the building envelope due to temperature difference, heat load from electric equipment, or solar radiation.

Rooftop units (RTUs) are compact and standalone devices incorporating all the components needed for efficient air renewal and indoor thermal comfort, control, as well as for the generation of cooling and heating capacity.

For many building types and applications, rooftop units are therefore the best option for a complete HVACR system solution that replaces separate heating, cooling, ventilation and control systems, while maintaining high energy efficiency, operating reliability and low investment costs.

Rooftop units can be fitted with high efficiency air filters to remove harmful particulate matter (PM) from the air supplied to the building, as well as eliminate disease- causing pathogens in the recirculating air.

The advantages and benefits of rooftop units, their construction, selection and many more useful information are presented in the following sections of this Guidebook.

1.2 What does thermal comfort mean?

Thermal comfort, which is essentially determined by a combination of temperature and relative humidity, means conditions that are perceived by people as satisfactory. It has a fundamental impact on wellbeing, health and productivity.

1.2.1 Optimal thermal comfort

There is no universal ideal thermal comfort that satisfies everyone and applies to all environments, as there are several factors that influence the perception of comfort. These include, for instance, type of clothing and its insulation, level of activity, air velocity and time of year. Furthermore, each human being perceives the comfort differently.

For this reason, PMV and PPD indices are used in the assessment of thermal comfort. Predicted mean vote (PMV) is an index that predicts the mean value of votes of a group of occupants on a thermal sensation scale. Zero on the scale indicates neutral conditions, while the extreme value of +3 indicates a hot perception, and -3 a cold perception. PPD stands for the predicted percent of disaffected people. Based on these two indices, general criteria for thermal comfort design can be defined.

The major European standard for the assessment of thermal environment, EN 16798-1, defines four categories for the indoor thermal comfort. The best category I assumes PPD < 6% and PMV within a range of -0,2 to +0,2, which means that the average perception of conditions will be close to neutral and only up to 6% of occupants will be dissatisfied. The worst category IV instead assumes PPD < 25% and PMV within a range of -1,0 to +1,0.

The recommended thermal comfort parameters in more practical terms, i.e., the ranges of acceptable temperature and humidity values, are usually given in the national building regulations depending on various factors such as building type, activity level and season. If

this information is not available, the default values of EN 16798-1 for typical buildings can be used. For example, for offices and spaces with similar activity (conference room, auditorium, cafeteria, restaurants, classrooms) the following default design values for buildings with mechanical cooling systems are given:

- Minimum indoor temperature for winter:
  21°C (category I) and 18°C (category IV)
- Maximum indoor temperature for summer:
  25,5°C (category I) and 28°C (category IV)

Regarding the humidity range in occupied spaces, if humidification or dehumidification system are installed, the recommendations are following:

- Maximum relative humidity (to start dehumidification):
  50% (Category I) and 70% (category III)
- Minimum relative humidity (to start humidification):
  30% (category I) and 20% (category III)

For specific applications such as production facilities and warehouses, thermal comfort conditions must be determined individually by the designer in cooperation with the developer and the process engineer.

1. Introduction

1.2.2 Impact on wellbeing, health and productivity

Numerous studies conducted over the past several years gave clear evidence of the direct and strong correlation between thermal comfort and wellbeing, health, and productivity. It was proven that, in general, too high temperature reduces mental work efficiency while too low temperature reduces manual work performance. Inadequate thermal comfort, even within physiologically acceptable limits, can reduce productivity by 5-15%[1] and result in increased number of accidents at work. The relationship between thermal comfort, wellbeing, and productivity is not only limited to the workplace. Student performance, especially among children, can be significantly influenced by thermal comfort, and, according to some studies, decreased by as much as 25%[2]. For these reasons, ensuring thermal comfort is crucial and the related investment pays off in a short time. It is worth remembering that a 5% increase in productivity means a 25 minute longer working day, and a 12% increase in student learning performance means one extra year of education.

Regarding the impact on health, exposure to cold air and rapid temperature changes can trigger asthma, while cold and dry environments can facilitate the spread of viruses such as influenza. In turn, overly warm and humid conditions are associated with respiratory issues and fatigue.

1.3 What does IAQ mean?

Indoor Air Quality (IAQ) refers to the degree of cleanliness of air in indoor spaces. The pollutants that affect IAQ are gases and particulate matter (PM). The main gaseous pollutants of relevance to general ventilation are carbon dioxide (CO_2) and volatile organic co mpounds (VOCs). PM is a complex mixture of solid and liquid particles of organic and inorganic substances suspended in the air, including black carbon, mineral dust, combustion particles, as well as airborne disease-causing pathogens.

1.3.1 How does the CO_2 level affect IAQ?

The main source of indoor pollution in public buildings is the people themselves, who use oxygen from inhaled air to produce energy, and emit carbon dioxide (CO_2), water vapor, as well as other metabolic products. In one day, the average person breathes out around 500 litres of CO_2. If there is no sufficient renewal of contaminated indoor air with clean outdoor air, the CO_2 concentration in the room increases and can reach level that is hazardous to health. It is widely recognised that without proper ventilation, indoor CO_2 concentration can be more than 10 times higher than in the outdoor air. Given that a typical CO_2 level in outdoor air is 350-450ppm, this means that the CO_2 concentration in a poorly ventilated room may reach well over 4.500ppm. The generally acknowledged CO_2 level for satisfactory IAQ ranges between 600-800ppm, while 1.000ppm is considered the upper acceptable range. An increase above 1.500ppm causes a rapid loss of concentration and productivity or a feeling of drowsiness. 5.000ppm is a maximum concentration for specific workplaces. Concentrations above 6.000ppm are critical and may be hazardous to health, including increased breathing frequency, headaches, nausea and loss of consciousness (at concentrations > 10%).

Due to the crucial impact of CO_2 on human wellbeing and health, its concertation is used as one of the main indicators of IAQ. Since the indoor CO_2 emission is directly linked to the number of room occupants, CO_2 sensors are used to adjust the amount of supplied outdoor air to the actual demand, to maintain the indoor CO_2 concentration at the required level and minimise energy consumption needed for outdoor air treatment.

Another significant indoor pollutant affecting IAQ is volatile organic compounds, which are emitted from building materials and furnishings, but also from several other sources such as aerosol sprays, cleaners and disinfectants, or office equipment (printers or copiers). VOC sensors can also be used to adjust ventilation rates to current demand.

In many EU Member States, the use of CO_2 and VOC sensors is, or will soon become mandatory.

[1] K. Parson Human thermal environments. The effects of hot, moderate and cold environments on human health, comfort and performance. Taylor&Francis, 2003
[2] P. Wargocki, J.A. Porras-Salazar, S. Contreras-Espinoza, The relationship between classroom temperature and children's performance in school, Build. Environ. 157 (2019) 197—204

Key learning points

- Nowadays, people spend most of their time indoors, which entails the need for high Indoor Environmental Quality in buildings.
- Indoor Environmental Quality has a key impact on wellbeing, health and productivity. It encompasses thermal comfort and Indoor Air Quality.
- Thermal comfort means satisfying temperature and humidity, while the main indicators of good Indoor Air Quality are the CO_2 level and PM concentrations.
- Stand-alone rooftop units are capable to provide thermal comfort and Indoor Air Quality in many types of buildings without the need of employing other HVAC systems.

1.3.2 Efficient air filtration for high IAQ

Another key reason for IAQ deterioration is outdoor air pollutants entering interiors. Besides volatile chemical compounds, these are harmful fine particulate matter including smog, fine dust, pollen, bacteria, and moulds along with other organic and inorganic hazardous particles. This aspect is particularly important where outdoor air quality is poor, which is the case in most urban and industrial areas. There are also indoor PM emissions from, for example, cooking or combustion.

The effects of particulate matter on human health have been extensively studied in the past. The results showed that fine dust can be a serious health hazard. The most important diseases which were associated with exposures to PM contamination in indoor air are allergy and asthma, lung cancer, cardiovascular diseases, chronic obstructive lung disease and dementia. It was evidenced that the smaller the particle size range, the higher health hazard. PM_{10} particles (diameter ≤ 10µm) can reach the respiratory ducts and cause decreased lung function, while PM1 particles (≤ 1µm) are tiny enough to enter the bloodstream and lead to cancer, cardiovascular diseases and dementia.

Depending on the outdoor air quality and indoor emissions, rooftop units can be equipped with high efficiency filters that remove PM particles from the air before it is delivered to the building, to ensure high IAQ and eliminate the indicated health hazard. Thanks to filters installed in the RTU, both the outdoor (from outdoor air) and indoor (from recirculation air) pollutants are effectively removed.

The class of applied filters depends on the ambient environment pollution and the specific building application.

For more information on the selection of ISO 16890 rated air filters, see the related Eurovent Recommendation 4/23.

2. What is a rooftop unit?

2.1 A bit of history of rooftop units

The first air conditioners were developed at the beginning of the 20th century. Freon-based refrigerant was invented in the late 1920s. This gave birth to the era of domestic air conditioners. End of the 1960s brought us rotary compressors which are still used in the refrigeration industry. Building on this experience, the first rooftop units were developed in the 1980s.

In the past, rooftop units were initially synonymous with low-cost and unsophisticated HVAC solutions. With constant airflow rates, manual on/off, basic components and no integrated smart controllers, these devices were neither energy efficient nor easy to control. These shortcomings are not the case anymore. Today, rooftop units are state of the art HVAC devices offering very high energy efficiency and flexible performance adjustment to the operating conditions. Built-in smart controls are compatible with any building management system (BMS), which means that due to sensor readings and intelligent management features, rooftop units are configurable and can adapt their outputs to the weather condition and the environments they serve.

2.2 The purpose of rooftop units

The main task of rooftop units is air-based full demand space cooling and heating for the thermal comfort of human beings, while units supplying outdoor air for ventilation also provide proper IAQ.

These objectives may be alternatively achieved by means of separate systems that combine different technologies. However, such an approach often entails challenges in adapting the individual systems to actual needs. It also involves higher complexity of the project and construction.

The compact design, low installation space requirements and versatile features of rooftop units in many cases simplify the design and fitting of the HVAC system.

2.3 The 'heart' of a rooftop unit

The key building blocks of a rooftop unit include the below mentioned parts.

2.3.1 Refrigeration circuit

The refrigeration circuit is the most important element of the rooftop unit. Very often it can work as a reversible cycle for both cooling and heating purposes. The most common refrigeration cycle consists of the main components such as compressor, evaporator, condenser, expansion valve and, of course, a refrigerant. In case of air-to-air systems, outdoor fans also are part of the circuit. These elements are used for thermodynamic processes that change supply air parameters.

2.3.2 Fans and economiser

Second part of the rooftop unit is the section consisting of fans and an economiser. These components ensure that thermal energy and outdoor air are delivered to the room. The supply fan generates airflow to distribute heat from refrigeration cycle and supply outdoor air. The economiser additionally allows free cooling functionality which means that the rooftop unit can increase amount of outdoor air to reduce energy consumption for room cooling.

This section also includes air filters to purify the outdoor and recirculation air supplied to the building.

2.4 Types of rooftop units

Rooftop units condition and distribute air within the building. They extract air from the building, mix it with outdoor air for ventilation, remove particles from it through filters, heat it or cool it in the indoor exchanger, and then force it through ductwork to the designed areas within the building by means of fans.

The main types of rooftop units are explained below. Presented diagrams are illustrative and the indicated location of air inlets and outlets is exemplary. In practice, rooftop units provide various options for duct connections arrangement, which facilitates adjustment to the ductwork layout.

2.4.1 Full recirculation units

Where ventilation is provided by other systems or sufficient infiltration, full recirculation rooftop units can be used. This type of unit does not supply outdoor air and solely serves for conditioning the indoor air.

2.4.2 Units with supply fan and recirculation

In case of basic units with supply fan and recirculation, which deliver outdoor air but do not exhaust air, overpressure is generated in the building. The higher the outdoor air rate for ventilation or free cooling, the higher the overpressure. This will not cause any issues in buildings with low air tightness and/or with doors frequently opened, however, this solution should be avoided in other applications.

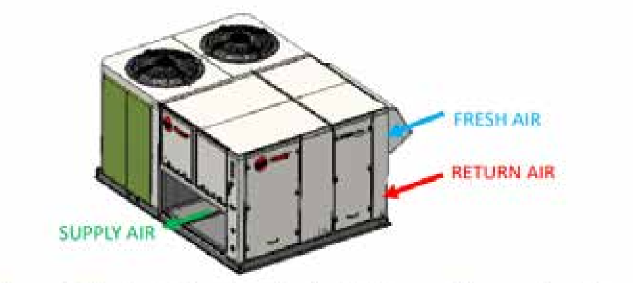


Figure 8.2 Horizontal supply – Horizontal return airflow configuration

2.4.3 Units with supply fan, recirculation and exhaust air

In applications where pressure balance in the building needs to be managed to prevent infiltration, rooftop units with an exhaust air section are used. This kind of unit can be equipped with an extract fan if the pressure balance must be controlled within a certain value.

2.4.4 Unit with supply fan, extract fan, recirculation and energy recovery

For further enhancement of energy efficiency, particularly in applications with a high ratio of outdoor air, rooftop units can integrate components for energy recovery from exhaust air, like a rotary heat exchanger, an additional refrigeration circuit or a dedicated exchanger integrated in the main refrigerant circuit. A way of energy recovery is also diverting exhaust air to the outdoor exchanger before it is ejected outdoors, which increases efficiency of the refrigeration circuit.

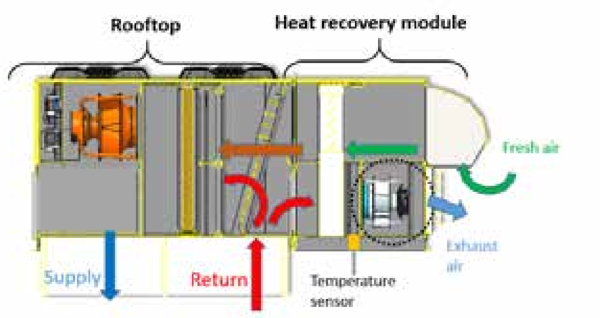


Figure 12.2.4 : Energy recovery module + temperature sensor

2. What is a rooftop unit?

Table 1: Overview of general features of the respective rooftop unit types

Unit Type		Supply fan and only recirculation	Supply fan and recirculation	Supply fan, recirculation and exhaust air		Supply fan, extract fan, recirculation and energy recovery
Feature						
Component and functions	Outdoor air	NO	YES	YES		YES
	Exhaust air	NO	NO	YES		YES
	Extraction fan	NO	NO	NO	YES	YES
	Passive Heat recovery[3]	NO	NO	NO	NO	YES
Advantages		Low-cost and simplicity	Low-cost and simplicity	Low-cost and simplicity Low overpressure (recommended only if pressure drop in extraction ductwork is low)	Pressure balance & possibility to manage a specific overpressure Thermodynamic heat recovery possible	Energy savings thanks to energy recovery systems (passive and/or thermodynamic)
Disadvantages		No ventilation	Overpressure (although it can be avoided with gravity dampers in the building) No passive or thermodynamic heat recovery	No passive or thermodynamic heat recovery	No passive heat recovery	Higher investment cost and complexity of the unit
Typical applications		Buildings where ventilation is provided by other systems or infiltration	Buildings with medium or low air tightness, doors frequently opened, and/ or gravity dampers	Installations with low pressure drop in the extraction ductwork	Installations where it is key to ensure pressure management	Installations where energy saving is the priority
Examples of applications		Warehouses and data centres (limited to no occupation)	Manufacturing and high street retail applications (limited occupation with sliding doors and or local extraction)	Larger malls and gyms (high occupation with need of fresh air)		Educational facilities, cinemas and auditoriums (maximising the fresh air intake, while optimising energy efficiency)

2.5 Differences between rooftop units and air handling units

At the design concept stage, the alternative use of rooftop units or air handling units (AHUs) is often considered. The following section explains major differences between these two types of devices to facilitate the right choice for a specific case.

Air handling units are typically designed to supply 100% of outdoor air to the rooms for ventilation and to provide high IAQ. Use for space heating and cooling is also possible. External generators like boilers for heating and chillers for cooling of the supply air are usually needed, but AHUs with integrated or packaged heat pumps are an available option. For correct thermal comfort indoors, AHUs can easily be integrated in advanced systems with devices such as radiators, fan coils and air conditioners.

AHUs are suitable for complex centralised multi-zone systems, as well as for small decentralised applications with low air volumes. AHUs may be installed indoors or outdoors. Because AHUs can be custom designed, they are easily adaptable to customers, service and hygienic requirements.

Rooftop units are intended to provide correct thermal comfort by means of air-based space heating and cooling, and to supply enough outdoor air to provide good IAQ. They are intended for use in applications where recirculation of air is acceptable.

Rooftop units are packaged devices with an embedded refrigeration system and other components needed for autonomous operation. They feature compact dimensions and easy installations outdoors, usually on the roof. Typically, rooftop units are suitable for medium to large volume buildings with a limited number of control zones.

Table 2: Typical and major differences between rooftop units and AHUs (non-residential ventilation units)

Feature	Rooftop units	Air handling units
Purpose	Providing thermal comfort and IAQ	Primarily providing IAQ but also suitable for both IAQ and thermal comfort
Outdoor air supply	Typically operating with recirculated air and outdoor air ratio of around 30%, which may be increased up to 100% at appropriate conditions	Typically 100%
Cooling and heating sy stem	Always embedded and used to provide full capacity for thermal comfort in the building	Optional and typically for conditioning the ventilation air
Design	Compact design	Modular/compact design
Controls	Always embedded	Typically embedded at compact design and optional at modular design
Heat recovery	Optional	Always used (bidirectional units)
Extract fan	Optional	Always used (bidirectional units)
Ecodesign requirements	Regulation (EU) 2016/2281	Regulation (EU) 1253/2014

2. What is a rooftop unit?

2.6 Support for climate change and environmental challenges

Rooftop units fit perfectly into the European Green Deal, which is a strategy to make the European Union (EU) climate neutral by 2050. Three pivotal elements of this strategy include promotion of heat pump technology (2.6.1), reducing the impact of refrigerants (2.6.2) and circular economy policies (2.6.3).

2.6.1 Heat pump technology

Today, around 30%[4] of commercial buildings in the EU are heated with natural gas. Air to air heat pumps could come to play a very central role in the quest to lower natural gas dependency. The heat pump technology applied in rooftop units is recognised as key in achieving the decarbonisation targets. It is a highly energy efficient substitute for heat sources based on the combustion of fossil fuels, such as natural gas. This technology also enhances independence from fossil fuel supplies, which are reliant on the fluctuating global situation. As heat pumps are powered by electricity produced increasingly from renewable resources, they are a real green alternative to traditional heat generation.

2.6.2 Reducing the impact of refrigerants

The F-Gas phase-down targets guide the industry towards reducing the impact of refrigerants. A comprehensive overview of industry actions ongoing or under investigation is presented in Figure 5.

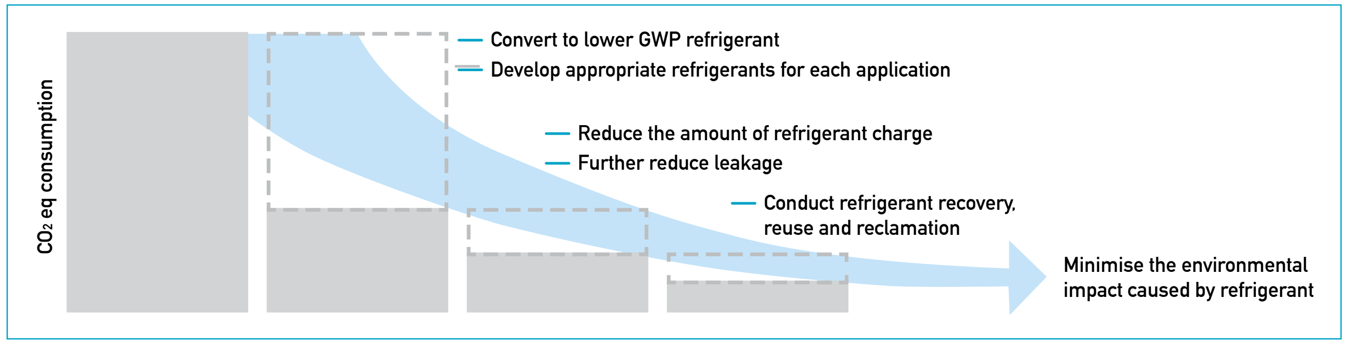


Figure 5: Comprehensive approaches towards CO_2 equivalent consumption reduction ©Daikin

The EU's F-Gas emissions will be cut by two-thirds by 2030 compared to 2014 levels by using refrigerants with a lower Global Warming Potential (GWP) and/or lower product refrigerant charge. There are various refrigerant technologies applied in the industry. Most common refrigerants used in the rooftop product industry are R-410A, R-32 and R-454B, which feature low GWP as showing in Table 3.

Table 3: Common refrigerants used in the rooftop products with their related GWP

Refrigerant type	GWP*
R-410A	2256
R-32	771
R-454B	531

* according to IPCC Assessment Report 6

2.6.3 Circular economy policies

The aim of the circular economy is to improve the repairability and upgradeability of products, as well as the reusability of their components and applied raw material. Compact design of rooftop units and easy access to their subassemblies that facilitates disassembling, essentially contribute to these objectives.

Key learning points

- Rooftop units are a well-established and proven stand-alone solution for providing heating, cooling and ventilation. In many cases, the use of rooftop units allows to simplify the HVACR system.
- Modern rooftop units are state-of-the-art HVAC devices offering very high energy efficiency and flexible performance adjustment.
- The main elements of rooftop units include the refrigeration circuit, fans, economiser section and energy recovery systems.
- The differences between rooftop units and air handling units allow selecting one of these devices as the best solution for a specific project.
- The design and technology of rooftop units play an important role within the EU Green deal energy transition plans.

3. Reasons to use rooftop units

3.1 Key advantages of rooftop units

Rooftop units provide, in a single packaged solution, everything needed to take care of thermal comfort and IAQ in the building. Thanks to its design and remarkable configurability, this centralised air conditioning system can turn, depending on the current demand and configuration, from a basic air conditioner into a comprehensive system capable of providing functions such as space cooling and heating, ventilation, air filtration and purification, humidification, dehumidification and free cooling.

The above should not lead to consider the rooftop unit as a central split or multi-split unit, nor as an AHU equipped with refrigerant circuit, because rooftop units provide their best when combining the need to maintain thermal comfort in a building with the need for ventilation.

Rooftop units, when equipped with dampers section, can combine outdoor air with recycled air, allowing the supply air to satisfy the building thermal load.

Compared to other design options, such as using an AHU for ventilation and auxiliary systems for thermal comfort, for example, the RTU-based solution offers an overall simplification of the HVAC system by using a single compact and autonomous unit with all functions and components engineered, optimised and factory-tested by a single supplier.

The embedded control system of the rooftop unit is factory-designed to optimise ventilation together with all other functions to achieve the required IAQ at the best energy efficiency.

The supply air variable flow control that is a common function in the last generation rooftop units, is more than the traditional variable airflow, which considers only the pressure drops in air system ductwork. In modern rooftop units, the energy consumption by the supply and extract fans, can be optimised according to the actual demand for cooling and heating, for dehumidification, for free cooling and for controlling CO_2 or VOC.

The more the IAQ approaches the set values, the lower the overall energy consumption of the device, both for the refrigerant circuit and the air side.

3.2 Efficient air renewal for good IAQ

Rooftop units alone can supply the required amount of outdoor air at the correct temperature and humidity to the rooms, ensuring high quality of the air for people to breathe, while providing the right thermal comfort in the indoor spaces.

In other words, rooftop units remove contaminated indoor air – either the actually polluted air or air that is just uncomfortably warm or cold – and replace it with clean, fresh, dehumidified (and sometimes humidified) air at the right temperature.

3.3 Right amount of outdoor air and heat recovery for energy optimisation

Air supplied by the rooftop unit is for the correct IAQ and thermal comfort. To provide proper IAQ an adequate ratio of outdoor air is needed in the supply air. Outdoor air treatment is more expensive in terms of energy used than recirculating indoor air. What can be done to save energy due to outdoor air treatment is to ensure that the amount of outdoor air really needed for ventilation is always treated. When the IAQ is related to the number of people in the building, the CO_2 level in the extract air may be used to control the outdoor air rate. The outdoor air damper is modulated to adjust the outdoor air quantity to close the gap between the actual and threshold CO_2 values.

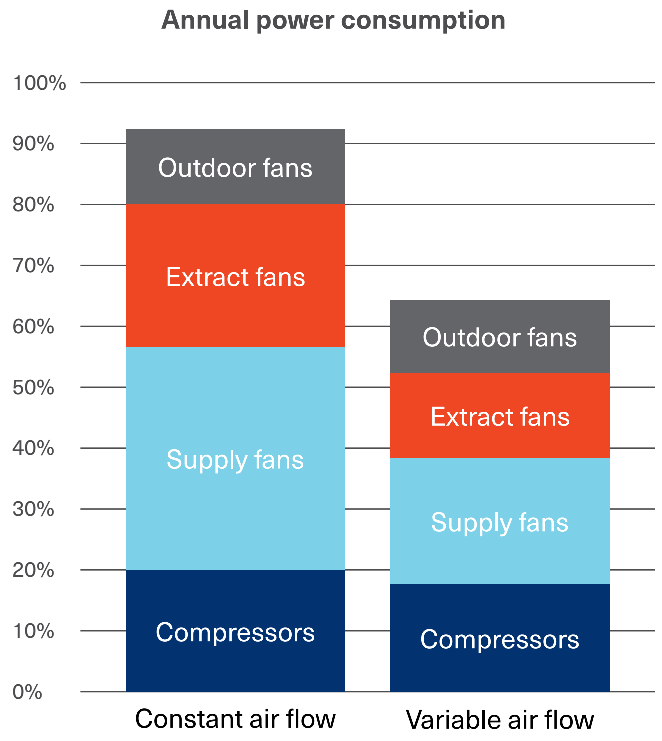
To further increase the unit efficiency by taking advantage of exhaust air energy, various types of heat recovery can be used. These include thermodynamic heat recovery, plate heat exchangers and rotary heat exchangers.

3.4 Variable airflow integrated into IAQ and thermal comfort control

Variable speed drives (VSDs) built into motors enable effective performance control to enhance the capability of fans. This facilitates adjusting the air volumes to actual facility needs. The extract fan and mixing section allow to make use of energy from extract air to heat outdoor air and reduce energy consumption, while CO_2 sensors and variable air volume (VAV) devices in the ductwork ensure that IAQ and temperature requirements in individual control zones are met.

Rooftop units can be equipped with pressure sensors to deliver stepless fan control based on the pressure difference caused, for example, by dirty filters or position of dampers.

3. Reasons to use rooftop units



3.5 Impact on the overall building energy efficiency

Rooftop units always feature embedded refrigeration circuits, and the generated cooling or heating energy is directly transferred from the refrigerant gas to the supply air that serves for space cooling and/or heating. This eliminates the intermediate fluid for energy transfer, simplifies the energy supply chain for building heating and cooling, and minimises the associated energy losses. In effect, the overall building energy efficiency increases.

Another feature that contributes to the energy efficiency of buildings is the free cooling (or free heating) function, which is typical for rooftop units. This function determines, depending on the outdoor air conditions, whether it is more beneficial in terms of energy to recirculate indoor air or to introduce outdoor air. For units that measure enthalpy, in addition to temperature, humidity is also considered in the assessment.

Thanks to the variable capacity control of components and the compatibility of in-build control systems with any building management system (BMS), rooftop units can accurately adjust their performance to the actual demand, depending on the weather and building load. This further contributes to the energy efficiency of buildings.

3.6 Ease of installation

Rooftop units are often defined as plug & play solutions. This is mainly due to the very simple installation procedure, which is limited to connecting the unit to the (pre-installed) air ductwork and to the electrical grid. Because of the common monoblock design, the installer benefits from one-time lifting from the truck and no need to join modules on the roof. No need to handle hydraulic or refrigerant connections dramatically simplifies the installation process, reducing related time and costs. In most cases, rooftop units are delivered factory-charged with a refrigerant. Units can be installed either on the building roof or on the ground, and the ducts can be placed outside the building to save installation space. Rooftop units can be delivered with a base frame for different options of ductwork connections, and the rooftop casing itself can provide different locations for air ducts connection as well. All this further facilitates installation. Finally, there are rooftop units integrated with an air duct terminated with a swirl diffuser, which simplifies the system even more, as no ductwork is then required.

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Key learning points

- Rooftop units are a single packaged solution for thermal comfort and Indoor Air Quality in the building.
- Outdoor air volume adjustment, variable airflow control, heat recovery and the built-in control system communicating with BMS optimise energy consumption.
- Integrated refrigeration circuit eliminates intermediate energy losses in cooling and heating of the building.
- The compact and stand-alone design of rooftop units simplifies and facilitates installation, reducing the related time and costs.

4. Variety of rooftop unit applications for different requirements

In commercial, industrial and many other applications, in addition to temperature and humidity requirements, IAQ must be ensured by appropriate air renewal.

Wherever air conditioning and ventilation is required, but there is no need for flexible and comprehensive zone control and air recirculation is acceptable, rooftop units can be considered as one of the most suitable solutions.

A non-exhaustive list of typical rooftop unit applications and their specifications is presented in the following paragraphs.

4.1 Retail buildings

Regarding retail buildings, rooftop units can be installed in 2 different types of premises, differing in volume:

- Large-volume shopping centres
- Retail stores of small/medium volume

In terms of comfort requirements for this kind of application, for both categories of objects, the thermal load can considerably vary depending on the location and related heat losses of the building envelope. These buildings typically feature high energy consumption and high operating costs.

Especially in shopping centres, the cooling demand can also occur during the winter season, due to high customer occupancy and heat gains from illumination.

For areas where the moisture content is very high, dehumidification may also be required.

In terms of air renewal, in retail stores as well as in the shopping centres, a minimum ventilation airflow rate is always needed. Depending on the design concept, ventilation can be provided by a rooftop unit or another system, such as a common AHU for outdoor air supply in the entire building. For the malls, when catering areas are present in the conditioned environment and where usually local extractions hoods are installed, a sufficient outdoor air rate in the air supplied by the rooftop unit is necessary to maintain the pressure balance.

Moreover, for both small and large volume applications, the percentage of air renewal can vary according to the CO_2 level in a served area, in relation to the current number of occupants.

4.2 Warehouses and logistic centres

Rooftop units are often installed in warehouses, large buildings where air conditioning is important to store goods in a suitable environment prior to their use, distribution, or sale.

Requirements for these buildings may vary according to the type of stored goods. However, the main common characteristics of a warehouse are the following:

- No need for constant air exchange, because of its large volume combined with low people presence and absence of indoor air-polluting sources
- Need for humidity control to avoid moisture from damaging goods and their packaging
- Need for temperature control, although its control range may be wider compared to other kinds of buildings where comfort for people is fundamental

If goods stored in the warehouse have specific needs, rooftop units can be customised to provide the required conditions.

4.3 Industrial production facilities

Industrial productions cover a wide variety of processes, which results in different requirements and needs in terms of ventilation and air treatment. First, air quality is very important for safety of workers and healthiness of workspaces. Industrial processes are often a source of substances, light or heavy dust particles, vapours, or smell. Therefore, it is very important to guarantee the necessary amount of outdoor air while expelling contaminated air outside the space where the process takes place.

Rooftop units can provide good air renewal and meet the needs in terms of extracted and supplied airflow. They can fully manage the needed air exchange or be easily integrated with other appliances for air expulsion, for example, if extraction hoods are present, such as in cooking industries or painting processes. Supply and return airflow of the rooftop unit can be different to keep the right ventilation balance inside the building.

In some cases, a rapid total air exchange can be necessary, so to handle the variation of fresh air amount introduced in the building, the flexibility of rooftop units is very important.

In terms of air handling a key aspect can be to ensure that some spaces are not contaminated by low-quality air. The rooftop unit is able to keep positive pressure in a room, preventing outside air from entering it (example: a process where humidity must be low and air coming from outside the space may affect the process itself), or to keep negative pressure, to make sure that air inside the room is expelled correctly and does not reach other adjacent rooms.

Some processes may require specific air conditions in terms of high-efficiency filtration (example: dust suppression for textile industry), temperature and humidity control.

The rooftop unit can operate in a wide range of outdoor conditions, providing cooling or heating for the process in contrast to basic ventilation systems dependent on the seasonal outdoor climate.

As air exchange is always present and air conditioning can be highly energy-consuming, an important feature for rooftop units is heat recovery, which can be integrated in the unit accordingly to the need and the conditions of extracted air.

4. Variety of rooftop unit applications for different requirements

4.4 Educational facilities

The following aspects characterise educational facilities as a type of environment to be conditioned:

- High air renewal (up to 60% of outdoor air), due to the high level of occupancy or the possible presence of a canteen
- Control of indoor humidity through humidification and dehumidification
- High filtration efficiency to ensure proper IAQ

A rooftop unit properly configured to the needs of the system can meet all these requirements, using a large proportion of the outside air and a heat recovery system that reduces energy consumption.

4.5 Sport venues

The main aspects which must be taken into account when a rooftop unit is designed for sport facilities are high percentage of outdoor air (up to 80%), control of indoor humidity (especially in terms of dehumidification) and high filtration efficiency.

Given the high rate of outdoor air, a heat recovery system is recommended for this type of application. Moreover, the airing function with 100% outdoor air shall be supported by the rooftop unit control system if the conditioned area has not been used for a long time or a rapid exchange of the indoor air is necessary. In addition, for better control of dehumidification and to avoid the risk of overcooling the room, a post heating device is needed.

4.6 Entertainment venues

Entertainment facilities are a similar application as educational facilities. High percentage of outdoor air, control of indoor humidity and high standards for filtration are common requirements that the rooftop units must meet.

Furthermore, when the conditioned area has not been used for a long time or a rapid indoor air exchange is required, the 100% outdoor air airing function should be supported by the rooftop unit control system.

4.7 Airports

Airports are large volume buildings where air quality for passengers is very important and where the outdoor environment is usually polluted.

Spaces occupied by people typically require up to 30% of outdoor air in the total airflow. Higher air renewal can by locally required for restaurant areas inside the airport or restrooms.

To ensure good air quality, rooftop units can be additionally equipped with activated carbon filters to eliminate odours from food courts or restrooms.

4.8 Exhibition centres

A rate of outdoor air is always necessary, but the versatility required by this type of application can result in many different configurations and control logics in relation to the served site. This includes, for instance, different types of heat recovery, different standard of filtration, indoor humidity control, and independent management of the supply and extract airflows.

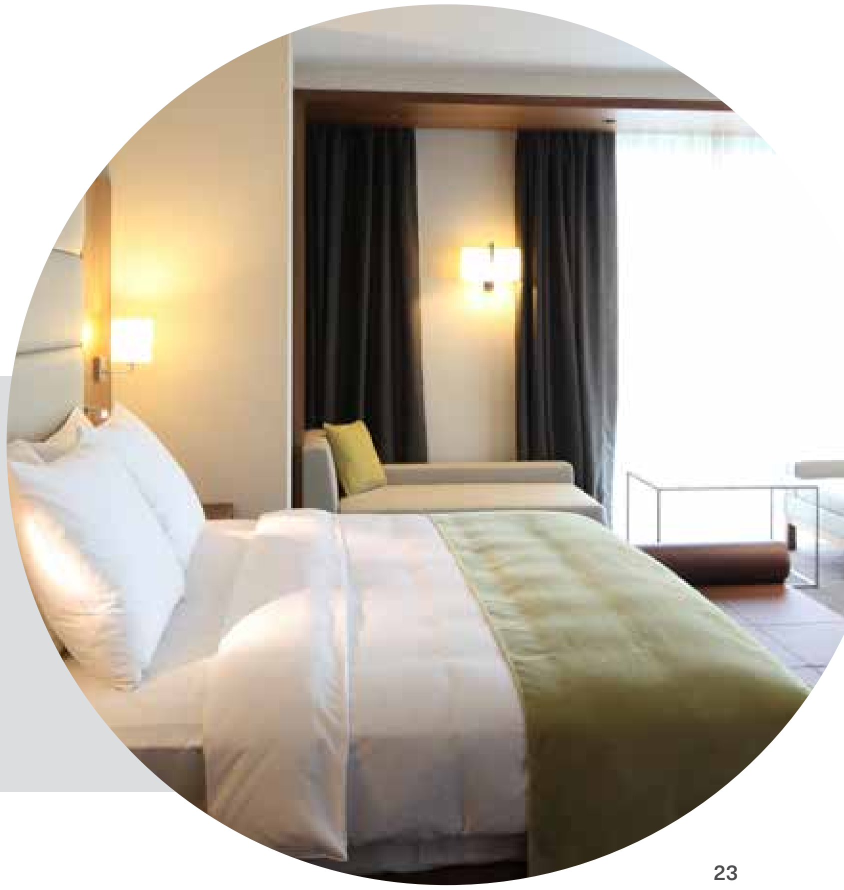
These applications benefit from the rooftop package solution. In practice, the same rooftop unit can be placed in different sites and an important advantage is easy installation without the need for connection to existing water systems.

4.9 Other applications

Rooftop units are an extremely versatile and customisable technology thanks to a wide range of options, configurations and accessories. In this way, a very wide range of different requirements can be met.

Key learning points

- Rooftop units may be considered as one of the most suitable solutions in all applications where air conditioning and ventilation is required but there
- is no need for comprehensive zone control and air recirculation is acceptable.
- Rooftop units are widely used in various types of public and industrial buildings.
- Configuration enables adaptation to specific project needs and requirements.



5. Functions and components of rooftop units

Rooftop units are compact and autonomous devices that deliver treated air into a building. They are equipped with all the components required for complete air conditioning, including the control system. The unit is connected to the air distribution ductwork without additional equipment. This design reduces the cost of installation, facilitates connections and ensures reliable operation.

Rooftop unit takes extract air from the building and mixes it with outdoor air by means of dampers to provide ventilation and guarantee high IAQ. The pollutant particles in the air are cleaned through filters and the air is heated or cooled in the indoor coil, then forced through ductwork to the designed spaces of the building thanks to the supply fan. It is usual that the rooftop unit also has an extract fan to extract the airflow equal to the supplied outdoor airflow and ensure pressure balance in the room.

The indoor coil is part of the refrigerant circuit(s), which also comprises compressors, outdoor heat exchanger, expansion valve(s) and 4-way valve(s) in case of reversible heat pump units.

Additional components can be integrated for energy recovery and heating back-up, among others.

1. EC plug fans with variable speed technology
2. Indoor air filtration: G4+F7 (65% isoCoarse + ePM1 55%), F5+F7 (85% isoCoarse + ePM1 55%), G4+F9 (65% isoCoarse + ePM1 80%)
3. Economizer for fresh air and free cooling with optional EC exhaust fan
4. Dual skin panels with 25mm thickness insulation
5. High efficiency axial outdoor fans (EC available as an option)
6. Variable speed scroll compressor with intermediate discharge valve and permanent magnet motor (Adaptive Frequency™ Drive)
7. Embedded Trane controller, pre-wired and preconfigured from the factory for quick start-up and commissioning
8. Auxiliary heat options (not shown): gas heater, electric heater, hot water coil
9. Optimized heat exchanger to improve efficiency in heating mode
10. Heat recovery module with enthalpy wheel (including purge function to avoid dirty air mixing) and integrated exhaust fan

5.1 Heating and cooling sections

5.1.1 Heating and cooling sections

In cooling operation, the indoor coil of the rooftop unit operates as an evaporator. The refrigerant circuit provides cooling effect in the evaporator and requires the heat energy to be ejected in the condenser (outdoor exchanger) to the outdoor source.

By integrating a 4-way valve, it is possible to reverse the direction of the refrigerant flow in the circuit allowing the indoor coil to work as a condenser to provide heating. The 4-way valve is also useful to reverse the cycle in heating mode to carry out defrosting.

5.1.2 Air-to-air units and water-to-air units

Rooftop units can be classified depending on the outdoor heat exchanger and therefore the outdoor source.

The indoor heat exchanger is always a coil, which provides heating or cooling to the airflow supplied to the building.

For air-to-air units, the outdoor source is outdoor air. These units are equipped with an outdoor coil and outdoor fans that force airflow through it.

For water-to-air units, when the outdoor source is water, the outdoor heat exchanger is typically a refrigerant/water plate exchanger.

5.2 Compressors

Compressors are components allowing the circulation of the refrigerant through the refrigerant circuit. It takes the gas refrigerant coming from evaporator coil, compresses it, and delivers it with higher pressure and high temperature into the condenser coil.

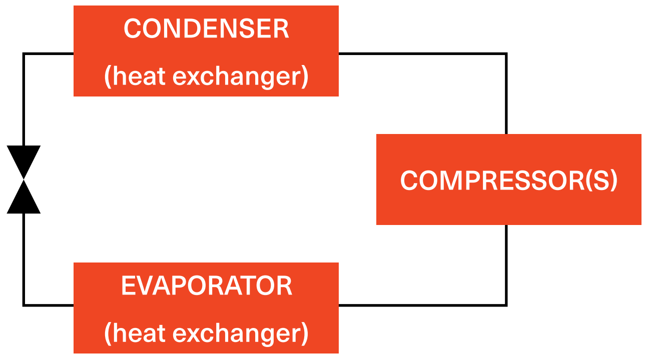
5.2.1 Multi-compressor configuration

Multi-compressor technology (scroll or rotary) consists of two compressors in parallel (tandem), or three compressors (trio) with equal capacity (even) or different capacity (uneven) in each refrigerant circuit.

Multiple compressors allow for a wide-range capacity adjustment and high efficiency in partial load operation, which is particularly important given that typically for 70% of operation time the performance is under half-load.

The refrigerant circuit is designed for full capacity. Therefore, at part load when the refrigerant flow through the coils is lower because not all the compressors are activated, the circuit is oversized (all the coil surface is being used).

This means higher efficiency, which can be further increased when combined with optimised airflow management through the coils by means of variable speed fans.



5.2.2 Inverter driven circuits

The inverter compressor is controlled by a variable frequency driver (VFD) and in contrast to step-controlled compressors, features modulated capacity. Compared to on-off compressors, its efficiency is higher at rotation speeds between 40% to 80% of the maximum speed but can be lower at full capacity. Such efficiency profile is matching greatly with the hourly spreading of the building thermal load. Meaning there is an extensive amount of operation during mid seasons where there is a moderate capacity requirement of 50~75%. These inverter compressors result in optimised part load efficiency and related seasonal performances in both heating and cooling operation.

5. Functions and components of rooftop units

5.2.3 Multi-circuit system

A multi-circuit system means the use of two or more separate refrigerant circuits. The heat exchangers are common but incorporate separate sets of tube circuits in one finned block.

By combining multi-compressor configuration with multi- circuit system or incorporating an inverter driven solution, it is possible to get a very precise modulation of the cooling or heating capacity and a high efficiency in full and partial load operation. In units with 2 circuits and 2 even compressors per circuit, it is possible to control the output within a range of 25% to 100%.

Multi-circuit is particularly common in air-to-air rooftop units to improve comfort during defrost operations (one circuit in defrost mode and the other continues to operate). Another advantage of a multi-circuit system is its ability to continue operation if the compressor of one system breaks down.

5.3 Air filters

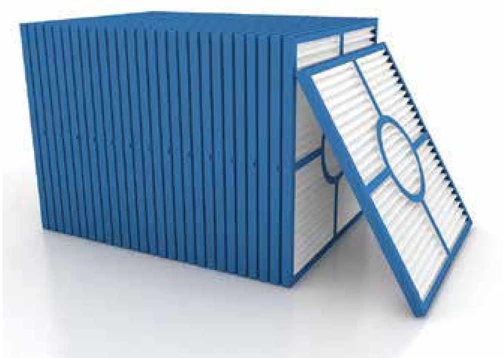
5.3.1 Filtration for good IAQ

Air filters play a fundamental role in providing good IAQ. They remove pollutants from the air before it is delivered to rooms. Basically, pollutants originate from the outdoor environment but can also include contaminants from indoor emissions transferred via recirculation air. The main outdoor pollutant is particulate matter – a mixture of solid and liquid particles and droplets including pollen, bacteria, yeast, and moulds along with other organic and inorganic matter.

The classification of the filter efficiency rating is defined in EN ISO 16890 standard, which replaced the former and obsolete EN 779. The classification distinguishes between the ISO Coarse, ISO ePM1, ISO ePM2,5 and ISO ePM10 groups.

In case of supplying air to rooms for permanent human occupation and very clean outdoor environment, which may be only temporarily dusty (Category ODA1), ISO ePM1 50% filters are sufficient. While for outdoor air with high concentrations of PM typical for urban areas (Category ODA2), or with very high concentrations of PM typical for polluted urban and industrial areas (Category ODA3), respectively ISO ePM1 70% and ISO ePM1 80% filters on supply are required. Comprehensive guidelines for filter class selection are presented in the dedicated Eurovent Recommendation 4/23 – Selection of EN ISO 16890 rated air filter classes.

In addition to fibre filters, electrostatic precipitators, also called electronic filters, UV lamps and ionisers represent an interesting alternative to air purification.



5.3.2 Protection of the unit and system

Filters are also crucial to keep the internal components of the rooftop unit clean and ensure a hygienic operation of the ductwork system.

5.3.3 Energy efficiency of filters

Another substantial feature of fibre air filters, besides the efficiency of particle separation, is their flow resistance which directly translates into energy consumption. The initial pressure drop, and the pressure increase due to dust load in the filter are the key parameters in this respect.

Comprehensive information on energy efficiency of filters is presented in the dedicated Eurovent Recommendation 4/23 – Selection of EN ISO 16890 rated air filter classes.

5.3.4 Gas and odour contaminants

In addition to particulate matter, outdoor and indoor air may contain gas pollutants such as odours or volatile organic compounds. If needed, these contaminants can be eliminated by carbon filters, also called gas phase filters. A common solution is to use filters having in the same frame two layers of different media, one for particle filtration and the second for gas phase pollutants.

5.4 Fans

5.4.1 Indoor fans for air supply and air extraction

The fans allow to provide available pressure to the air distribution ductwork and to overcome the flow resistance of rooftop components. Nowadays, electrically commutated plug-fans are the common choice in most of rooftop units. They are highly efficient and allow airflow control in both constant air volume (CAV) and variable air volume (VAV) systems. Furthermore, they enable maintaining a set airflow rate regardless of filter fouling. In addition, they offer a soft- start function which is required for textile duct applications.

Rooftop units may incorporate only the supply fan or the supply and extract fans.

5.4.2 Outdoor fans (in case of air-to-air units)

The electronic control adjusts the speed of axial fans to the operating conditions and actual demand, which considerably reduces energy consumption and increases efficiency in partial load operation.

5. Functions and components of rooftop units

5.5 Mixing section

Rooftop unit takes extract air from the building and mixes it with outdoor air to provide for ventilation and guarantee high IAQ. This is carried out in the mixing section by means of outdoor air dampers combined with extract air damper or just by the exhaust fan.

5.5.1 Outdoor air management and free cooling

The outdoor air ratio in the supply air can be adjusted by different strategies:

- Ventilation with constant outdoor air ratio: The fixed percentage of outdoor air is set by parameter.
- Demand controlled ventilation (DCV): The outdoor air ratio is variable and adjusted to the real demand depending on the occupancy to maintain the correct IAQ, which is measured by sensors. This control strategy provides significant energy savings compared to the constant outdoor air ratio.

The outdoor air volume can be increased (up to 100%) when the outdoor conditions are favourable for cooling (or heating) energy savings. This function is called free cooling. In temperature-based free cooling control, only temperatures are considered to determine if outdoor conditions are favourable. The enthalpy-based free cooling is an alternative when the humidity is also controlled or for climates with high humidity.

5.5.2 Pressure balance in the building

Extract fans in combination with supply fans and pressure sensors can ensure the complete pressure control in the building or its part. Typical example is the restaurant area, where overpressure needs to be ensured, to avoid odours coming from the kitchen, that will be kept in negative pressure.

In case of rooftop units supplying outdoor air for ventilation but without an exhaust section, overpressure can be generated in the building. The higher the outdoor air rates for ventilation or free cooling, the higher the overpressure. This phenomenon may be acceptable where air relief is provided separately by overpressure dampers, where doors are frequently opened, or if the building features low airtightness.

5.6 Humidity control

5.6.1 Humidifiers

In cold climates, outdoor air has a very low moisture content in winter. Thus, depending on the outdoor airflow rate, it may be necessary to use humidifiers to maintain minimum indoor humidity. The humidifier may be integrated in the rooftop, or in the supply air ducts but it is directly controlled by the rooftop unit. The following types of humidifiers are usually used:

- Evaporation: Air flows through a moist media and increases its humidity thanks to the water evaporation process
- Vaporiser: Steam from electrodes or vapor from a boiler is blown in the air
- Spray: Water is directly diffused in fine droplets in the air

5.6.2 Dehumidification

Dehumidification is needed to prevent the acceptable level of indoor humidity being exceeded due to high moisture emissions indoors or humid outdoor air entering the building. Year-round humidity control is crucial in some applications, such as cold storage warehouses, to avoid condensation on goods or frosting of glass doors.

Cooling of supply air in the evaporator involves a reduction of its temperature but also a reduction of its moisture content (air is dehumidified). The greater the temperature reduction, the greater the reduction in moisture content. In summer,

at high outdoor temperatures, the demand for supply air cooling is high and the dehumidification effect is sufficient to maintain correct indoor humidity in the building.

However, in intermediate seasons, when cooling demand is low but indoor moisture emissions are high (people breathing, cooking, etc.) and/or the moisture content in outdoor air is high, the dehumidification effect in the evaporator may be too low to control the correct indoor humidity.

To properly ensure dehumidification in these cases, it is necessary to cool the air more than what should be strictly required to meet the thermal load and then reheat the supply air to avoid temperature discomfort. To reheat the air, the unit can be equipped with a post heating section or a condenser energy recovery circuit with an additional indoor coil to secure high energy efficiency.

5. Functions and components of rooftop units

5.7 Auxiliary heating devices

The rooftop unit can be fitted with an auxiliary heating device located upstream or downstream of the indoor coil to provide additional heating, which may be needed in cold climates and for dehumidification. This option gives full control of the supply temperature during the defrosting cycle and allows to provide cooling in extreme winter conditions exceeding the operating range of the refrigerant circuit.

Typical auxiliary heating section types are the following.

5.7.1 Electric heaters

Electric heaters are located in the airstream and usually feature 2 or 3 stage or proportional output control. Despite high electrical consumption, electrical heaters simplify installation as they only require a connection to the electrical supply. This kind of heating is mainly used in mild climates with few required hours of auxiliary heating and/or in countries where electricity is cost-effective and produced from renewable sources with low CO2 emissions. More in general, they can also be used as preheaters to increase the heating operating envelope.

5.7.2 Hot water coils

The water coil needs to be connected to a separate hydraulic circuit supplying hot water from a boiler or other heat sources such as a high temperature air-to-water heat pump or a system recovering energy rejected from a separate process. Standard control of the coil includes a 3-way valve managed by the rooftop unit, which ensures high precision of capacity adjustment.

Anti-freeze protection of the coil is generally required to avoid damages at low outdoor temperatures when the unit is not in operation.

5.7.3 Gas heating modules

The exchanger module incorporating a natural gas or propane modulating burner can be mounted in the rooftop unit to directly heat the supply air stream.

Ecodesign Regulation (EU) 2016/426 sets minimum requirements for burners regarding the efficiency and low emissions. To ensure ‘clean’ combustion, NOx emissions must be below 70 mg/kWh HCV and to provide high efficiency, condensation gas heating modules must be used.

5.7.4 Hot gas reheat coil

This coil is integrated in the main refrigerant system and placed downstream of indoor coil. It operates in cooling mode, when higher latent then sensible capacity is required. It allows a post heating of dehumidified supply air avoiding indoor thermal discomfort. In addition, it increases the energy efficiency of the unit by recovering part of heat otherwise ejected in the outdoor exchanger.

5. Functions and components of rooftop units

5.8 Exhaust air energy recovery

There are various ways to recover energy from exhaust air that can be applied in rooftop units.

5.8.1 Thermodynamic recovery

Exhaust air has generally more favourable temperature and humidity conditions that the outdoor air. This allows the refrigerant circuit to operate with higher evaporating

temperature in winter and lower condensing temperature in summer, significantly improving the overall efficiency of the rooftop unit. In addition, during winter, this feature reduces defrost cycles frequency and their duration. Thermodynamic recovery can be performed:

- Through diverting the exhaust air to the outdoor exchanger before it is ejected outdoors (see Figure 1)
- By means of an additional exchanger integrated in the main refrigerant circuit
- By means of a dedicated refrigerant circuit to additionally optimise the free cooling or free heating mode (see Figure 2)

Example of common thermodynamic recovery system design is shown below.

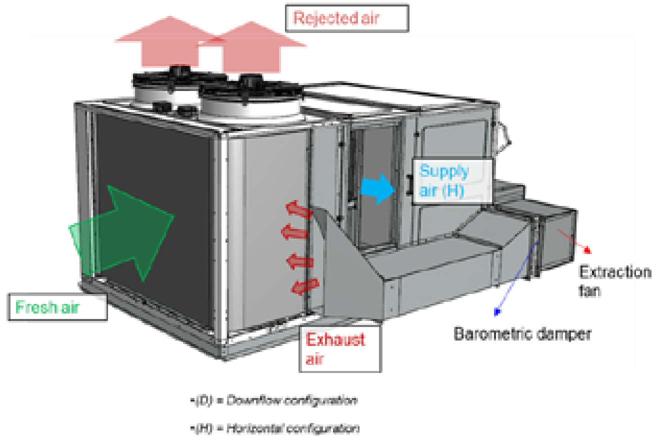


Figure 1

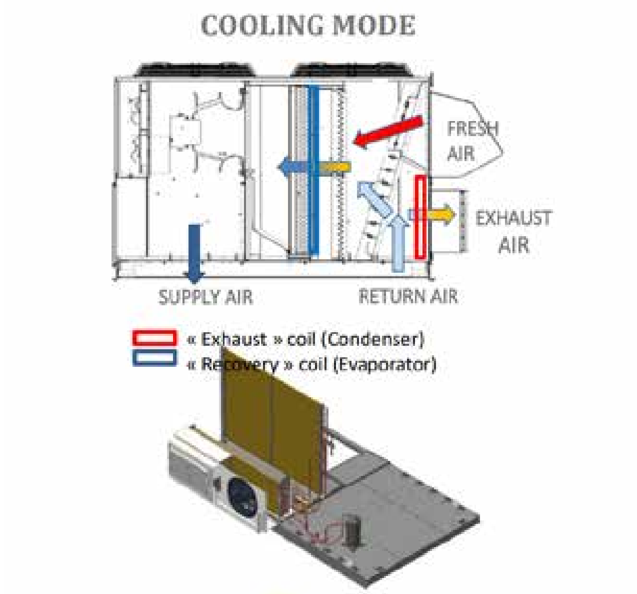


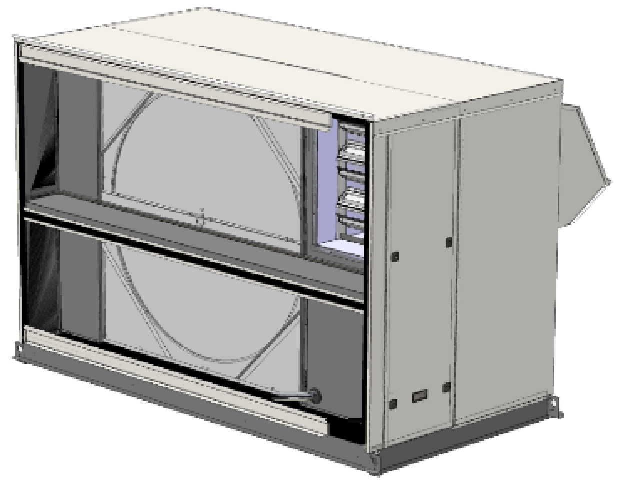
Figure 2: ERC operating in cooling mode

5.8.2 Passive recovery

For the passive recovery, a heat exchanger is located between outdoor and exhaust air in rooftop units with supply and extract fans. Generally, two different types of exchangers are used: a rotary or a plate heat exchanger.

The rotary heat exchanger typically offers higher efficiency at a lower pressure drop and a more compact design.

Depending on the rotor wheel material, only sensible (temperature) or sensible and latent (moisture) energy can be recovered. Moisture recovery is worth to considered in cold climates to avoid too low indoor humidity in winter due to supply of very dry outdoor air.

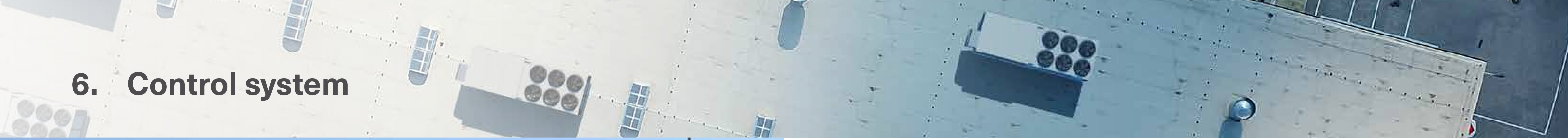


5.9 Control system

Rooftop units are fitted with integrated control system that accurately manages the operation of each component according to the actual condition and building demand to provide optimal performance of the unit at full and partial load. For more information on control systems, refer to chapter 6.

Key learning points

- Rooftop units are complex standalone devices comprising many subassemblies and systems to provide heating, cooling, ventilation, air filtration and comprehensive control.
- The outdoor source of energy for cooling and heating may be outdoor air (air-to-air units) or water (water- to-air units).
- Multi-scroll refrigerant circuit provides wide range capacity adjustment and high efficiency in part load operation, while applying a multi-circuit system further extend the flexibility of capacity control, ensures comfort during defrosting at very low outdoor temperatures and secures continuous operation of the unit in case of compressor failure in one of the circuits.
- Depending on the specific project needs, rooftop units can be configured to also provide year-round indoor humidity control and incorporate additional heating devices.
- Rooftop units are fitted with filters to clean the air supplied to the building. The suitable filter class depends on the outdoor air quality and type of served indoor spaces.



6. Control system

6.1 Why is the control system important for a rooftop unit?

Like most HVAC devices, rooftop units are typically selected and sized for the full load design condition. As the building load changes throughout the year and even throughout the day, rooftop units need to adjust their capacity accordingly to provide adequate IAQ and comfort, while ensuring high energy efficiency. Integrated control system is an indispensable solution to reach this target.

6.2 What is the influence of a rooftop unit control system on the overall efficiency?

Thanks to the control of cooling and heating capacity, variable air volume and free cooling function, rooftop units increase the overall system efficiency. In addition to altering the cooling and heating capacity according to the building load, the control system reduces air volume to diminish energy consumption if conditions are appropriate. When the outside temperature is low enough, the unit maintains the required indoor temperature without using mechanical cooling, by supplying more cool outdoor air. In most of applications, a simple daily time schedule turns off the unit when no occupation and no ventilation is expected in building.

All mentioned above properties reduce energy consumption and improve system's overall efficiency.

6.3 Which components of the rooftop unit are managed by the control system?

Besides main unit components such as indoor and outdoor fans, refrigeration circuit elements (compressors, electronic expansion valves, solenoid valves, 4-ways valves, etc.), air dampers, various sensors like pressure transmitters, temperature, humidity, CO2 and VOC sensors, and safety electronic devices like voltage monitor equipment and pressure switches are connected to the unit control system.

Several other devices such as a heat recovery exchanger, humidifier and post heater can also be connected to the rooftop unit control system.

6.4 What is the significance of the building management interface on the rooftop unit control system?

Rooftop units are able to communicate with different communication protocols of the BMS. Employing the user interface software facilitates the exchange of data between different types of devices and control systems, which provides user convenience. This helps to increase the overall energy efficiency of the building.

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Key learning points

- Built-in control system manages operation of all rooftop unit components to adjust its performance to the actual demand while ensuring thermal comfort, Indoor Air Quality and energy optimisation.
- Communication with the building management system further increases the overall energy efficiency of the building.

7. Selection, installation, commissioning and maintenance

7.1 Selection: how to properly the right product?

Selection of the rooftop unit is based the following main factors:

- Design outdoor and indoor temperatures and humidity for summer and winter
- Volume of served indoor spaces
- Required renewal airflow rate for ventilation determined according to the maximum occupancy and based on the relevant standard (e. g. EN 16798-1) and/or the local requirements that must be considered as binding in the first instance

In addition, the right selection of the unit involves the analysis of other factors, such as:

- Installation site design conditions
- Setpoint range for indoor temperature and humidity
- Building thermal performance and internal loads
- Volume of individual rooms
- Variability in the attendance of people

Based on the above conditions and requirements, the supply airflow including outdoor air renewal rate is determined.

This enables to select the size and cooling/heating capacity of the unit needed to provide proper air conditioning depending on the building insulation and designed indoor conditions.

The selection software offered by manufacturers significantly facilitates designers in selecting the right unit. Such software allows to select the most suitable unit just by providing the desired conditions and required accessories. In addition, these tools allow to calculate performance under non-design conditions, which enhances the analysis and considerations of system designers.

7.2 Installation and commissioning: monoblock plug and play product

Rooftop units are high performance stand-alone devices that incorporate all system components. They are factory assembled, inspected by the manufacturer and usually preloaded with refrigerant.

Rooftop units are designed with standard configuration combinations which, on the one hand, offer many options for customising the unit to each specific application and, on the other hand, simplify the installation and integration of the product into the building as much as possible.

Since all system components are included in the rooftop unit, there is no need to integrate many various products from different suppliers. Instead, it is sufficient to only adjust the right parameters on the unit controller during the commissioning. In this way, the product ideally suits the needs of the building and the users, offering a perfect compromise between simplicity and flexibility.

One of the main operations to be carried out during commissioning is the verification of the correct installation, in accordance with the manufacturer's technical documentation, by checking the main points that could lead to malfunctions, such as:

- Installation of unit supports and anti-vibration joints
- Respect of spaces required for functional purposes and maintenance around the unit
- Correct design and installation of the ductwork
- Correct position of air inlets and outlets to avoid air by-passing or stratification
- Electrical wiring connections

The commissioning itself mainly consists of setting the parameters to properly adjust the rooftop operation to the ductwork and user requirements:

- Positive/negative pressure or pressure balance in the rooms
- Fan external static pressure to adjust the supply airflow
- Supply airflow management (constant or variable)
- Free cooling/free heating and auto changeover settings
- Main set-points and settings according to customer needs
- Adjusting PI/PID regulators depending on building characteristic

7.3 Maintenance

Similar to other technologies, to ensure highly efficient and trouble-free operation of the plant, rooftop units require periodical checks. In particular, the maintenance concern three aspects:

- Filter replacement
- Heat exchanger cleaning
- Refrigerant leakage check

7.3.1 Filter replacement

Regular and timely replacement of filters is crucial for IAQ, thermal comfort, energy consumption and protection of internal components such as heat exchangers from fouling to ensure their high performance. Failure to change filters leads to their clogging and, consequently, to excessive energy consumption, reduced airflow velocity (which may result in malfunction of the refrigeration circuit) and possible filter damage.

Filters should be replaced in accordance with the manufacturer instructions. For ISO ePM filters, this should typically be when the pressure drop is three times or 50 Pa higher than the initial (clean filter) pressure drop. Furthermore, due to hygienic requirements, it is recommended to change filters at least every 12 months.

In case of electronic filters there is no need of replacement and the mainteinance phase consists only with washing its components with special products or degreasers.

7.3.2 Heat exchanger cleaning

Filter maintenance strongly limits the indoor coil fouling. A correct cleaning of the heat exchangers is crucial to ensure the regular operation of the rooftop unit to prevent capacity drops and abnormal operation, which might cause alarms and malfunctions. Rooftop units have at least two air/ refrigerant heat exchangers: an indoor coil and an outdoor coil. Both heat exchangers must be kept clean and without dirt and scales. The cleaning procedure can be performed with a soft brush, an aspirator or an air stream and it is important to remove the dirt not only from surfaces, but also around the unit to avoid possible future damages. To better clean the coils, suitable sanitising chemical products and water can be used also.

7.3.3 Refrigerant leakage check

Refrigerant leakage checks shall be done according to the requirements set out in the F-Gas Regulation (517/2014). Compared to other technologies, this operation is easier because all components to be checked are placed in a limited space and, having all the refrigerant circuit components preassembled and tested by the manufacturer, it is less likely to have leakages determined by possible refrigerant connections performed on field.

7.4 Remote monitoring

Remote monitoring simplifies and enhances the monitoring and control of main rooftop unit parameters, allowing energy managers to keep under control many systems simultaneously. In addition, a regular monitoring of the system operation can prevent malfunctions of the rooftop unit and system downtime due to component failures.

Evaluation and analysis of recorded performance and running time of components can indicate abnormal functioning that potentially leads to failure well in advance. Unreasonable changes in energy consumption may in particular identify anomalies. Access to data, ideally remote e.g. via cloud, allows to implement more advanced controls also, such as predictive maintenance. To this end, communication between the control system and internal components of a rooftop unit, such as damper and valve actuators, sensors, fans and drives is essential.

Since rooftop units have all the system components included in one package, by analysing the parameters of the unit it is possible to check the operation of the whole plant from one point and possibly identify any faults on the distribution side.

Key learning points

- The main factors determining the selection of a rooftop units include design indoor and outdoor parameters, required outdoor airflow for ventilation, heating and cooling loads of the building and installation site conditions.
- Selection software provided by rooftop unit manufacturers significantly facilitates the selection process and allow the designer to perform a comprehensive analysis.
- Integration of all system components into the rooftop unit and its compact design essentially simplifies installation. Usually, the installation and commissioning are limited to connecting the ductwork and electrical supply, setting control parameters and the assembly check.
- Rooftop units require periodical maintenance to ensure high-efficient and trouble-free operation. Maintenance activities primarily concern changing air filters, cleaning heat exchangers and checking refrigerant leaks.

8. Reliable data

8.1 Eurovent certified performance

With over 20 years of experience, Eurovent Certita Certification is the number one Third-Party certification body in Europe in the field of Indoor Climate, Ventilation and Air Quality, and Process Cooling & Food Cold Chain. 66% of the HVAC products sold in Europe are certified by Eurovent Certita Certification under the 'Eurovent Certified Performance' (ECP) mark, a renowned and trusted certification that guarantees that products not only comply with Standards, but also perform as advertised.

The Eurovent rooftop unit certification (RT) programme covers air-cooled packaged rooftop cooling only and reversible units below 100kW (in cooling mode), with an option to certify air-to-air units from 100 kW to 200 kW and water-cooled packages rooftops, using tests done in participant laboratory.

8.2 Benefits of Eurovent certified data

Participation in the certification programmes provided by Eurovent Certita Certification offers a solution for fair competition and reliable data. It is also the basis for the reliable study of HVAC system energy performance.

The rooftop unit programme is based on annual tests done by independent accredited laboratories, ensuring common evaluation criteria, integrity, and impartiality.

This comprehensive procedure guarantees customers that those products perform as declared. Furthermore, the certification assessment includes the energy efficiency label, helping planners, installers, and end-users to select the most suitable product for their application Besides obvious benefits for the end-users, the certification provides numerous advantages to the manufacturers and contributes to a level playing field. The major benefits can be summarised as follows:

- Increasing consumer confidence
- Fair market comparison through easy access to performance data of all certified products
- Reducing need for customer witness test
- Enhancing the product brand

Learn more about Eurovent Certita Certification.

8.3 Eurovent certified performance: energy efficiency

Through the Eurovent certification scheme, the following performances are certified: Cooling and heating capacity, energy efficiency in standard rating conditions, seasonal performance and sound power level.

EUROVENT CERTIFIED PERFORMANCE

Eurovent Certified Performance mark ©Eurovent Certita Certification

In addition, the rooftop unit certification programme includes energy efficiency classes, developed by Eurovent Certita Certification, helping to select the best units for each type of rooftop unit, in cooling and in heating mode. Less efficient products will disappear progressively. With these requirements, the verification of the published data by a third-party body such as Eurovent Certita Certification will add value to verify the announced performance as a complement to the market surveillance and to help compare the products thanks to its online database.

The Eurovent Certified Performance Energy Efficiency Label is based on seasonal efficiency performance.

9. Standards, regulations and other helpful information

9.1 Commission regulation (EU) 2016/2281

The Commission Regulation (EU) 2016/2281 establishes Ecodesign requirements for the placing on the market and/ or putting into service of (inter alia) rooftop units.

Specifically, it sets (inter alia) requirements for rooftop heat pumps and rooftop air conditioners, which are defined as:

- Rooftop heat pump is defined as air-to-air heat pump, driven by an electric compressor, of which the evaporator, compressor and condenser are integrated into a single package
- Rooftop air conditioner is defined as air-to-air air conditioner, driven by an electric compressor, of which the evaporator, compressor and condenser are integrated into a single package

These requirements apply into two different tiers (Tier 1: From 01 January 2018, Tier 2: From 01 January 2021 onward) and are set as it follows.

	Tier 1	Tier 2
Heat pump function	ηsh > 115	ηsh > 125
Air conditioner function	ηsc > 117	ηsc > 138

The Commission Regulation (EU) 2016/2281 should be under review in 2022 and the review shall include an assessment of the appropriateness of setting stricter Ecodesign requirements for rooftop and ductable air conditioners and heat pump. The review process did not start yet.

9.2 Testing methods and en standards

9.2.1 EN 14511 and EN 14825

Today, the main standards for testing and rating the performance of rooftop units are EN 14511:2018 and EN 14825:2018. The first standard, EN 14511:2018, provides definitions and test methods for the following major performance data:

- Cooling capacity
- Heating capacity
- Total power input in cooling and heating mode
- Energy efficiency ratio (EER) for cooling operation
- Coefficient of performance (COP) for heating operation
- External static pressure and nominal airflow rate

The second standard, EN 14825:2018, concerns testing and rating at part load conditions and calculation of seasonal performance. The main performance indicator defined in this standard include:

- Seasonal energy efficiency ratio (SEER) for cooling season
- Seasonal coefficient of performance (SCOP) for heating season
- Seasonal space cooling energy efficiency (ηs,c)
- Seasonal space heating energy efficiency (ηs,h)

In addition to characteristics provided in the above EN standards, the Eurovent Seasonal Efficiency classification for cooling and heating operation was introduced in the Eurovent Rooftop Certification Programme (PC-RT).

9.2.2 prEN 17625

The scope of both EN 14511:2018 and EN 14825:2018 applies not only rooftop units but covers much wider range of products including air conditioners, liquid chilling packages and heat pumps.

Given the specific properties and operation of rooftop units, which differ significantly compared to other air conditioning products, the European Committee for Standardization (CEN) is developing a new standard dedicated to this product.

The draft upcoming standard, prEN 17625, specifies the terms and definitions, test conditions and test methods for rating the performance of rooftop units with electrically driven compressors, which may be equipped with a supplementary post heater. The standard covers air-to-air and water-to-air units, with 2, 3 or 4 dampers.

The draft standard provides the part load conditions and calculation methods based on EN14825 but considering the rooftop units specific features, such as free cooling and airflow mixtures for:

- Seasonal energy efficiency SEER and SEERon
- Seasonal space cooling energy efficiency s,c
- Seasonal coefficient of performance SCOP, SCOPon and SCOPnet
- Seasonal space heating energy efficiency s,h

The terminology and typology for rooftop units are also comprehensively defined.

Tentatively, the publication of standard may be expected by early 2024. Once the standard is available, it is intended to request the European Commission for a mandate to

harmonise it for Regulation (EU) 2016/2281. If the mandate is granted, the Annex ZA will be added to the standard during its first revision to become a harmonised standard.

Eurovent Certita Certification experts and Eurovent members actively contribute to the development of EN 17625.

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