Controlled mechanical ventilation (CMV) in residential buildings

Michele De Carli

Angelo Zarrella

GENERAL ISSUES: WHY VENTILATION?

Yesterday:

- numerous leaks, infiltration through windows and doors
- high consumption for heating

Today:

- Airtight Buildings
- Low permeability to outside air

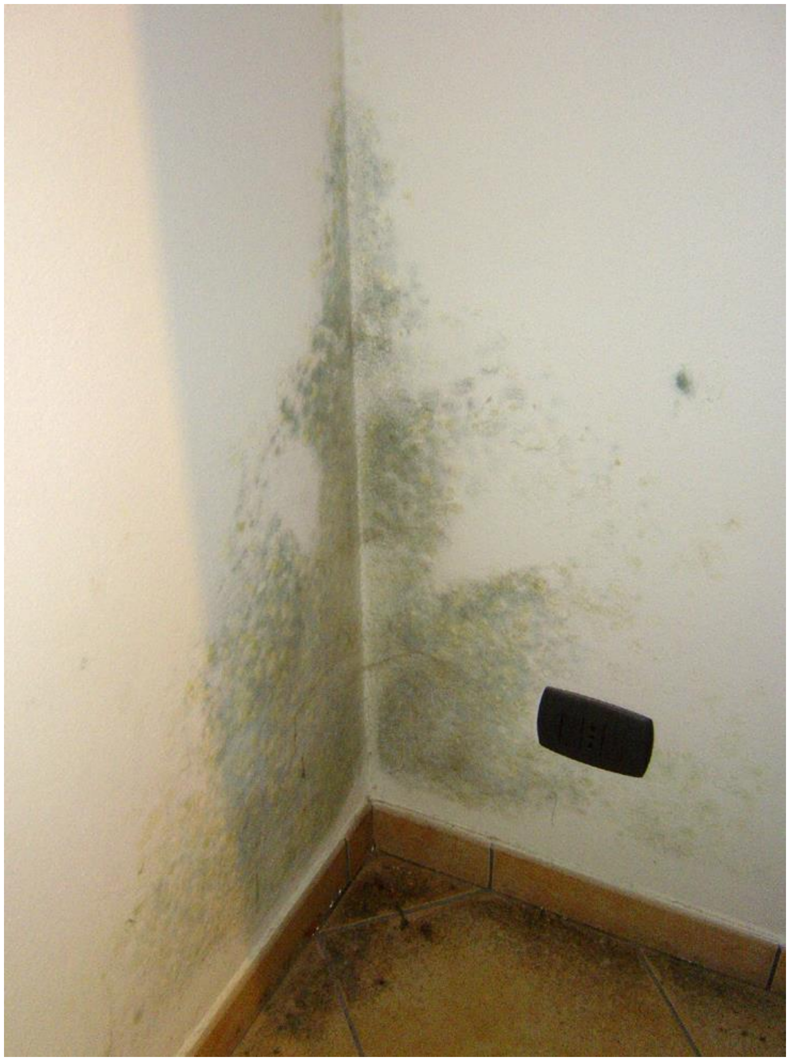
Natural air change is impossible.

GENERAL ISSUES: WHY VENTILATION?

Main indoor pollutants:

1. VOCs (volatile organic compounds): benzene, toluene, formaldehyde, oxygenated compounds
2. Gases produced by combustion
3. Airborne particulate matter
4. Bacteria, molds and other organisms
5. Organic by-products of animals and humans
6. Asbestos and mineral fibers
7. Radon
8. Cigarette smoke

THE CONSEQUENCES OF INADEQUATE AIR CHANGE



A) SURFACE CONDENSATION and possible appearance of mold

B) INTERSTITITIAL CONDENSATION and possible deterioration of building materials with consequent decrease in the degree of thermal insulation

C) LOW INTERNAL AIR QUALITY and the onset of pathologies.

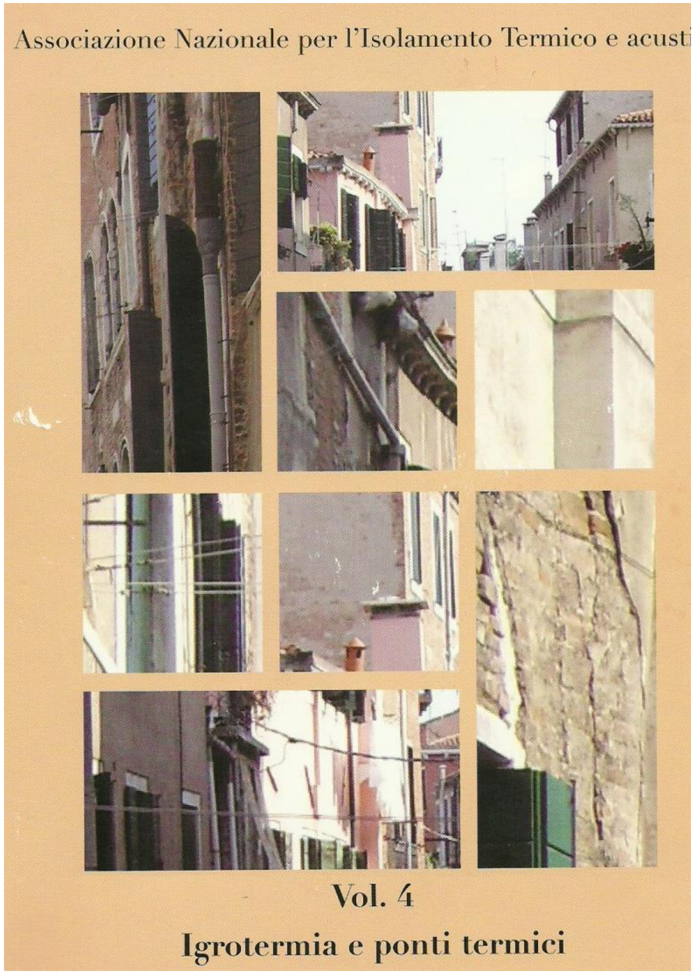
MOISTURE IN BUILDINGS

BUILDING: Unavoidable presence of moisture.

- physiologic
- pathologic

It always contains water vapor:

- normal air composition;
- consequence of vapor production for activities performed by users.



THE IMPORTANCE OF VENTILATION

VENTILATION OF INDOOR ENVIRONMENTS:

is a fundamental human need;

is indispensable for the preservation of the building structure;

must not be considered a "burden";

involves an energy requirement that varies depending on the technology adopted;

THE IMPORTANCE OF VENTILATION

- Dilution and removal of indoor pollutants
- Dilution of specific pollutants (odors from toilets - cooking vapors)
- Ensure air for metabolic activity of occupants
- Ensure control of indoor humidity and avoid the formation of condensation and subsequently mold
- Providing the right amount of combustion air in the presence of gas appliances for domestic use

POSSIBILITIES FOR AIR CHANGE

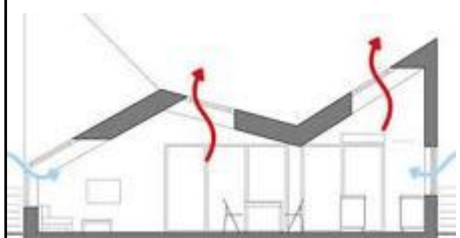
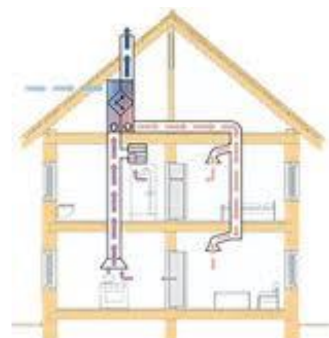
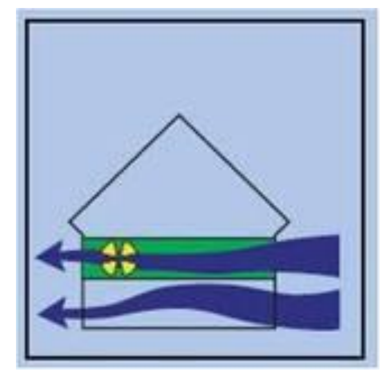
1: Opening of window frames (AERATION) and infiltration

2: Natural ventilation

3. Mechanical ventilation

4. Hybrid ventilation

System design

			
1	2	3	4

AERATION AND VENTILATION

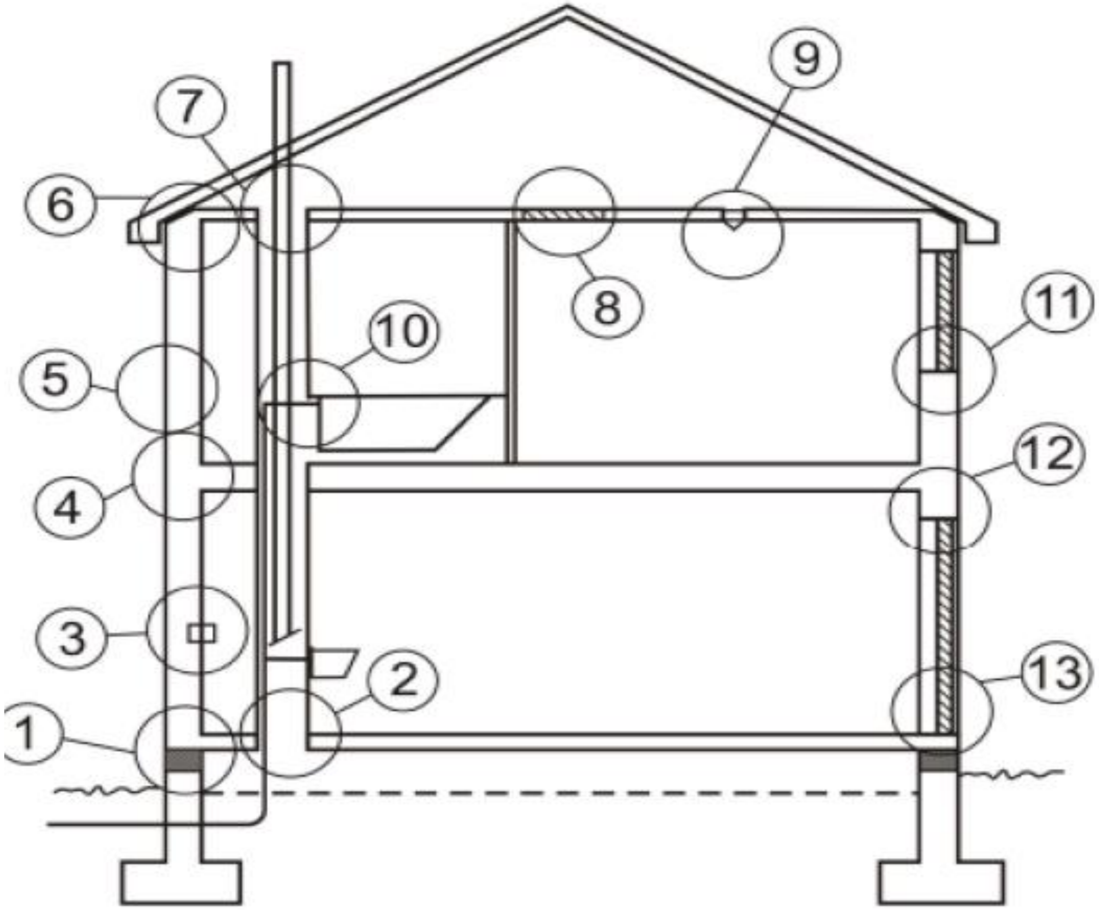
There is a frequent misunderstanding about the concept of ventilation in residential construction.

The UNI EN 12792:2005 Standard highlights the difference between "ventilation" and "aeration":

The term ventilation indicates a method of air exchange by opening windows. Ventilation, on the other hand, means the intake and corresponding extraction of air, both calculated, into and from a given space.

The Standard UNI EN 16798:2019, also clearly specifies that ventilation must be continuous in buildings when occupied, and can be decreased, but not canceled, when they are not. The same Standard indicates ventilation rates, at times of occupancy of housing, significantly higher than those tended to be suggested by energy assessment procedures and the same UNI TS 11300-1.

INFILTRATION



NATURAL VENTILATION

When openings are placed in the building envelope, the pressure differential between the various facades (or between different areas of the same facade) generated by the wind and/or the difference in temperature (and therefore density between the exterior and interior) gives rise to an internal airflow, which can be used for ventilation.

NATURAL VENTILATION

Pressure uses the principle of the chimney effect: warm air, which is lighter than cold air, tends to rise, drawing in more cold air. The temperature differences in the various rooms of the house determine a ventilation that allows the air to be exchanged.

The depression exploits the effect of the wind: when a building is hit by the wind, the wall directly exposed is subject to a strong pressure, while the wall located on the opposite side (downwind) is affected by a depression. The difference in pressure between the two facades is sufficient to create a natural ventilation of the rooms.

Ventilation according to EN 12792

Balanced ventilation (dual flow):

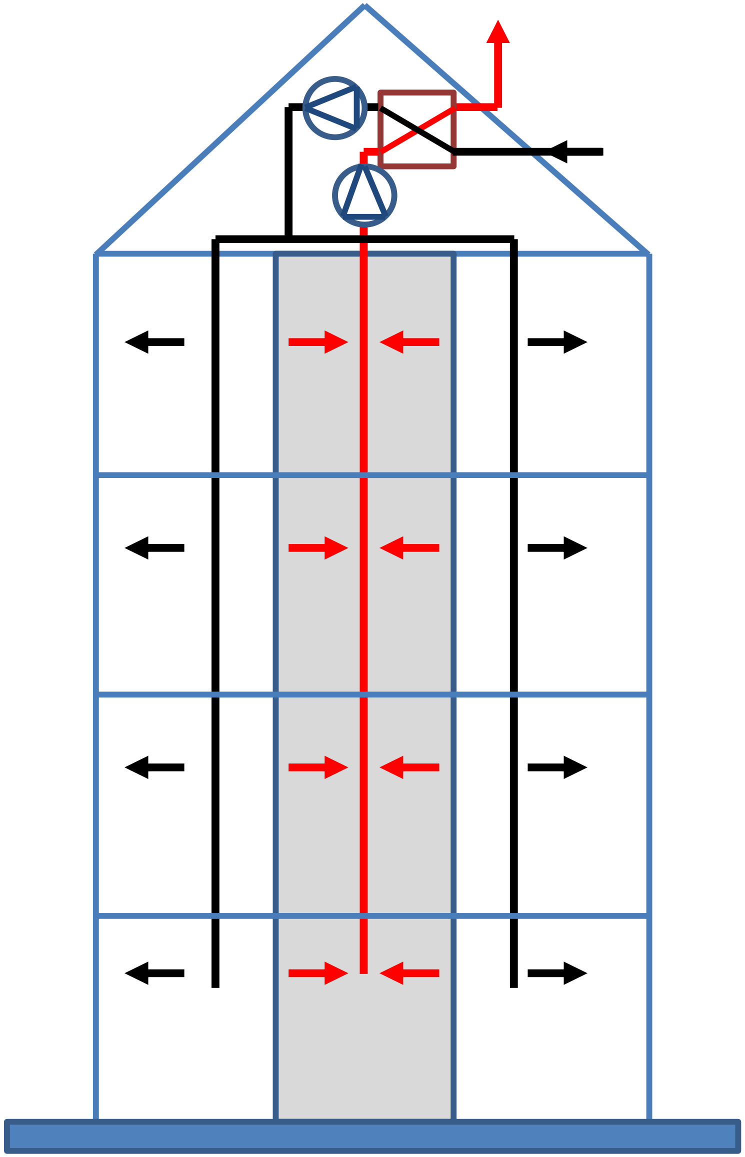
Air is supplied and taken back into the rooms.
There is a supply fan with fresh air
There is an expulsion fan with exhausted air

Pro:

- **Possibility of thermal recovery**
- **Possibility of air treatment with cooling and dehumidification coils**
- **Possible integration with GAHE (air-ground exchangers)**
- **Good air flow control**
- **Centralized maintenance**

Cons:

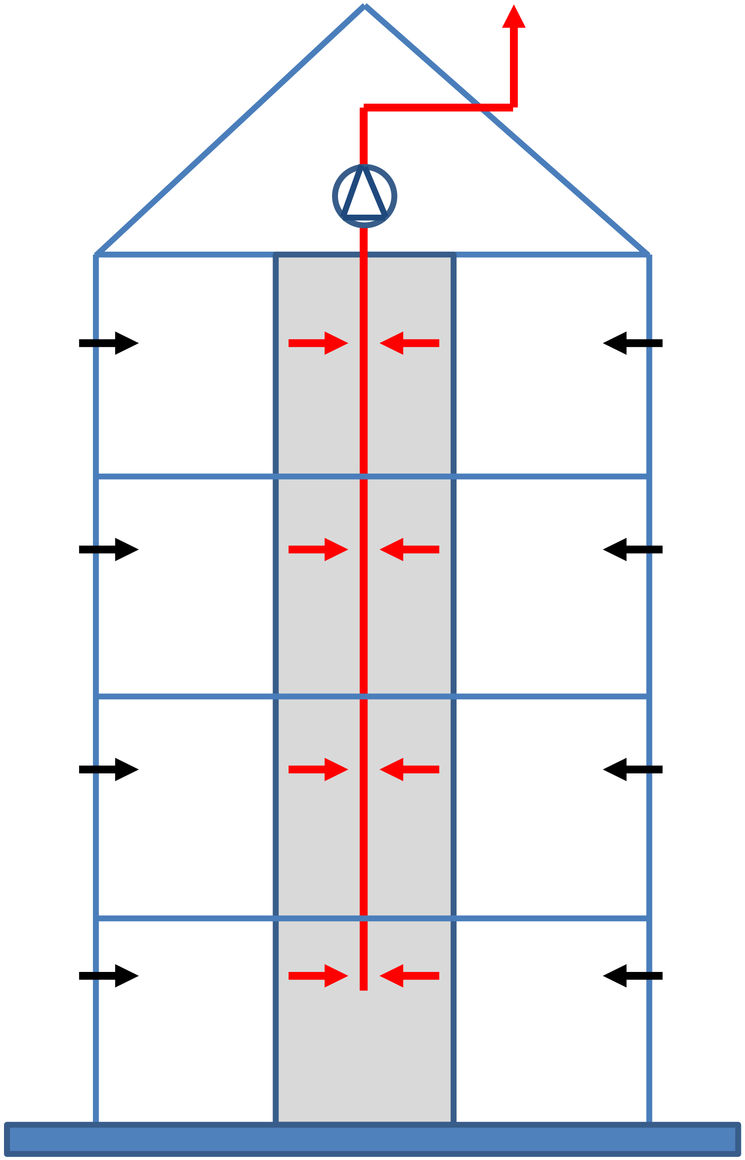
- **High costs;**
- **In case of more users, impossibility of autonomous management of the plant**



Ventilation according to EN 12792

Exhaust ventilation (single flow):

The air is returned to the rooms.
There is an exhaust fan for the exhausted air
The air enters through openings in the casing or in the window frames



Pro:

- **Inexpensive;**
- **Adjusts the opening of the vents according to the relative humidity (and therefore the actual presence of people)**

Cons:

- **Maintenance delegated to the user**
- **In case of more users, impossibility of autonomous management of the plant**
- **It does not allow heat recovery (unless you put a Heat Pump on the expulsion)**
- **There is no control on the flow rate actually entering the single environment**
- **Inlet air cannot be prehandled**

Ventilation according to EN 12792

Supply ventilation (single flow):

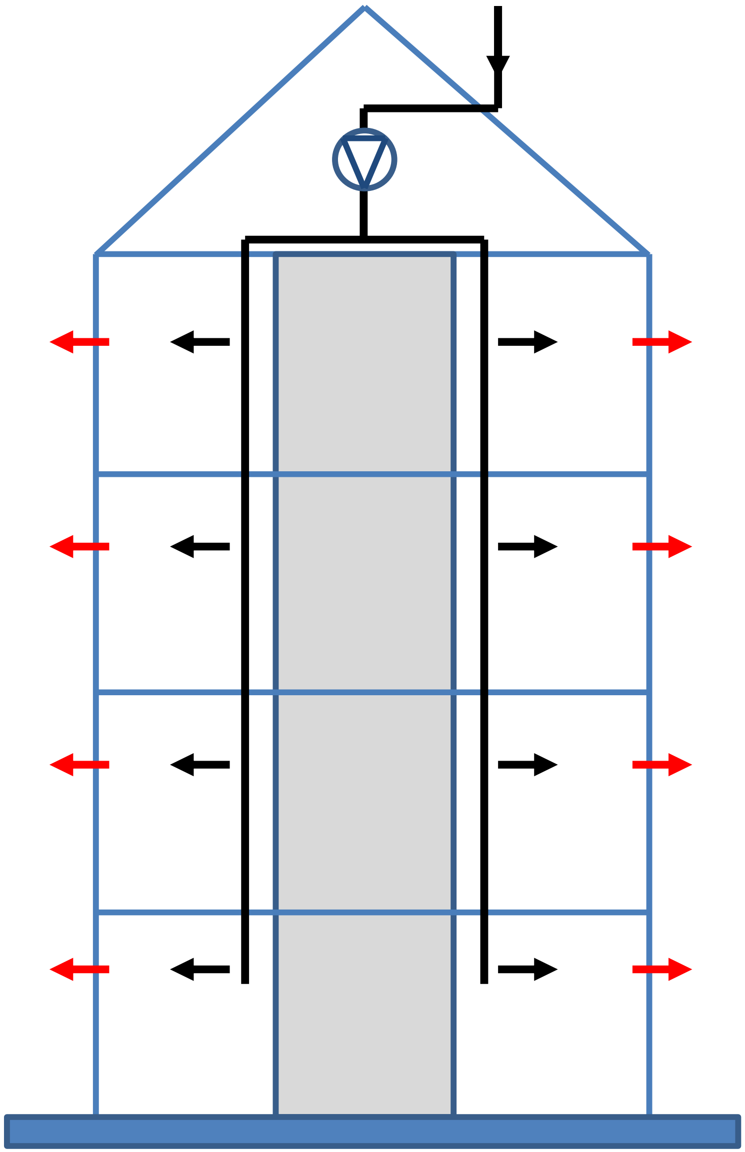
Air is returned to the rooms.
There is a supply fan with fresh air
The air exits through openings in the casing or in the window frames

Pro:

- **Possibility of air handling with cooling and dehumidification coils**
- **Possible integration with GAHE (air-ground exchangers)**
- **Good control of air flows**

Cons:

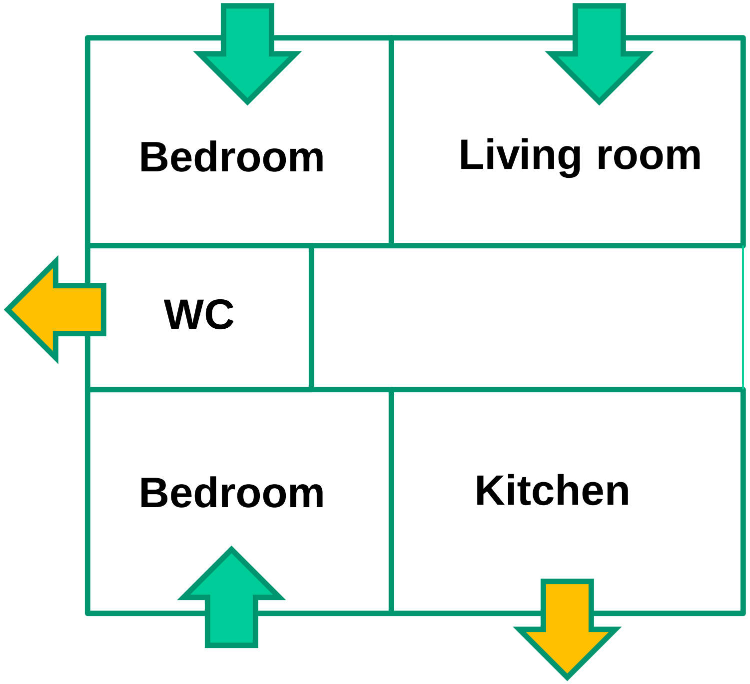
- **Maintenance delegated to the user**
- **In case of more users, impossibility of autonomous management of the plant**
- **Does not allow heat recovery**
- **Difficulty in balancing flows in operating conditions**



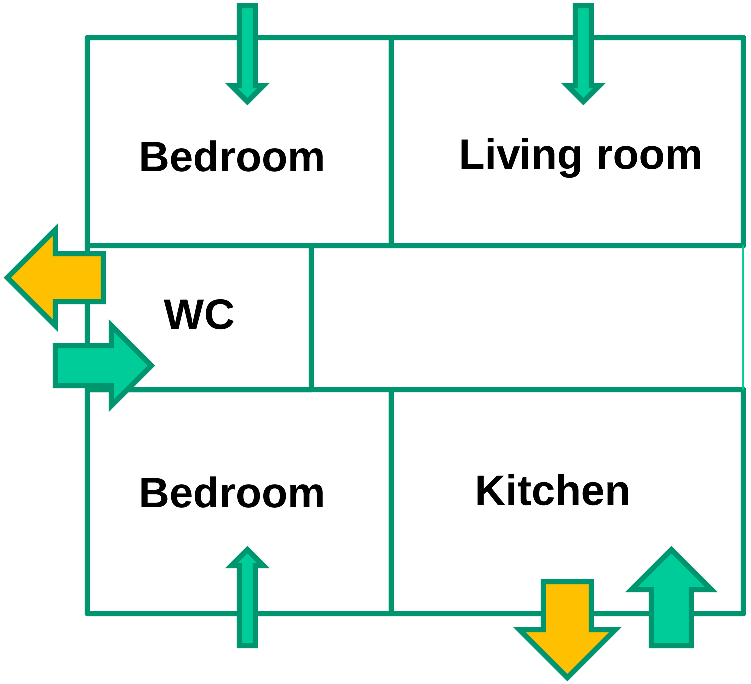
Criticality of single-flow (exhaust) vs. dual-flow ventilation

- Enclosure losses are greater than air flowing from vents
- Air enters predominantly negative pressure environments
- Result: lower effective air flow rate into the room

ideal



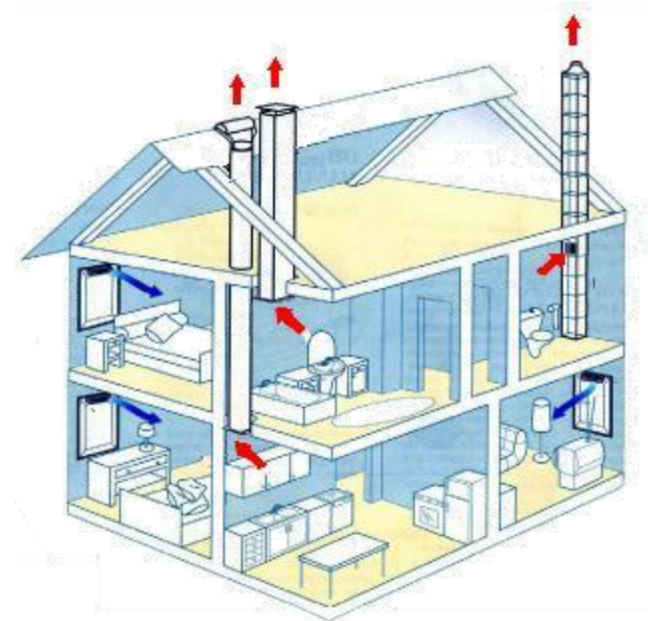
real



Mechanical ventilation

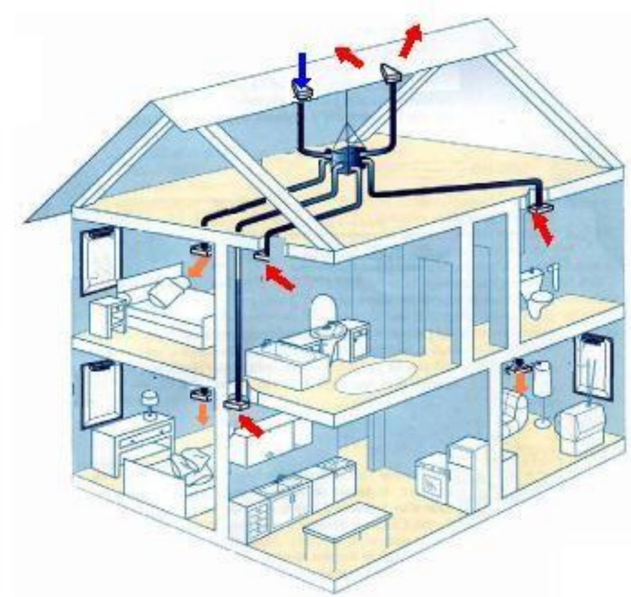
Single flow

The system provides the mechanical extraction of the stale air while the inflow of external air takes place through outlets equipped with devices for the flow rate self-regulation.



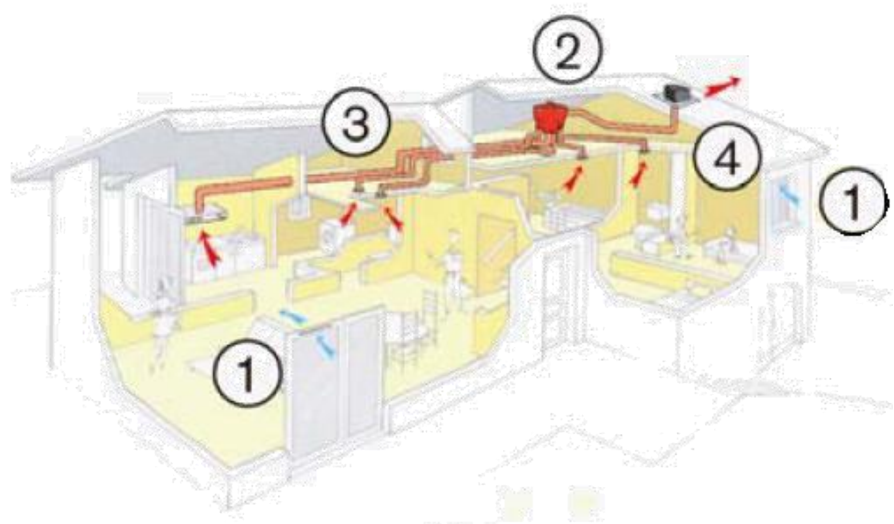
Dual-flow

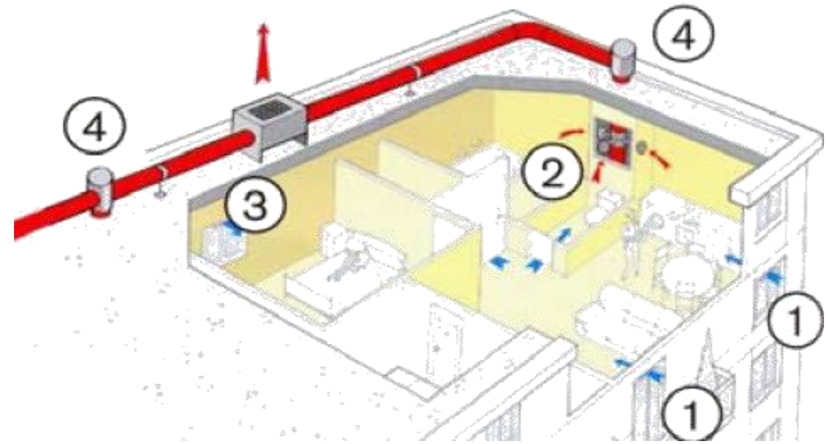
The system provides the mechanical extraction of the stale air and the contemporary introduction of fresh air which can be previously filtered and/or pre-heated before being introduced into the system.



Mechanical ventilation – Single flow

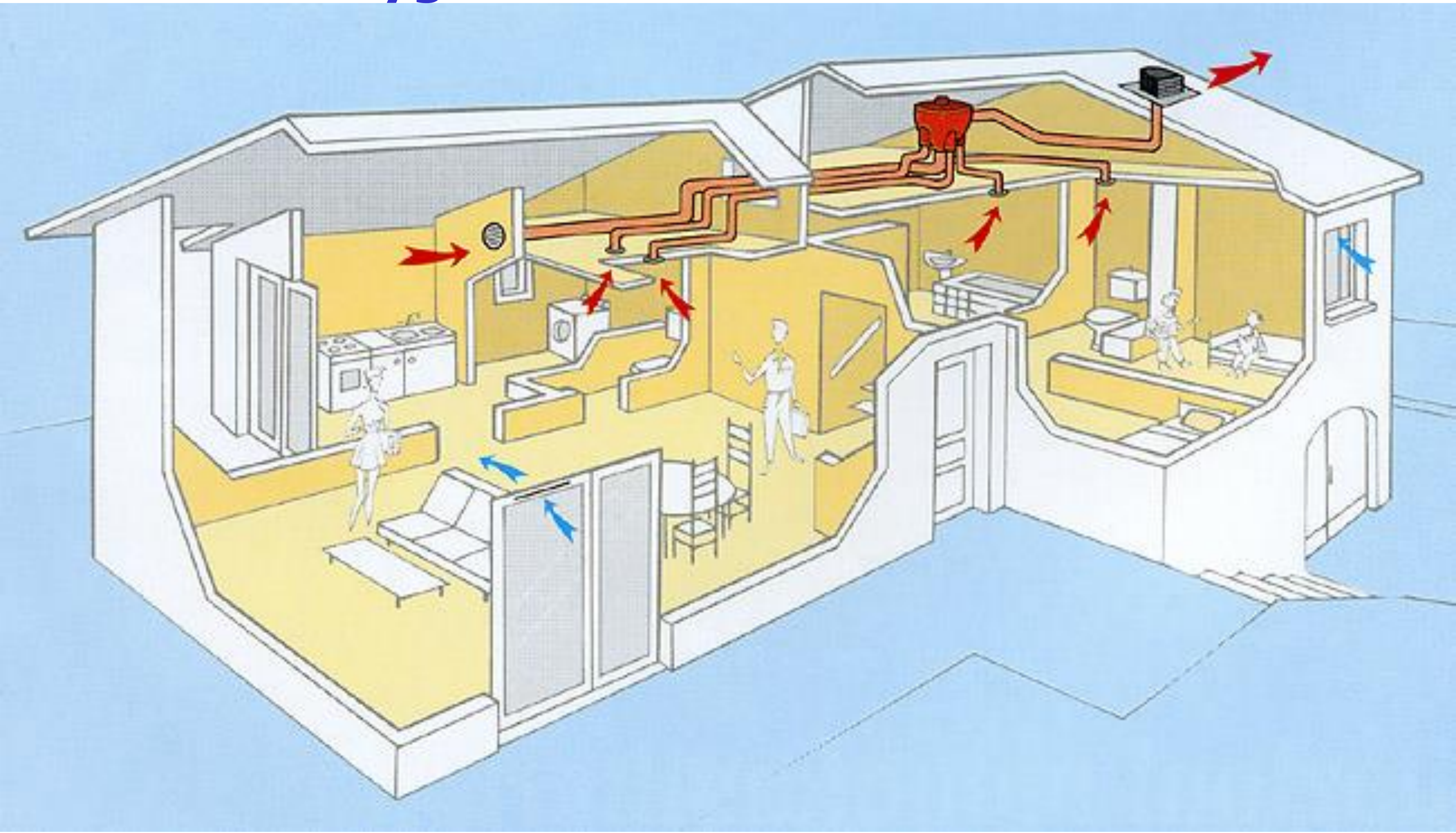
- The system consists of a small electric fan for air extraction connected by rigid and/or flexible ducts to extraction grilles located in the service rooms (kitchen and bathrooms).
- The inflow of external air takes place by means of vents, placed on the external walls or on the window frames of the "main" rooms (living room and bedrooms), equipped with self-regulating flow rate devices or devices sensitive to the relative humidity of the environment.
- For centralized condominium installation, a single fan is installed (in the attic or outdoors) from which a series of ducts branch out connecting the risers.





1) Air inlet
2) Extraction
3) Ducts
4) Exit on the roof

Single-family flow (self-regulating or) hygro-controlled ventilation



Mechanical ventilation – Single flow

Pro:

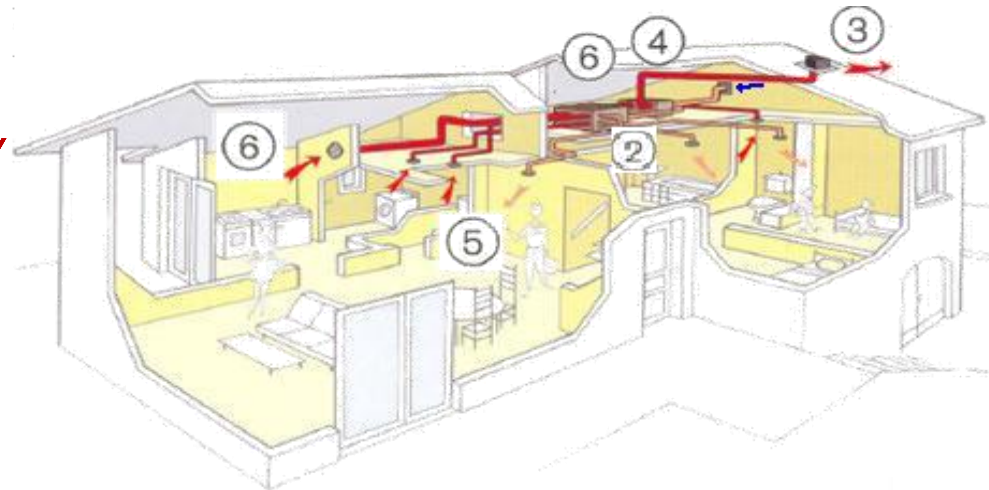
- Air flow control
- Possibility of integration with natural ventilation
- Independence from inconstant weather factors or random occupant behavior
- Adaptability to seasonal climatic conditions
- Limitation of ambient noise
- Control of air speed in the environment

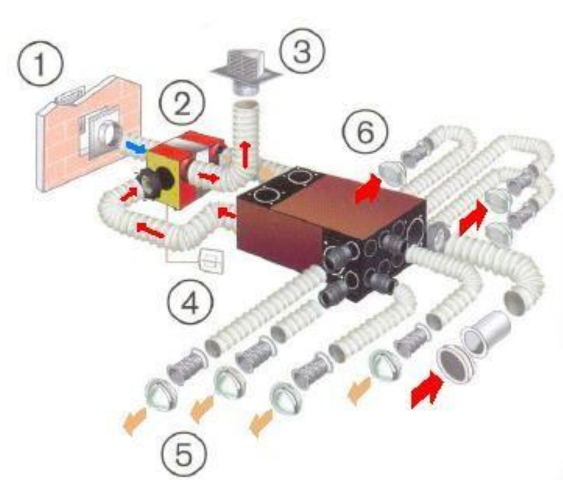
Cons:

- Cost of the plant and its operation
- Impossibility to control the quality of fresh air
- Energy loss in the cold season
- Intake of too hot air in summer

Mechanical ventilation – Dual flow

- *A dual-flow system mechanically provides both supply and return air to the room.*
- Extraction is the same as for single flow systems.
- The inlet is also made through ducts and vents in a separate circuit from the previous one.
- The inlet and outlet flows are coordinated by a control system





1) Inlet + filter
2) Fan
3) Roof extraction
4) Heat exchanger
5) Inlet points
6) Outlet points

Mechanical ventilation – Dual flow

In more complex systems, it is possible to handle the fresh air before it is introduced into the environment, i.e. filter it, cool it or heat it, humidify it or dehumidify it. Finally, with dual-flow systems, energy recovery is also possible of the exhaust air through heat recovery units.

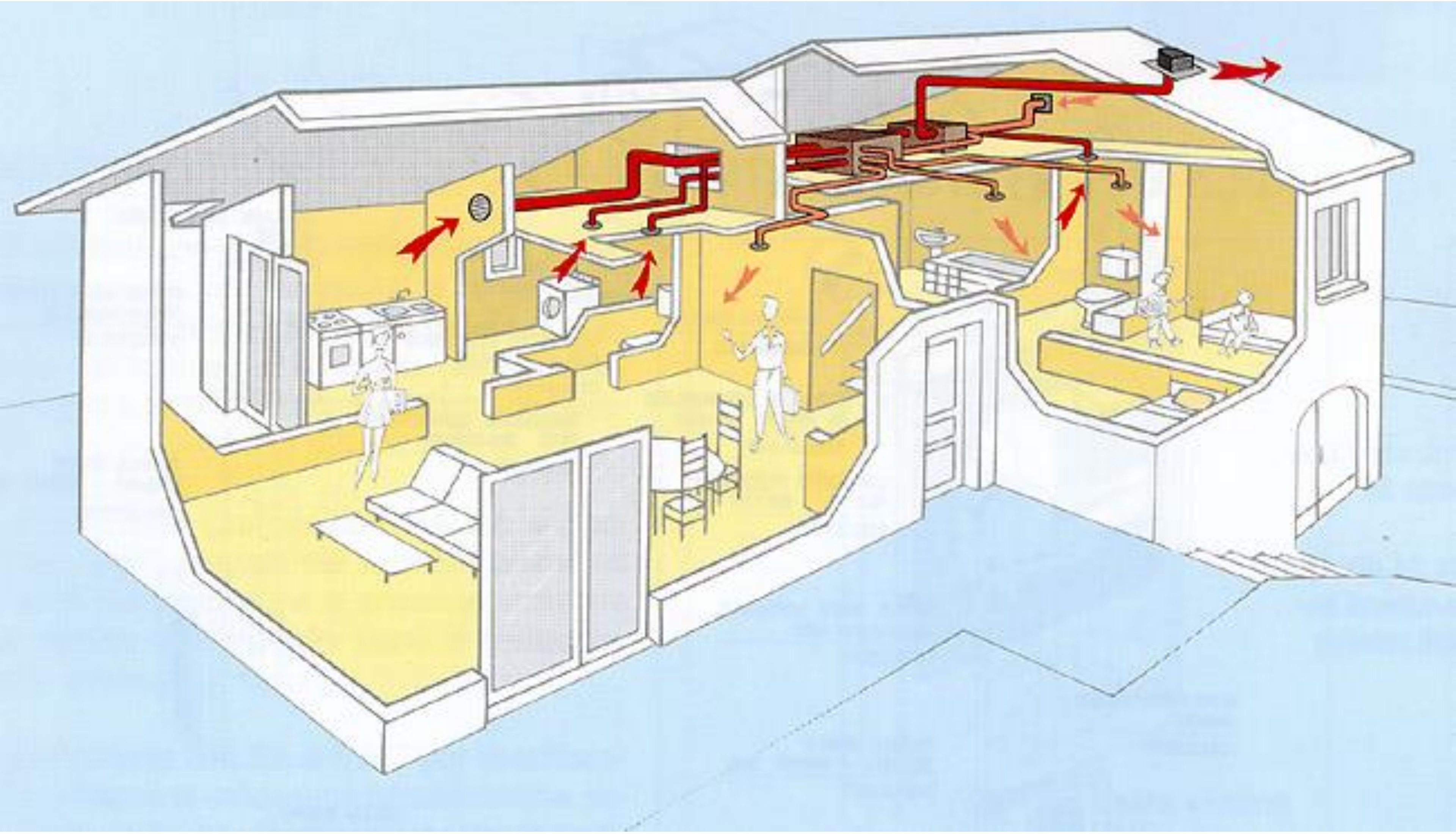
Pro:

- Air flow control
- Possibility to combine a heat recovery unit
- Possibility of integration with natural ventilation
- Independence from inconstant meteorological factors or random behaviors of the occupants
- Adaptability to seasonal climatic conditions
- Limitation of noise in the environment
- Control of air speed in the room
- Control of fresh air quality

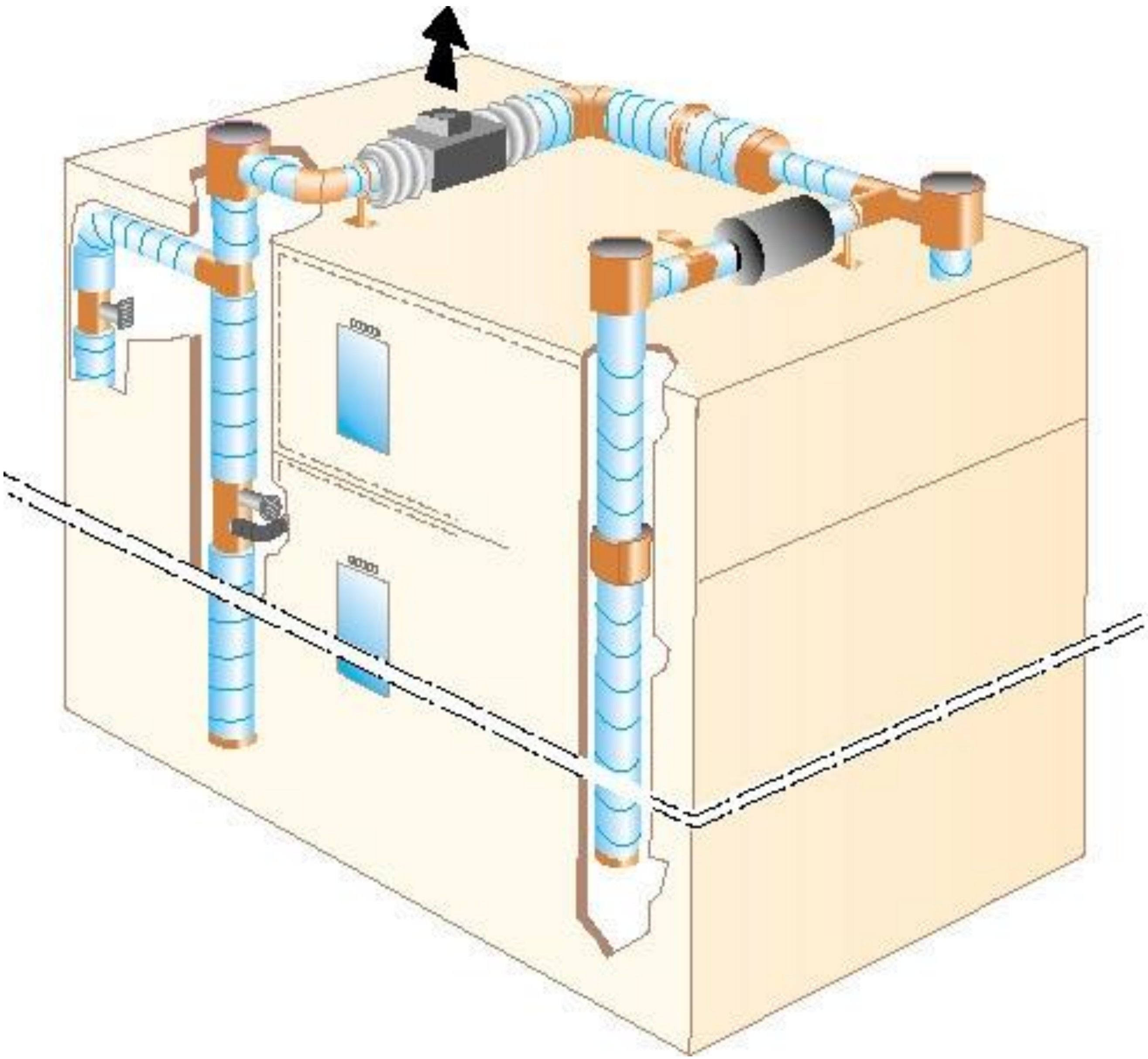
Cons:

- Costs

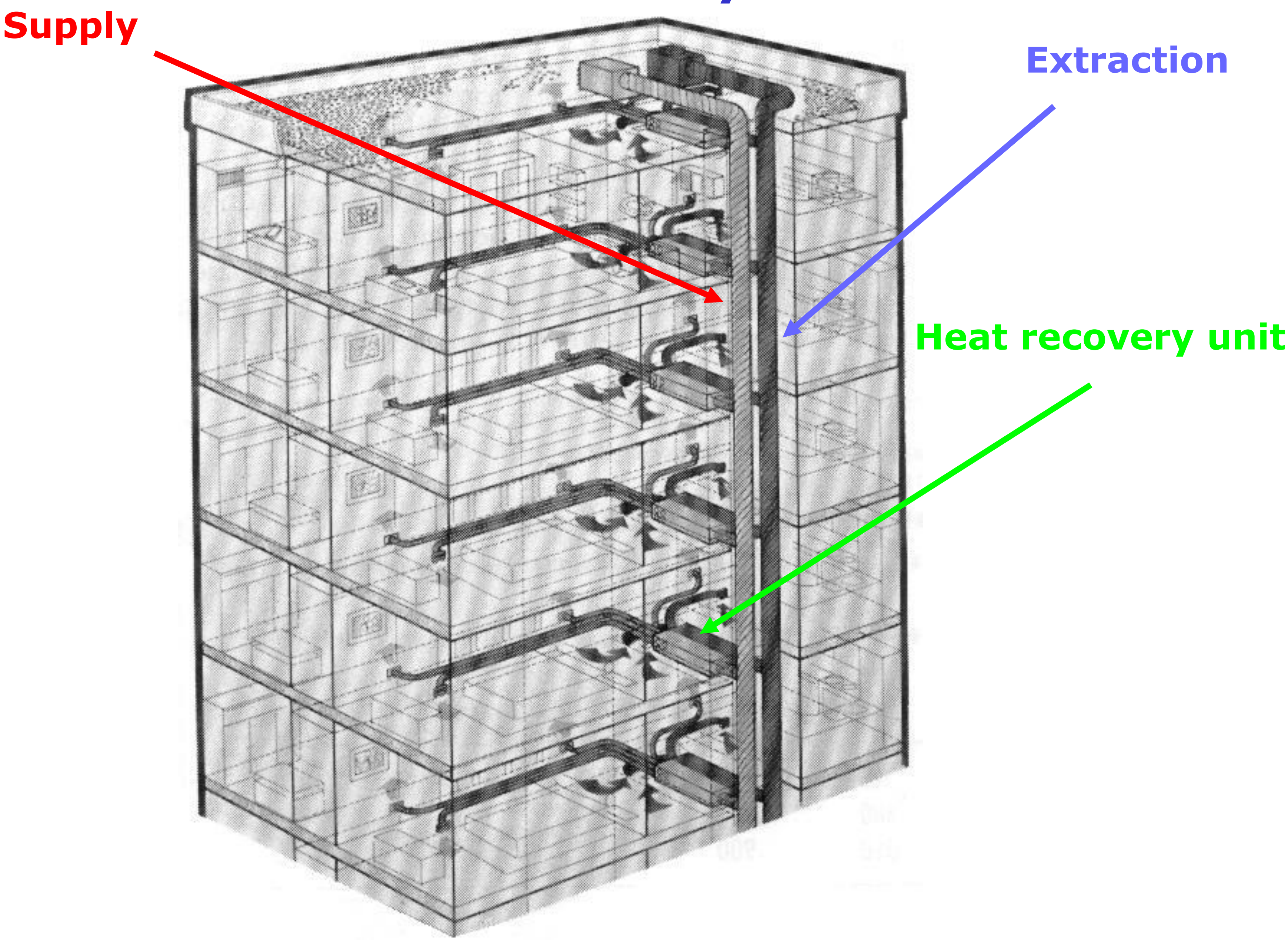
Single-family dual-flow ventilation with heat recovery



Single Flow Ventilation in Apartment block



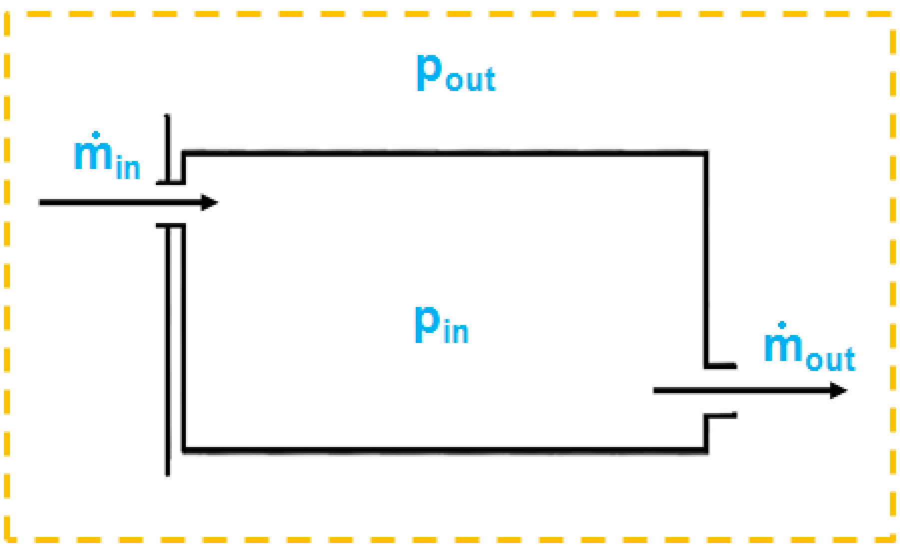
Dual-Flow Ventilation in Apartment block with heat recovery



Mechanical ventilation - local conditions

Pressurized room → If you want to prevent air from entering you create an overpressure → $p_{in} > p_{out}$, $m_{in} > m_{out}$

De-pressurized room → If you want to prevent the air from escaping you create a depression → $p_{in} < p_{out}$, $m_{in} < m_{out}$



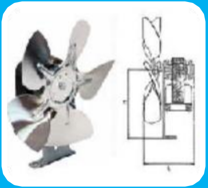
FANS

- Fans force air into (out of) the interior (exterior) of the building
- They can be placed in false ceilings, in the attic or outside the building.

On the roof

Axial fan

Centrifugal fan



Low flow axial fan

Low flow compact axial fan

Ducts and tubes for forced ventilation










- Ventilation ducts and pipes are spiral galvanized sheet metal ducts of variable diameter designed to convey fresh air inside the room and stale air outside.

- In case of narrow cavities (in the case of renovations) oval ducts can be used, obtained through a process of crushing the circular model.

- In the connection sections of the outlets with the main network flexible channels are used, usually also in galvanized steel.

Cloth filters

- They consist of a mesh of fibers whose dimensions are much smaller than the distances between them (so that the airflow is not greatly disturbed by the filter). The depth of the filter is much greater than the size of the particles, which are therefore forced to take a long and tortuous route through the filter.
- The air flow passes through the filter fibers and, solid particles with a diameter larger than the distance between the fibers constituting the filter, are stopped exactly as it happens through a sieve (sieve filtration mechanism). Smaller particles, on the other hand, are fixed along the filter fibers by elementary electrical forces.

Flat Panel

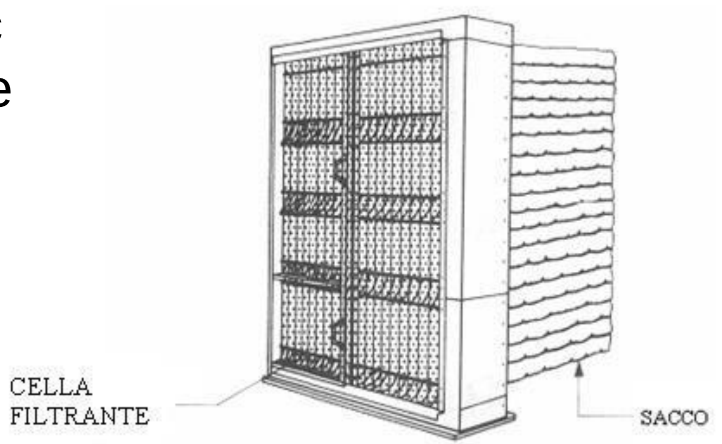
With rigid pockets

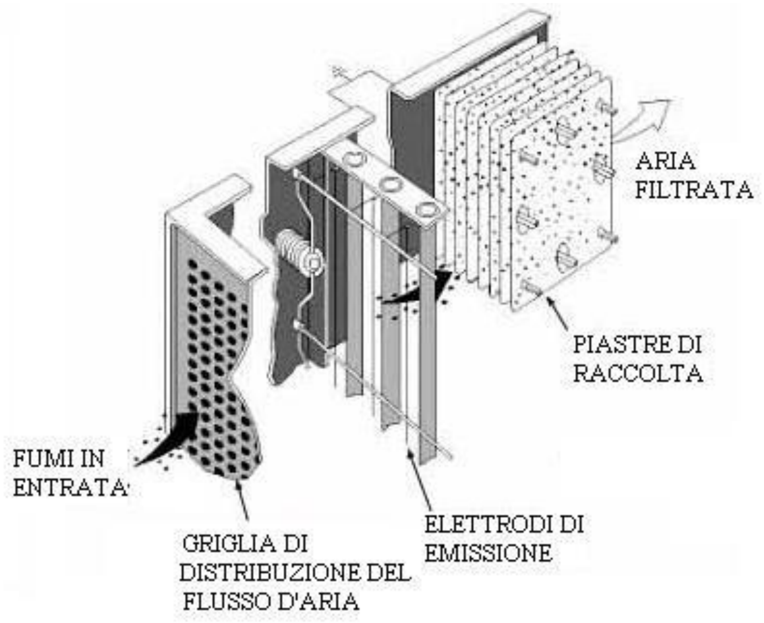
With floppy pockets

Roller

Electrostatic filters

- The process involves the use of an electric field that positively or negatively charge the solid or liquid particles present in the gaseous emissions.
- The electrically charged particulate matter is deposited by electrostatic attraction on the collection electrode from where it can be removed as dry material (dry electrofilters) or washed away with water (wet electrofilters).
- This removal is always essential since the layer of material that is deposited decreases the intensity of the electric field and therefore the effectiveness of abatement.

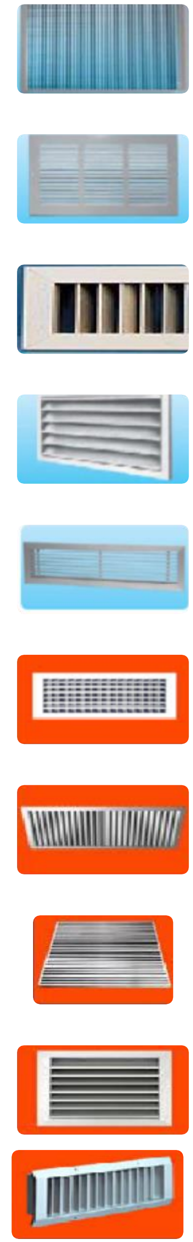


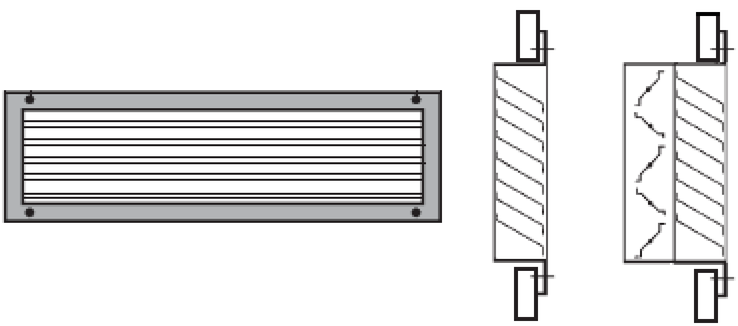


Inlet vents

- The penetration of the inlet jet depends on the inlet velocity and the inlet area.
- The higher the input speed and the higher the velocity, the more penetrating the jet is

Inlet vents





a) b) c)

Supply air vents

- Self-adjustable: they are equipped with deformable PVC membranes that modify the passage section; they are sized to introduce in the rooms the same quantity of air that is extracted from the services to make up for the internal depression.
- Adjustable: they are equipped with a humidity sensor directly connected to a calibration damper (if humidity tends to fall, the device limits the air flow, maintaining a minimum value); they must be installed in the main rooms of the house (bedrooms, living room) in order to create a wash in the direction of the technical compartments.

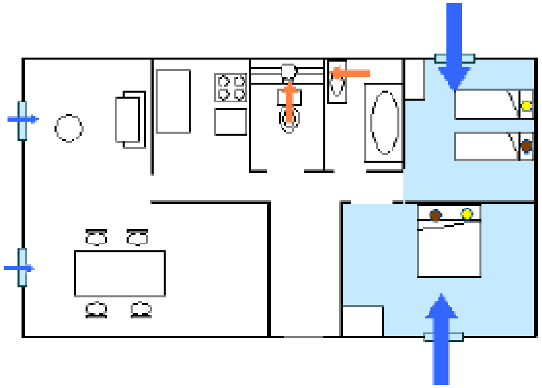
They can be installed on the upper part of the box or frame and on the window frame; they are of the linear type made of plastic and equipped with soundproofing.

Outlet air vents

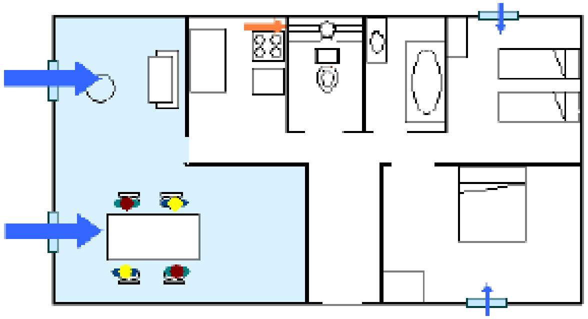
Self-adjustable: they are made of PVC and have, at the center, a self-adjustable regulating device consisting of a rubber membrane that modifies the air passage section according to the pressure it is subjected to.

Hygro-controlled: made of PVC, they have a humidity sensor in the center and a membrane capable of regulating the amount of extraction air according to humidity; it works for pressure differences between 70-130 Pa.

The total ventilation rate calculated for the sleeping area is extracted from the wall vents in the bathroom, while the ventilation rate for the living area is extracted from the wall vent in the kitchen.

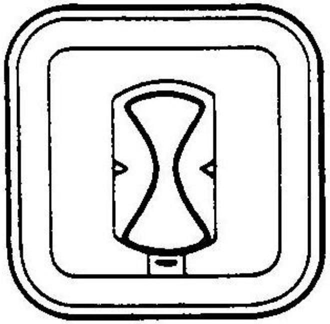


Night

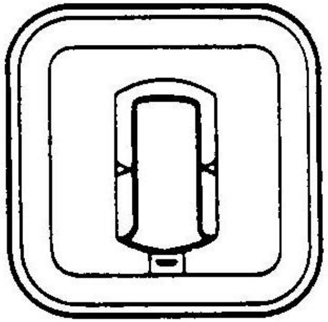


Day

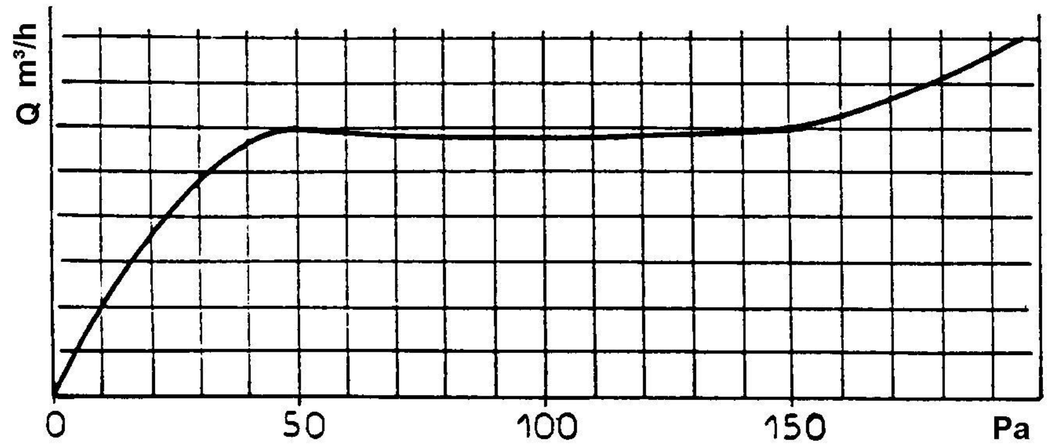
Example



MEMBRANA A RIPOSO



MEMBRANA SOTTOPOSTA A UNA DEPRESSIONE



Diagram

Self-adjustable air vents

In winter in the coldest periods there is still entrance from infiltration (not perfectly sealed envelope) because of the large internal-external Δt which causes large internal-external Δp.

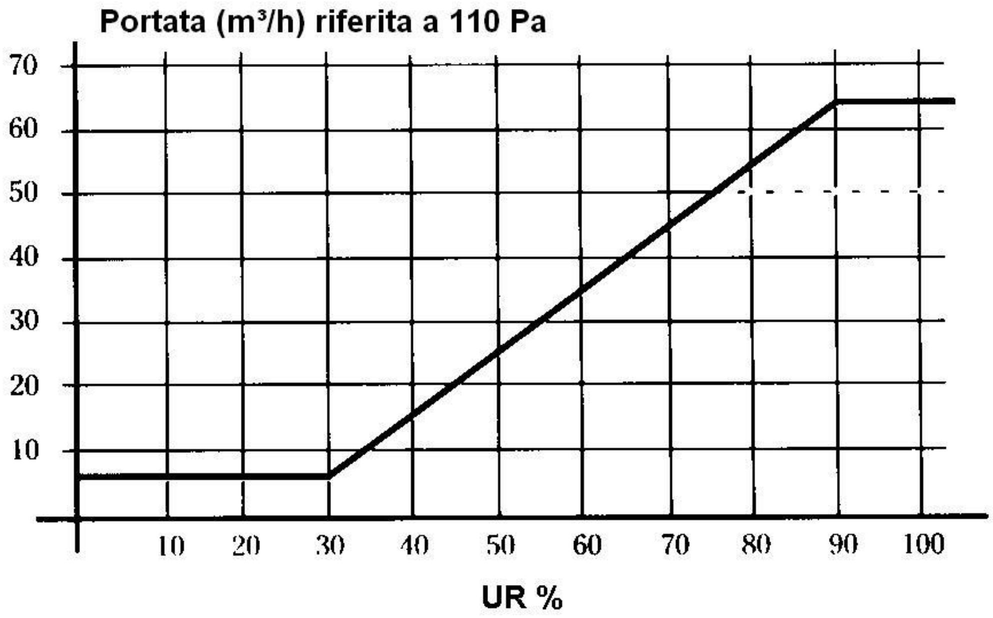
The sealing aspect of the envelope is all the more important the colder the winter climate.

Example

Hygro-controlled

Presence of a hygroscopic element that opens or closes the vent depending on the RH in the room.

It can be installed for inlet (more frequent or for expulsion)



It can provide variable flow rate (different ventilation needs in presence/absence of people in residential). A variable speed fan is needed.

In case of high infiltration in cold periods the relative humidity drops and therefore the vents limit the air entering the room.

Examples

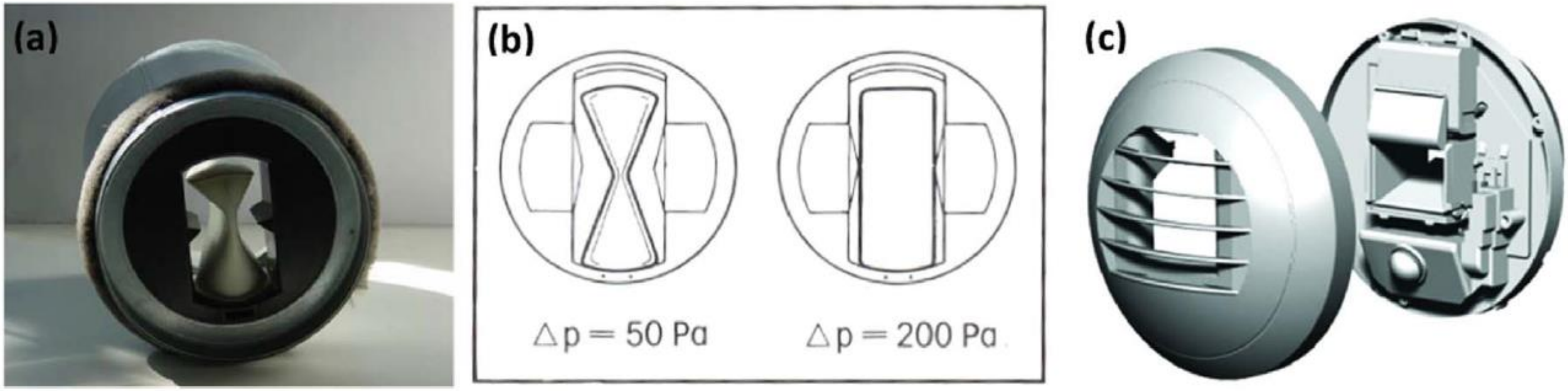
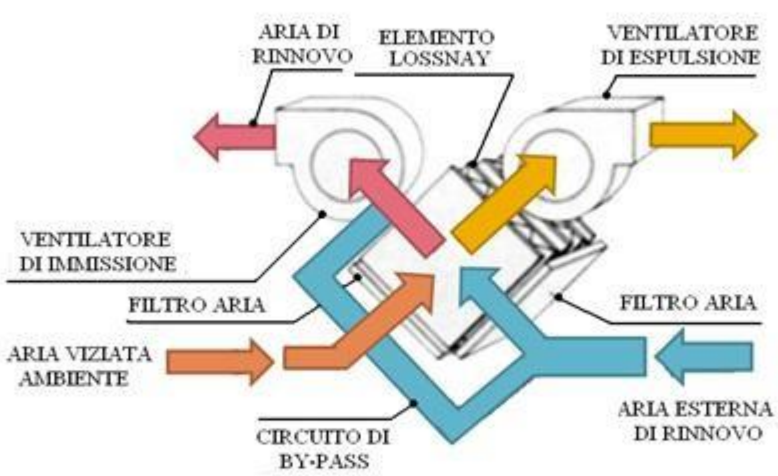


Fig. 1. (a, b): Constant flow extract unit with auto-adjustable silicon membrane [source: Aldes]; (c): Hygro-adjustable extract unit [source: Ecoclima].

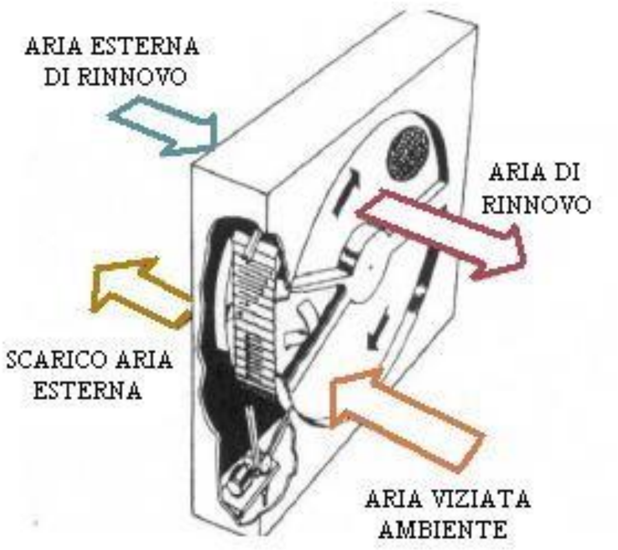
Heat recovery unit

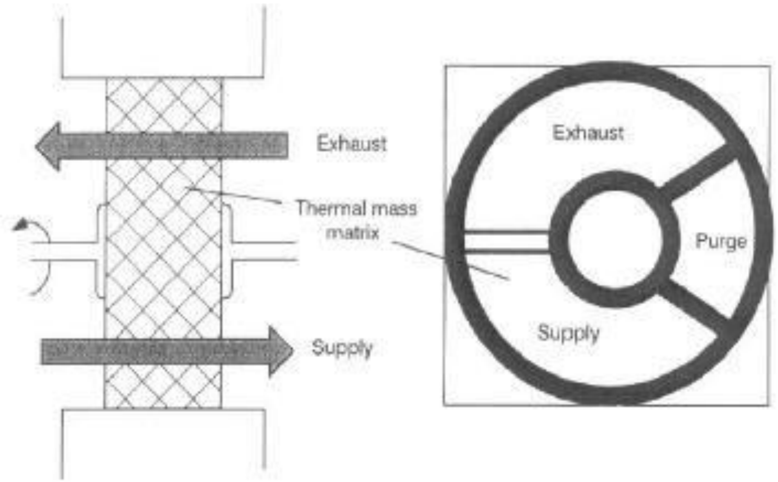
Through heat exchangers called heat recuperators it is possible to recover part of the thermal energy possessed by the outgoing air flow in favour of the incoming flow. This type of plant allows to extract the stale air and introduce into the environment preheated. This type of plant allows to extract the stale air and introduce in the environment at the same time fresh air preheated without additional energy costs.



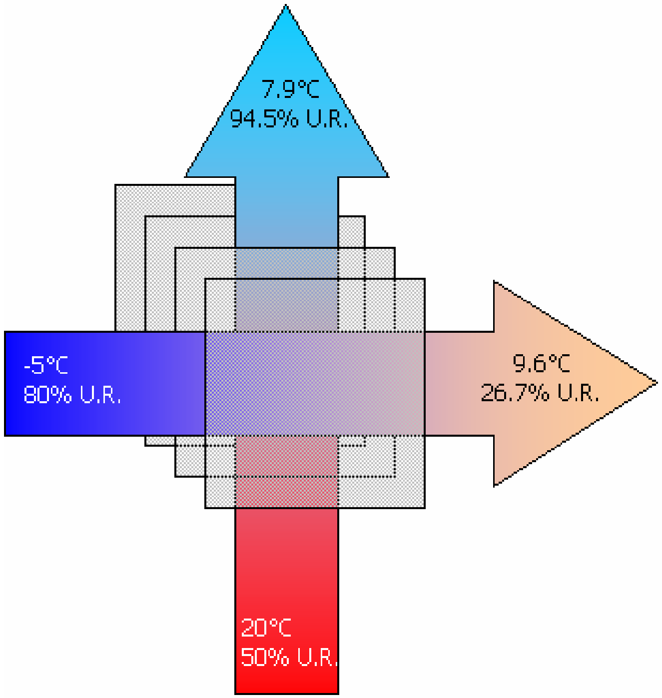
Inside the recuperators the outgoing and incoming air flows cross each other (without mixing), so that the hot air flow cools down while the other one heats up.

Heat recovery unit





Heat recovery unit



- Continuing to recirculate always in the same environment, the air is loaded with carbon dioxide and pollutants, it must be replaced.
- Fresh renewal air, oxygenated, should be taken from outside, heat treated and sent to the environment.
- The resulting increase in energy costs can be contained by using a system that recovers a large part of the heat contained in the exhaust air stream and transfers it to the fresh air stream.

Heat recovery unit

Heat recuperators used in air conditioning systems are exchangers that allow the transfer of heat and/or humidity between a flow of exhaust air and a flow of supply air, under the action of a difference in temperature (or humidity).

A distinction is made between heat recuperators and heat recovery units; the latter are made up of, in addition to the recuperator itself, a series of accessories such as filters, pre-heating devices, dampers, regulation equipment, assembled in a box with flanges for connection to the ducts.

Heat recovery unit: efficiency

The efficiency of a heat exchanger, according to ASHRAE Standard 84, is defined as the ratio of the energy or moisture actually transmitted to the maximum transmissible values

$$\varepsilon = \mathbf{W_i\,(X_{iu}-X_{ii})\,/\,W_{min}\,(X_{ei}-X_{ii}) = W_e\,(X_{ei}-X_{eu})\,/\,W_{min}\,(X_{ei}-X_{ii})}$$

where:

ε = efficiency (sensible, latent ot total)

X_{ii} = supply inlet temperature or humidity or entalpy

X_{iu} = supply outlet temperature or humidity or entalpy

X_{ei} = exit inlet temperature or humidity or entalpy

X_{eu} = exit outlet temperature or humidity or entalpy

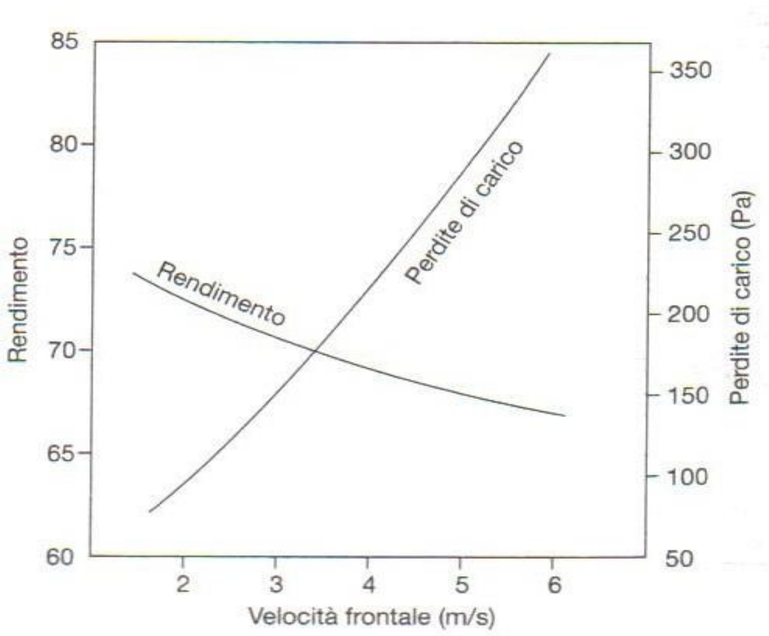
W_i = supply flow rate

W_e = exit flow rate

W_{min} = the lesser of W_i and W_e

In the case of temperature efficiency, the flow rates should be multiplied by the specific heat of the dry air.

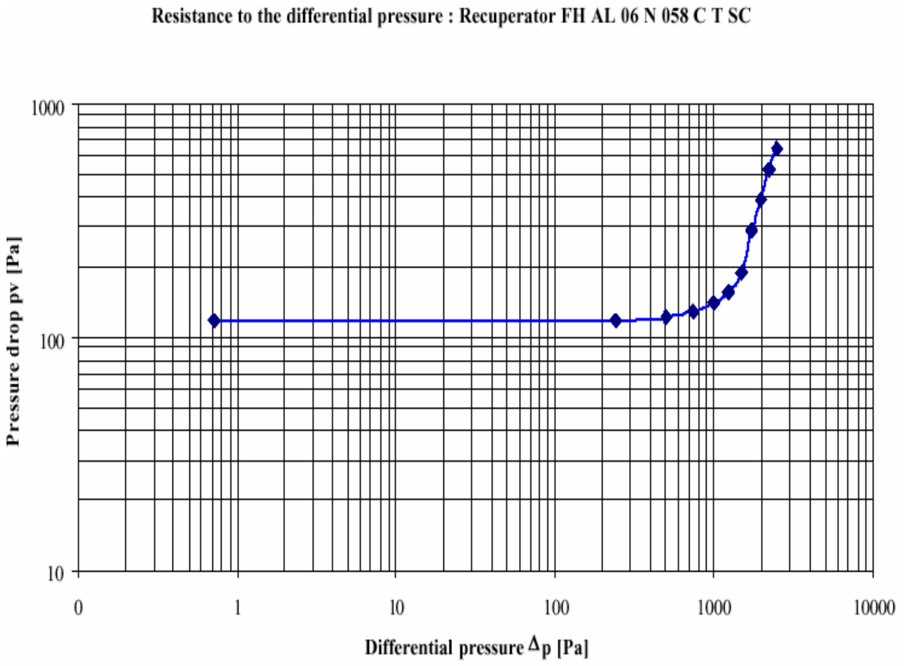
Heat recovery unit: pressure loss



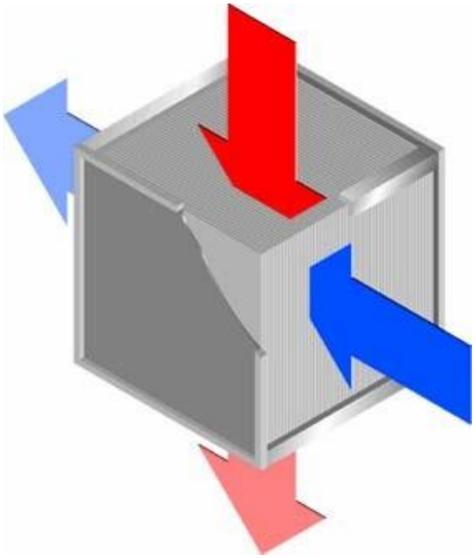
The pressure drop of a recuperator is defined as the total pressure difference, measured on each of the two flows, between the inlet and the outlet of the recuperator. This pressure drop must be compensated for the head of the fan.

Heat recovery unit: differential pressure

The two flows crossing the recuperator can have a different pressure. This pressure difference (differential pressure) affects the flow rate leakage from the unit. In addition, the mechanical structure of the unit must be adequate to resist the deformation generated by the differential pressure.

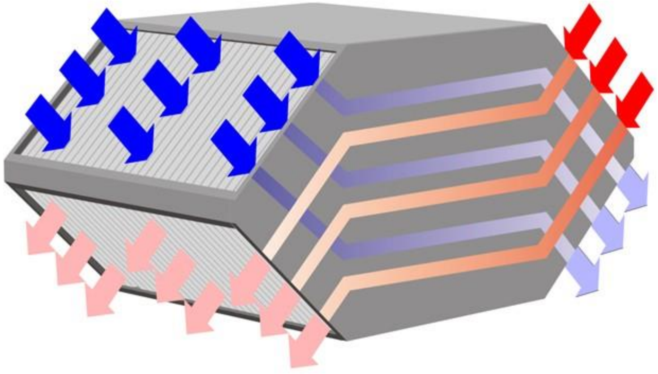


Static plate heat exchangers



They have the possibility of recovering both sensible and latent heat.

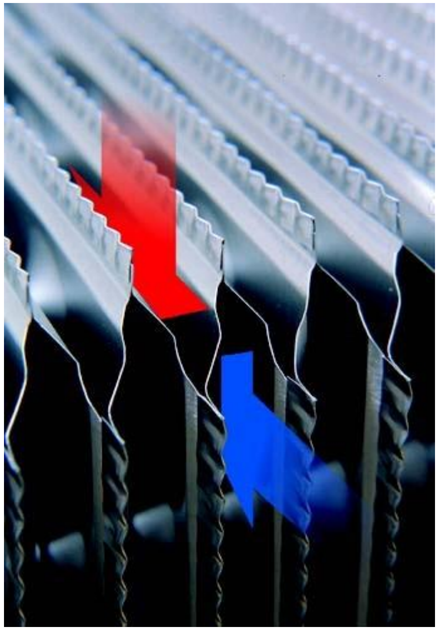
In fact, when the walls of the exchanger are colder than the dew temperature of the extracted air, the steam contained in it condenses and the condensation heat is transferred to the fresh air. In case of condensation it is advisable that the fins are arranged vertically.



Normally the air movement is cross-flow and the efficiency has values between 40 and 70%.

Counterflow models are also available with efficiencies of over 80%, but with a higher unit cost.

Static plate heat exchangers



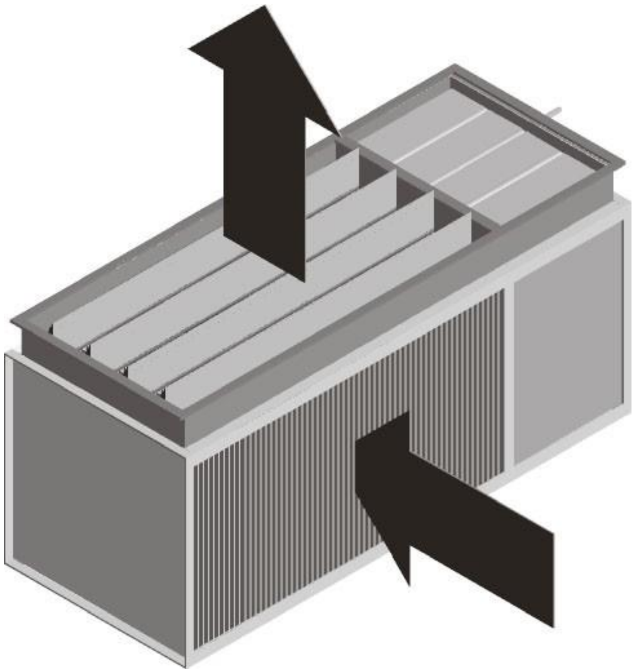
They are made up of flat layers, with variable spacing depending on the type of use. The exhaust and inlet flows are kept separate by special seals. The heat is transferred directly from the flow at warmer temperature to the one at colder temperature.

The overall resistance to heat transfer of the recuperator is composed of convection on both faces of the plate and conduction through the thickness of the plate.

Static plate heat exchangers

The material from which plates are commonly made is aluminum because of its corrosion resistance, ease of fabrication, flammability and durability.
In more corrosive environments, aluminum can be protected with an acrylic paint. In the presence of high temperatures (over 200°C) and where cost is not a key factor, stainless steel alloys are used.
For low cost requirements combined with corrosion resistance, plastic or even glass materials are used.

Heat recovery unit: control



In many cases, other heat sources (people, machinery, lighting, etc.) are present in the ventilated space and bring additional heat to the system.
Under certain conditions, overheating may occur.
In these conditions the power of the recuperator must be reduced.
In the plate heat recuperators a bypass damper is used that excludes from the recovery treatment a part or all of the external air.
This method of reducing the flow rate, by means of the bypass damper, is also used when there is a risk of frost in the winter period.

Static plate heat exchangers

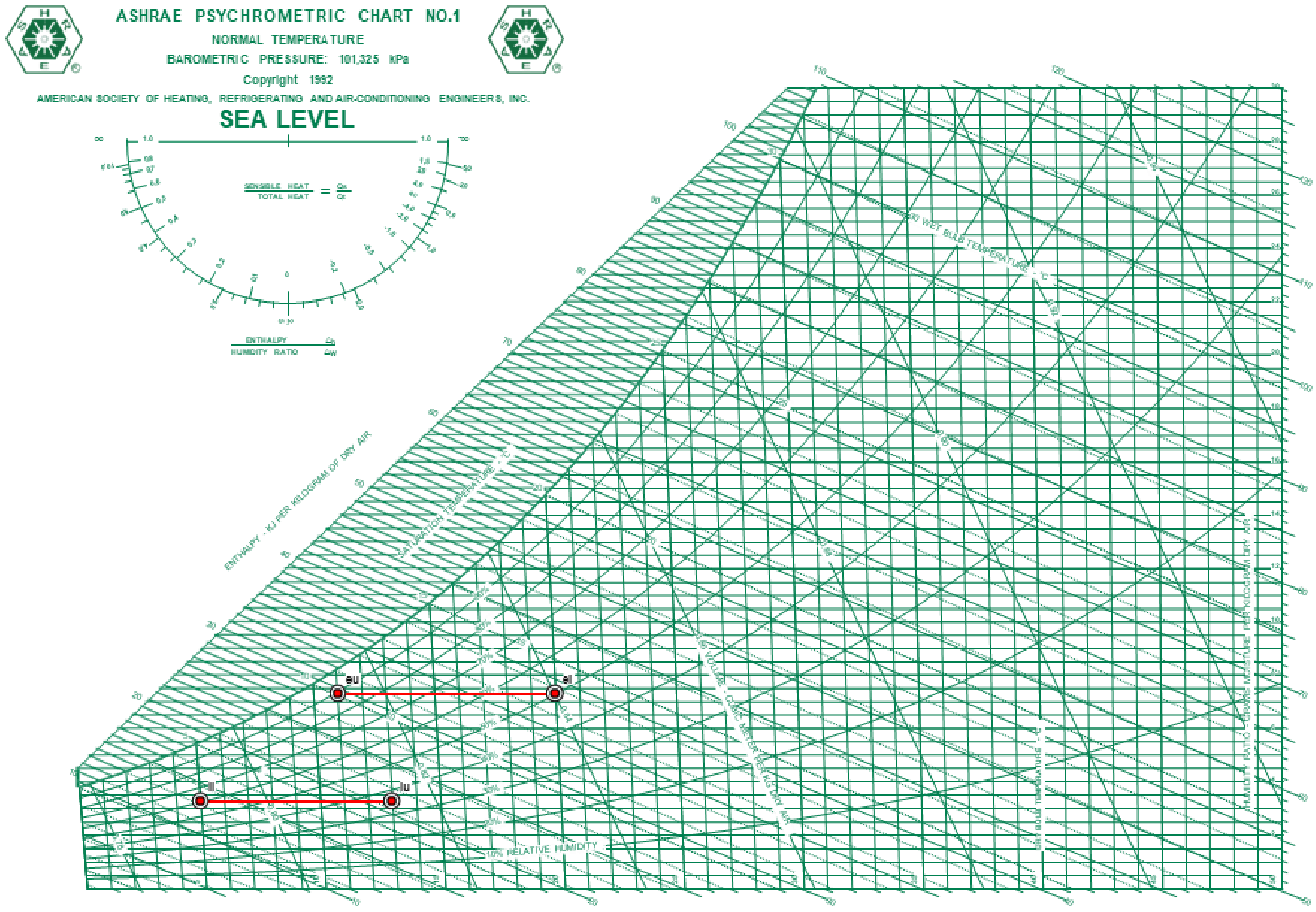
Pro

- little or no contamination between streams
- no moving parts
- flexibility of construction that adapts them to any use
- manufactured with materials adapted to the characteristics of different environments
- low pressure drops
- easy cleaning
- effective noise dampening action

Cons

- The latent heat transfer occurs only on condition that the surface temperature of the recuperator falls below the dew point of one of the two air streams, condensing the humidity present.
- The two air flows, exhaust and fresh air, must be contiguous.

Example



ASHRAE PSYCHROMETRIC CHART NO.1
NORMAL TEMPERATURE
BAROMETRIC PRESSURE: 101.325 kPa
Copyright 1992
AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS, INC.
SEA LEVEL
SENSIBLE HEAT / TOTAL HEAT = Qs / Qt
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
ENTHALPY - KJ PER KILOGRAM OF DRY AIR
SATURATION TEMPERATURE - °C
WET BULB TEMPERATURE - °C
VOLUME - CUBIC METER PER KG DRY AIR
10% RELATIVE HUMIDITY
DRY BULB TEMPERATURE - °C
HUMIDITY RATIO - GRAMS MOISTURE PER KILOGRAM DRY AIR
eu
el
lu

Example

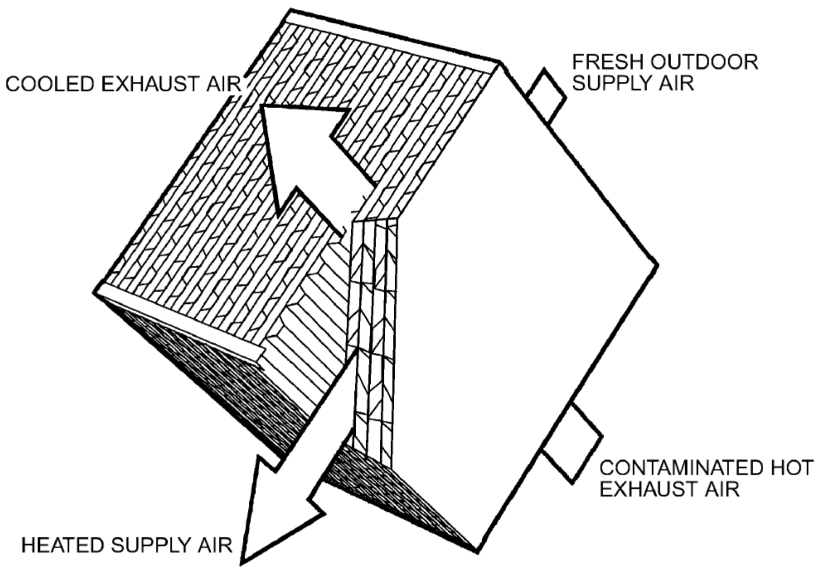


Fig. 2 Fixed-Plate Cross-Flow Heat Exchanger

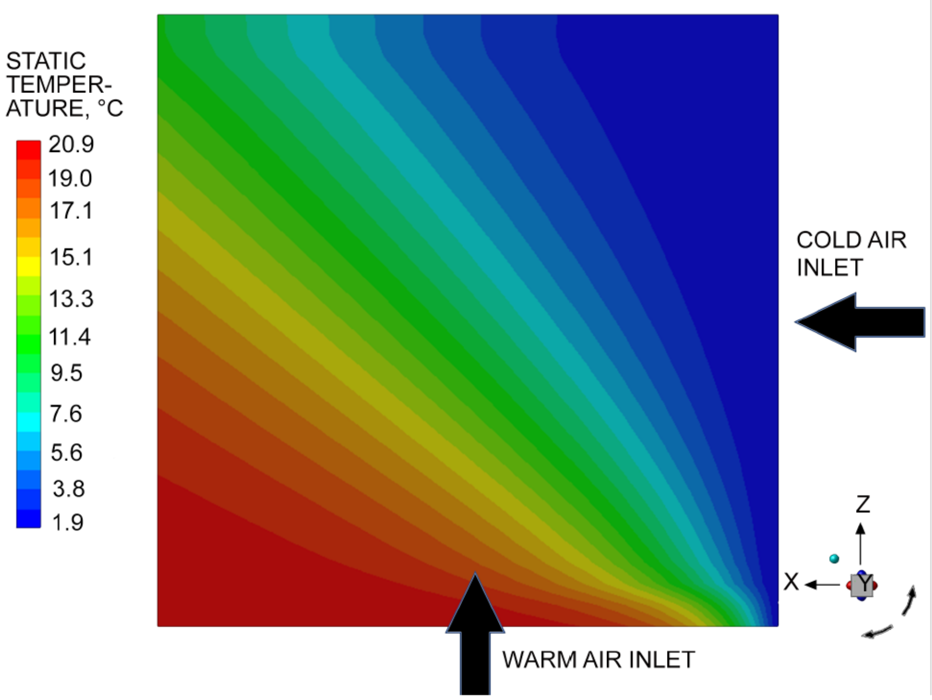
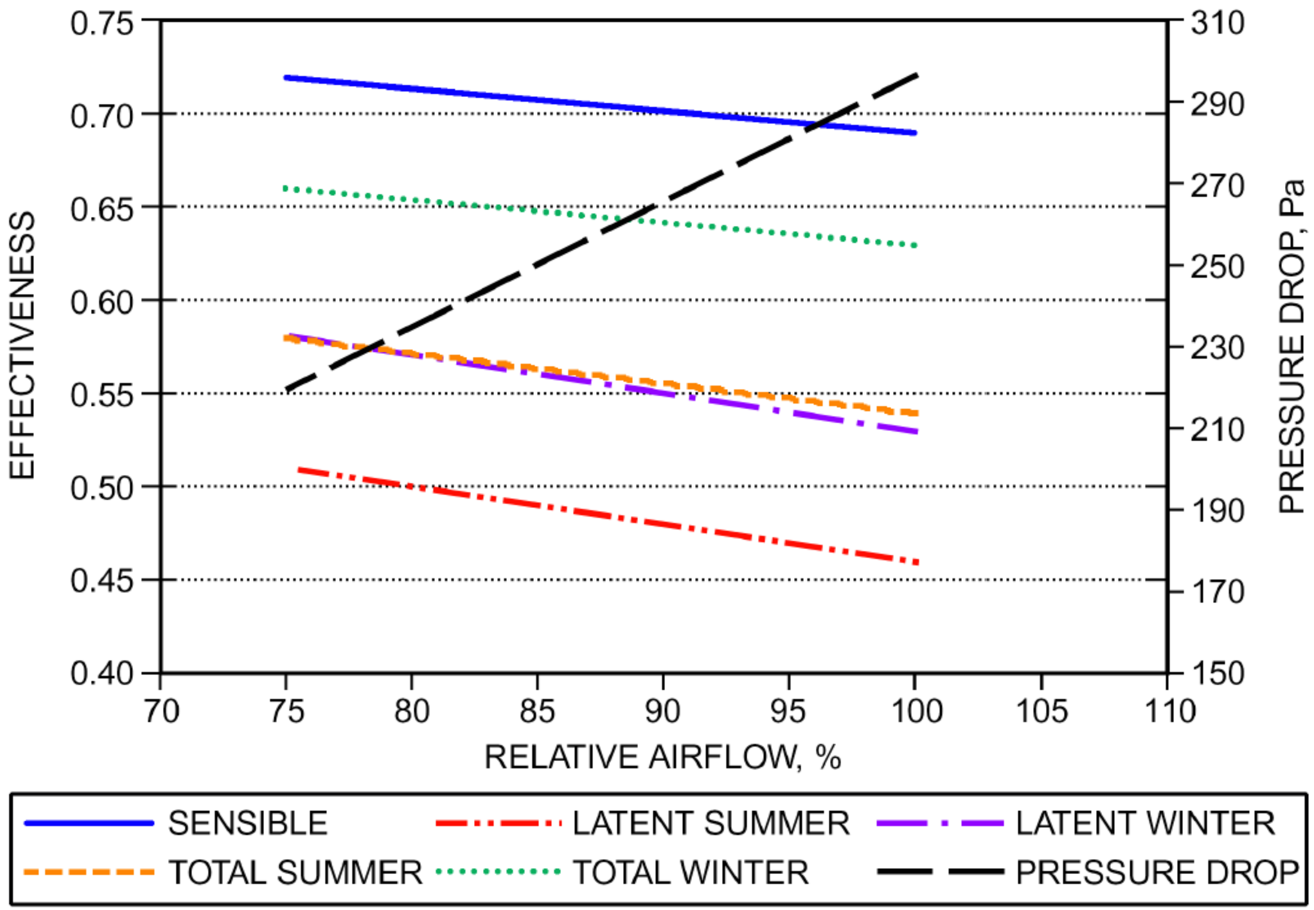


Fig. 4 Typical Temperature Stratification at Outlets of Cross-Flow Heat Exchanger

Example

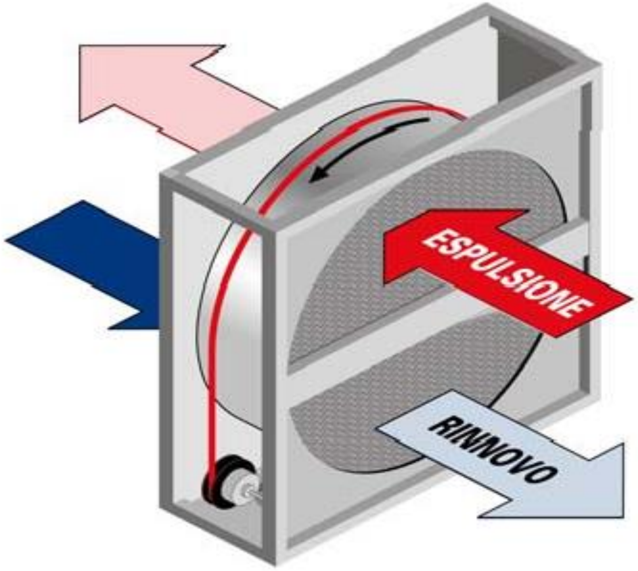


0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
EFFECTIVENESS
310
290
270
250
230
210
190
170
150
PRESSURE DROP, Pa
70
75
80
85
90
95
100
105
110
RELATIVE AIRFLOW, %
SENSIBLE
LATENT SUMMER
LATENT WINTER
TOTAL SUMMER
TOTAL WINTER
PRESSURE DROP

Heat recovery wheel

The heat recovery wheel consists of a cylindrical rotor built in such a way as to be permeable to air, characterized by a very high surface development; the fresh air and the exhaust air each cross one half of the exchanger, flowing in countercurrent.

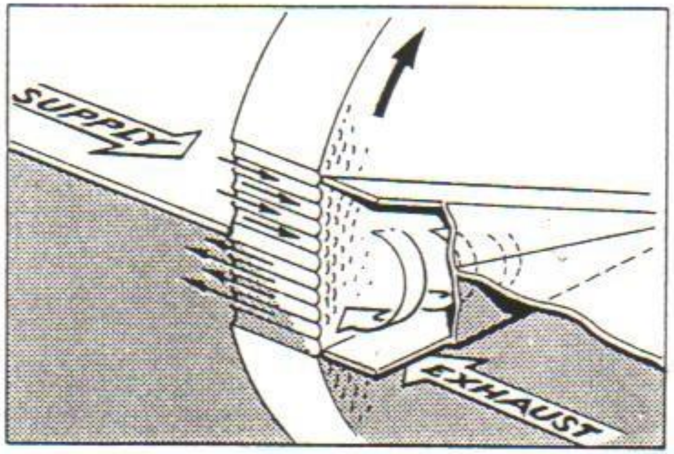
Heat recovery wheel



The heat exchange in these recuperators is by storage: while the cylinder rotates slowly, the exhaust air crosses one half of the casing and releases heat to the rotor matrix that accumulates it. The fresh air, which crosses the other half, absorbs the accumulated heat. As the rotation continues, the heat-absorbing and heat-delivering parts are continuously reversed, and the process can continue indefinitely.

In summertime it is the outside air that is cooled and dehumidified; in wintertime the incoming air, cold and dry, absorbs heat from the rotor and, if necessary, humidity, in appliances with hygroscopic surfaces..

Heat recovery wheel



There is the possibility of contamination between the two airstreams by entrainment.

Air that is trapped inside the ducts is transferred to the other flow due to rotation. To eliminate this, the recuperator is equipped with a cleaning sector.

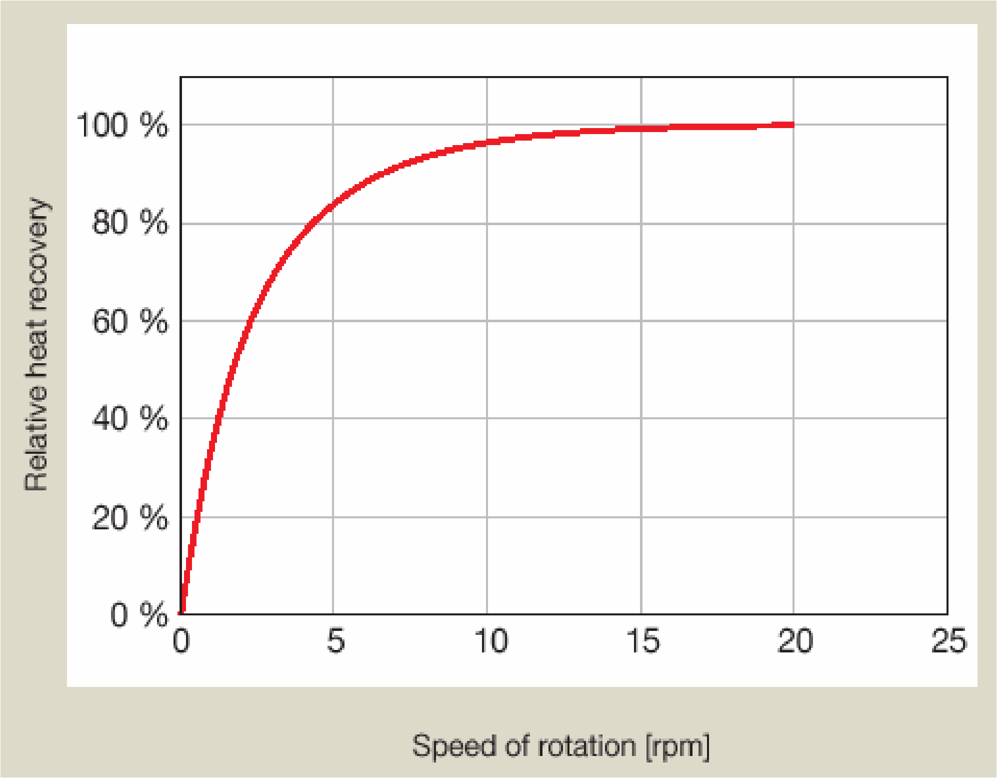
The cleaning sector is located downstream of the rotor, at the point where the rotor passes from the expulsion side to the inlet side.
In this way, a small amount of the supply air will be transferred into the exhaust air ducts allowing it to be cleaned.

Heat recovery wheel

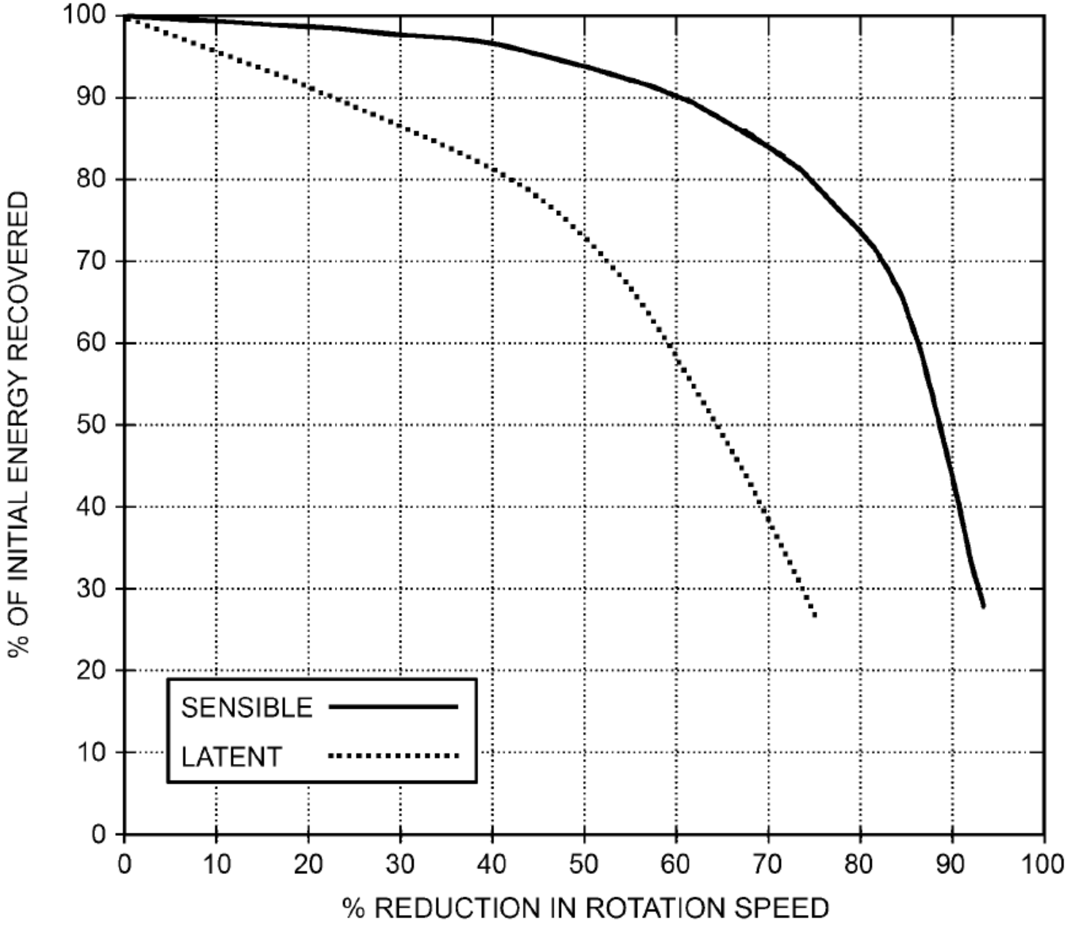
In order to exclude overheating, especially in the intermediate seasons (spring and autumn), a control on the delivery temperature is carried out, according to the needs of the plant, by means of a regulation of the rotation speed.

A variable speed drive motor is used and it is therefore possible to modulate the efficiency between a minimum and a maximum value.

The amount of heat recovered increases as the speed of rotation increases. Usually, therefore, the rotation speed of the recuperator is enslaved to the required temperature.



Heat recovery wheel



(A)

Heat recovery wheel

Pro

- The exchange surface, very high in relation to the volume, allows higher yields than other types of recuperators.
- The high efficiency and the possibility of recovering humidity as well as heat make it possible to significantly reduce the installed capacity of a system.
- The possibility of recovering humidity makes it possible to reduce humidification devices.

Cons

- Contamination between the two flows by entrainment and leakage
- In entrainment, air trapped inside the volume can be transferred to the other flow.
- Critical applications, such as hospitals, operating rooms and clean rooms require strict control of entrainment flows to prevent any risk of contamination.

Alternate Flow Ventilation

This simplified system consists of machines that half the time extract and half the time introduce air from the same duct.

Heat recovery is limited, no special filtration is provided.

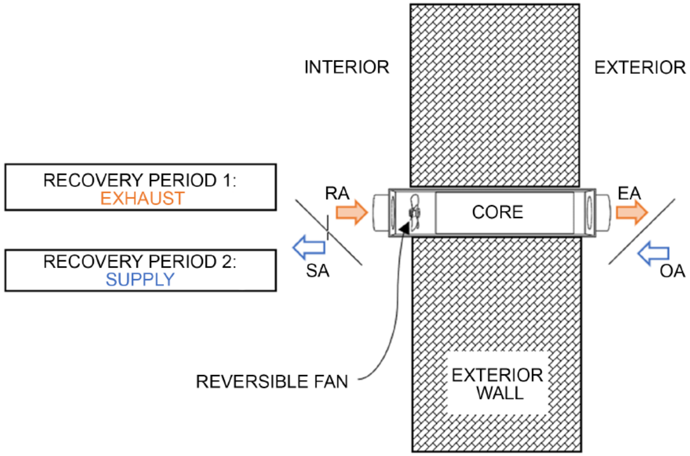
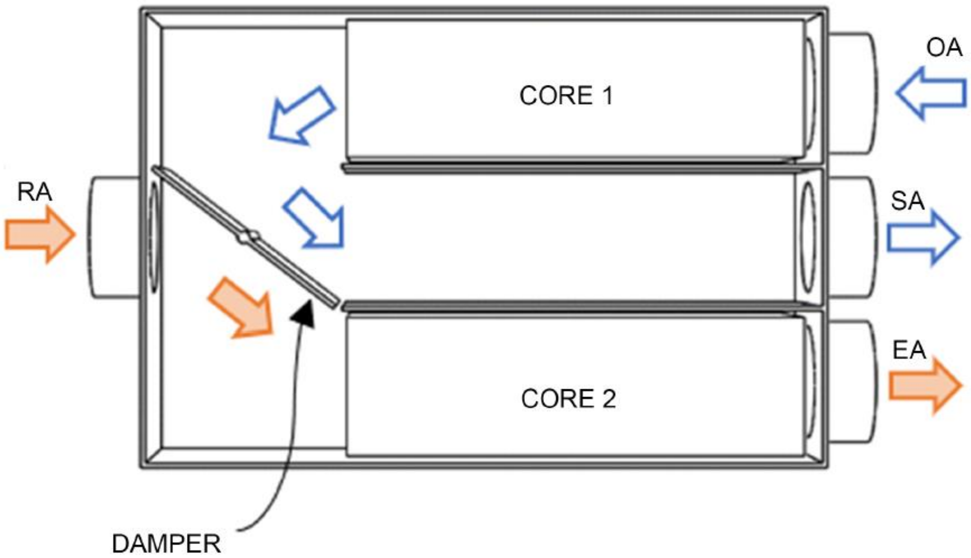
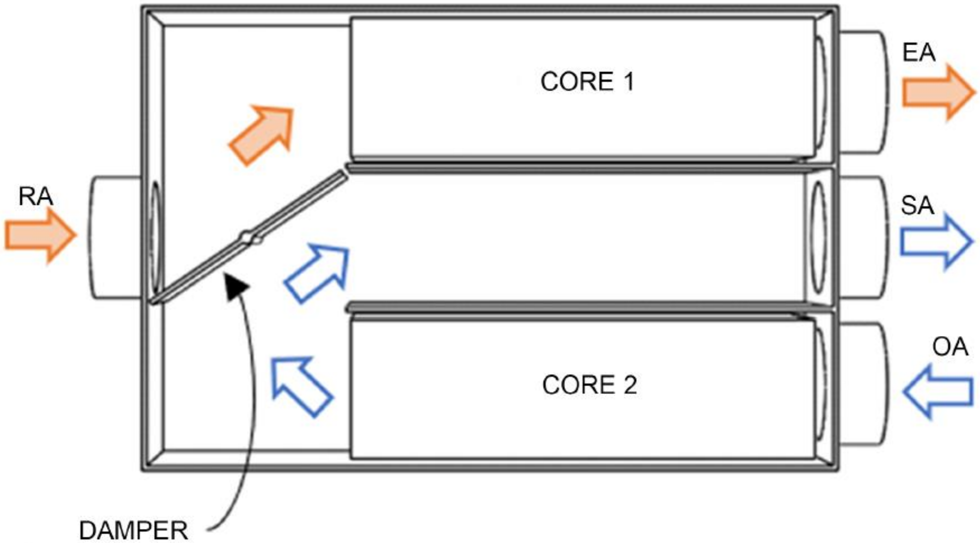


Fig. 23 Single-Core Fixed-Bed Regenerator

Alternate Flow Ventilation



RECOVERY PERIOD 1



RECOVERY PERIOD 2