Technical Focus

Thermodynamic energy recovery

Comparison with rotary heat exchangers (enthalpy wheel)

Application for air source rooftop

CLIVET®

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INTRODUCTION

Energy saving is a must when designing buildings. It has a direct impact on the use of resources that are becoming less and less available and reduces the overall running costs during the whole lifespan of the building.

Air-conditioning units are one of the greatest energy-consuming elements in the whole building. To ensure the requested comfort, they provide heating and cooling and carry out air renewal:

- they extract stale air and expel it outside
- they draw in outdoor air, purify it, determine its temperature and humidity and introduce it into the building

The recovery of energy contained in exhaust air reduces, even noticeably, consumption for these operations.

This is why the energy recovery from exhaust air is governed by a lot of regulations and laws, which recommend it and make it even mandatory in many applications in the service industry.

Below are compared the operating features and energy performance of conventional recovery devices with the thermodynamic recovery technology used in Clivet's systems.

ENERGY RECOVERY SYSTEMS

Traditional recovery units are passive air-air heat exchangers that allow for the transfer of temperature, and in some case humidity as well, between the exhaust and renewal air flow, directly or via intermediate fluids.

Thermodynamic energy recovery is instead based on reversible heat pump technology, which uses exhaust air as a source of heat.

As the physical operating principles are different, the efficiency indicators are different as well:

- the performance of the passive air-air heat exchangers are measured with the exchange efficiency (η) governed by the European standard EN 308;
- the performance of the heat pumps is measured with the coefficient of performance (COP) governed by European standard EN 14511.

For an objective analysis of the benefits and costs of the various solutions, we have taken into consideration two of the most common recovery units used.

The actual conditions of use and not just the nominal performance, as is often the case, will be taken into consideration. Indeed, they represent a minimal part of the time during which the system is used and therefore they cannot show the actual annual operating cycle.

Enthalpy rotary recovery unit

The enthalpy wheel recovery unit carries out the temperature recovery, (the sensible recovery) and humidity (latent recovery).

It usually consists of an aluminium rotor, half of which is hit by exhaust air and the other half by renewal air. It keeps rotating thanks to an electric drive motor.

The rotor contains a dense matrix of small air channels formed by a series of corrugated metal sheets joined together. The aluminium mass retains the heat and transfers it from one flow to the other. The hygroscopic surface handling allows for the transfer of humidity between the flows.

Here are the general features of these devices:

- the output depends directly on the enthalpy difference (temperature and humidity) between the indoor space and outdoors: it increases with cold outdoor temperatures and drops considerably in milder weather;
- the dense matrix of the rotor and the necessary protection filter generate pressure drops and therefore increase the power and the energy expended for ventilation;
- the potential contamination between the two flows of air is usually mitigated by a washing section, if there is one. This is why they cannot be used in very sensitive buildings such as hospitals, nursing homes and laboratories.

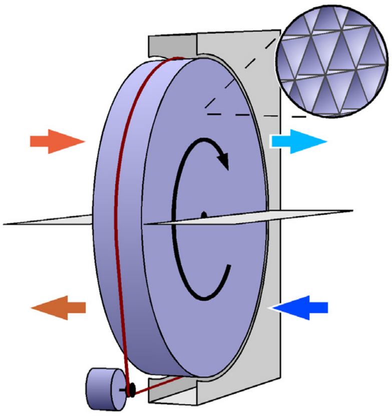


Fig. 1: The operating diagram of the enthalpy wheel shows the electric drive motor and the structure of the exchange matrix.

Thermodynamic recovery unit

Thermodynamic energy recovery is based on reversible heat pump technology. The heating and cooling capacity production circuit employs exhaust air as a source of heat, which is favourable both in the winter and summer operating mode.

This is why:

- the seasonal capacity production is greater than a conventional refrigeration circuit, which employs outdoor air as a source of heat;
- the capacity output is much more stable compared with passive exchangers as the outdoor conditions vary,
- does not employ passive exchangers and therefore also eliminates higher consumption due to ventilation;
- it is integrated in the unit, which has an extremely compact design.

Fig. 2: The thermodynamic recovery employs reversible heat pump technology by means of a refrigeration circuit built into the unit.

ROOFTOP APPLICATION: COMPARISON METHOD

The two recovery systems are analysed in terms of energy and operation under the real conditions of use of an air-conditioning unit in a typical application.

Namely, the comparison is related to the electricity required to fulfil the annual air-conditioning demands of an area in a commercial building in Milan.

The system is on from 8am to 8pm from Monday to Saturday.

For the purposes of simplicity, the number of persons, which is determined in accordance with current regulations, is kept constant.

Design Data

Space served

Net surface	m^2	500
Total height / Diffuser height	m	4,5 / 3,5
Room volume / Technical volume	m^3	2.250 /1.750

Main load indicators

Lighting	W/m^2	30
Attendance (0,15 persons/m^2)	n°	75
Renewal air (10 l/s per person)	m^3/h	2.700

Fig. 3: *Space loads considered include people and lighting.*

Design summer loads (Outdoors 35°C, 50%R.H. - Indoors 26°C, 55%R.H.)

Sensible / latent space load	kW	34,1 / 3,4
Sensible / latent renewal air load	kW	8,1 / 14.6
Total cooling capacity required	kW	60,1

Design winter loads (Outdoors -5°C, 80%R.H. - Indoors 20°C, 40%R.H.)

Sensible / latent space load	kW	19,5 / -3,4
Sensible / latent renewal air load	kW	22,5 / 8,9
Total heating capacity required	kW	47,5

Annual demand of the building

During the year, the building's load varies, even considerably, compared to the conditions reported in the project.

This is why the *"bin method"* analysis considers the capacity required under the various indoor and outdoor conditions and the number of hours during which this occurs based on the outdoor air temperature and this way determines the overall energy demand.

The thermal loads include all the usual components: space loads, heat gains and losses and fresh air due to the presence of people.

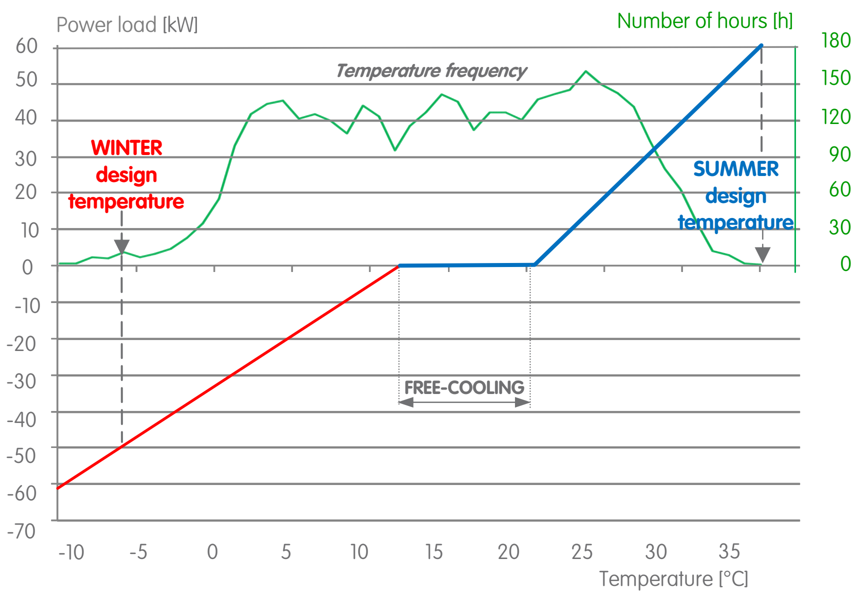


Fig. 4: *The maximum capacity is required only for just a few hours a year. With favourable outdoor temperatures, the introduction of outdoor air, even with an air flow that differs from the one reported in design, allows for cooling without having to turn on the compressors (FREE-COOLING).*

ROOFTOP APPLICATION: UNIT SELECTION

Consider an all-air system with an independent rooftop packaged unit. The units compared have the same standard operating and design features:

- refrigeration circuit with reversible air-air heat exchanger fitted with modular Scroll technology (two compressors per circuit) and external fans with speed modulation;
- high-efficiency handling fan section with electronic air flow control;
- outdoor air intake and extraction/exhaust fan section.

The units differ only in terms of the exhaust air recovery system: there is a passive one with an enthalpy wheel in one case and a thermodynamic one in the other.

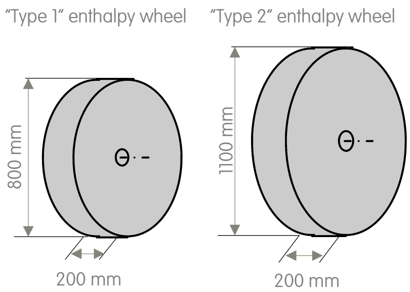


Fig. 5: *The face velocity and therefore the output and consumption during the system's entire life cycle depend on the size of the enthalpy wheel.*

As the performance of the passive recovery units mostly depends on the face velocity, two different selection criteria are considered for the enthalpy wheels to examine its effect on the annual operating cycle.

Therefore, we have compared three units:

- Rooftop with type 1 enthalpy wheel (nominal face velocity 3,2 m/s)
- Rooftop with type 2 enthalpy wheel (nominal face velocity 1,8 m/s)
- Rooftop with thermodynamic recovery

The size of all the units is based on the design conditions.

As required by regulations, the flow of outdoor air used for renewal is calculated based on the number of people in the served space (attendance) and the amount of outdoor air per person.

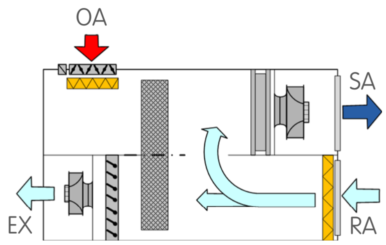
In applications with medium attendance, supermarkets, large supermarkets and shopping centres, where the total air flow treated by the unit is 5 volumes per hour, the resulting portion of outdoor air is about 30%.

In passive recovery units, the performance of the enthalpy wheel involves the selection of a refrigeration circuit that is less powerful compared with the thermodynamic recovery unit.

Technical design of the units compared

All the units fulfil the winter and summer design loads.

Unit with enthalpy wheel recovery



Unit with thermodynamic recovery

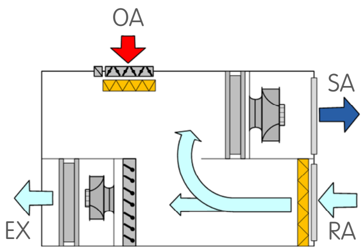


Fig. 6: *The units compared employ the same technology for the refrigeration circuit and the fan sections: they only differ in the exhaust air recovery unit system.*
(RA = Return air, EX = Exhaust air, OA = Outdoor air, SA = Supply air)

		Unit with enthalpy wheel		Unit with thermodynamic recovery
		type 1	type 2	
Cooling (Outdoors 35°C - Indoors 26°C, 55% R.H.)				
Refrigeration circuit power output	kW	50,4	50,3	61,2
Recovery unit power output	kW	11,9	13,8	included
Compressor power input	kW	13,2	13,2	14,9
Heating (Outdoors -5°C - Indoors 20°C, 40% R.H.)				
Heat pump power output	kW	37,3	38,1	49,2
Recovery unit power output	kW	21,1	23,1	included
Compressor power input	kW	9,2	9,3	10,3
Ventilation				
Supply air flow	m³/h	9.000		
Renewal air flow	m³/h	2.700		
Supply/return available pressure	Pa	150 / 100		
Pressure drop Supply/exhaust recovery unit	Pa	130 / 130	80 / 80	-
Power input Supply/exhaust recovery fan	kW	2,2 / 0,4	2,0 / 0,3	1,5 / 0,2
Power input enthalpy wheel drive motor	kW	0,39	0,28	-

All the selected units have a safety device to deal with extreme conditions during winter operation:

- speed changer and antifreeze electric heaters for the enthalpy wheel;
- additional electrical heaters for thermodynamic recovery units.

FREE-COOLING

When the outdoor temperatures are cold enough, the units can automatically vary the flow of outdoor air to introduce into the space and cool it in FREE-COOLING mode without activating the refrigeration circuit.

In this mode, the outdoor air flow can be as much as 100% of the total air flow handled by the unit and exhausts the corresponding amount of stale air.

This is a great opportunity for saving energy and money, especially in commercial applications with a high space load that allows extensive use of FREE-COOLING.

Under these operating conditions, the enthalpy wheel is stopped to avoid accidentally heating the outdoor air before it is introduced into the space.

The greater air flow determines a further increase in pressure drops and therefore in the capacity absorbed by the fans.

This problem could be remedied with an enthalpy wheel bypass system. This is almost never featured on rooftop units because it involves a noticeable increase in size and cost of the unit.

		Unit with enthalpy wheel		Unit with thermodynamic recovery
		type 1	type 2	
Operating mode	Outdoor air flow (m^3/h)	(Supply / exhaust passive recovery pressure drop, Pa) **Supply / exhaust fan absorbed capacity, kW**		
Standard	2.700 (30%)	(130 / 130) **2,2 / 0,4**	(80 / 80) **2,0 / 0,3**	(0 / 0) **1,5 / 0,2**
FREE-COOLING	9.000 (100%)	(460 / 460) **3,5 / 2,7**	(260 / 260) **2,4 / 2,0**	(0 / 0) **1,1 / 1,0**

In the FREE-COOLING stage, the increase of the air flow passing through the enthalpy wheel recovery unit causes a noticeable increase in the pressure drops and therefore greater electrical absorption due to ventilation.

ENERGY ANALYSIS

With the energy balance, the building's energy demand can be determinate according to the external conditions vary.

The energy demand is concentrated when the outdoor conditions allow maximum efficiency with thermodynamic recovery, whereas they are minumim with passive exchanger.

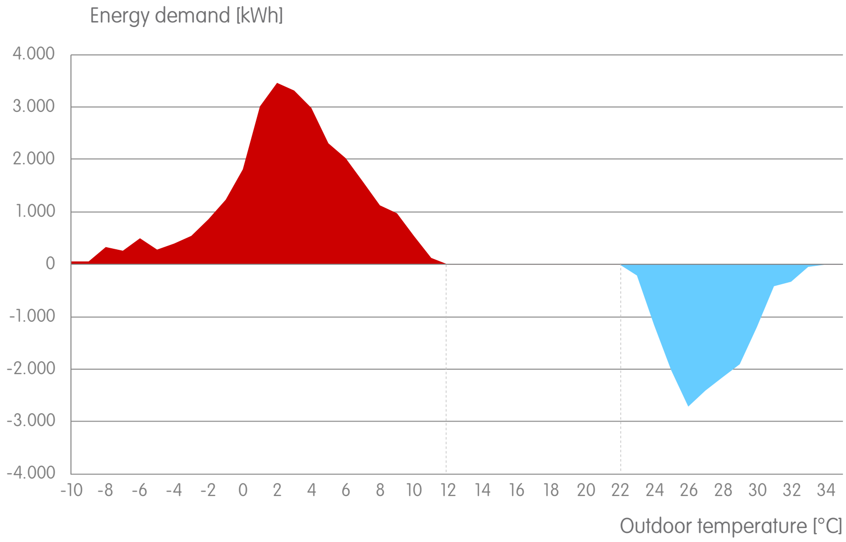


Fig. 7: *Energy demand of the building's air-conditioning net of FREE-COOLING: the highest demand is under conditions not closely associated with the ones in design.*

Similarly, the unit power input when the external conditions vary, allow to obtain the consumption in terms of energy absorbed, in the different cases considered.

For greater clarity, the absorbed energy is distinguished based on:

- production of heating and cooling capacity: compressors, external fans, electrical heaters and drive motor for the enthalpy wheel, collectively called the Thermodynamic Circuit;
- air handling: supply fans and exhaust fans, collectively called Handling fans.

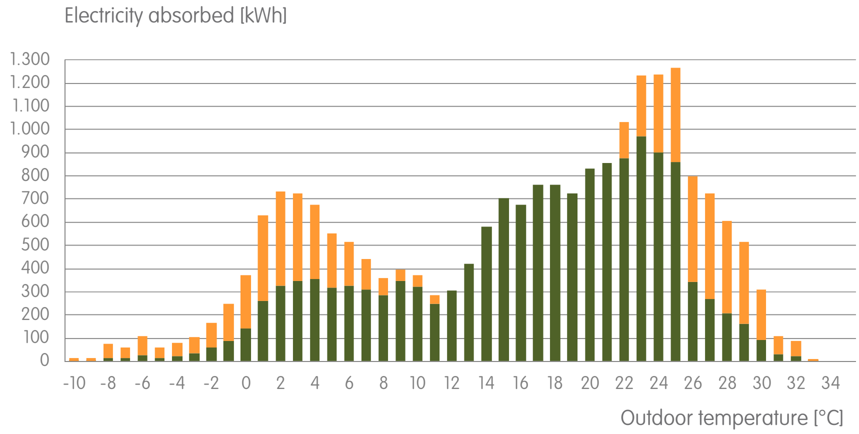
The comparison of the overall electrical consumption during an annual cycle confirms the high consumption levels due to ventilation for rooftop units with enthalpy wheel recovery.

It represents:

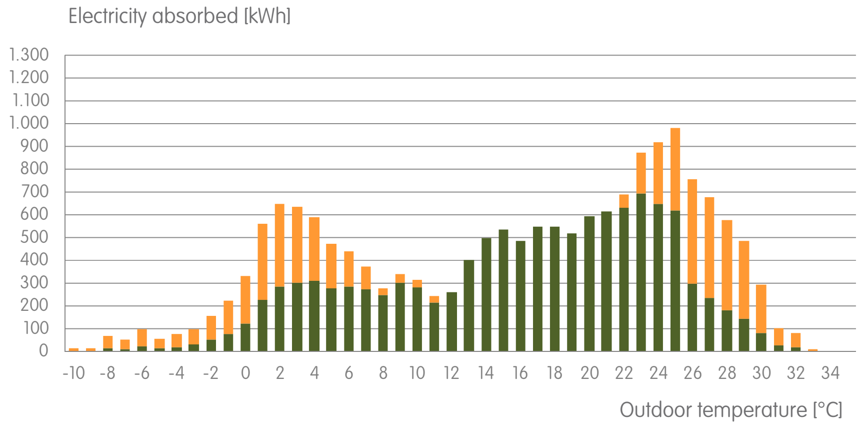
- 71% for rooftop units with a type 1 wheel (diameter 800 mm)
- more than 68% for units with type 2 wheels (diameter 1.100 mm).

The thermodynamic recovery unit makes greater use of the compressors, both to generate capacity and to carry out the recovery on exhaust air, thereby reducing the energy absorbed by ventilation .

Rooftop with type 1 enthalpy wheel (diameter 800 mm)



Rooftop with type 2 enthalpy wheel (diameter 1.100 mm)



Rooftop with thermodynamic recovery

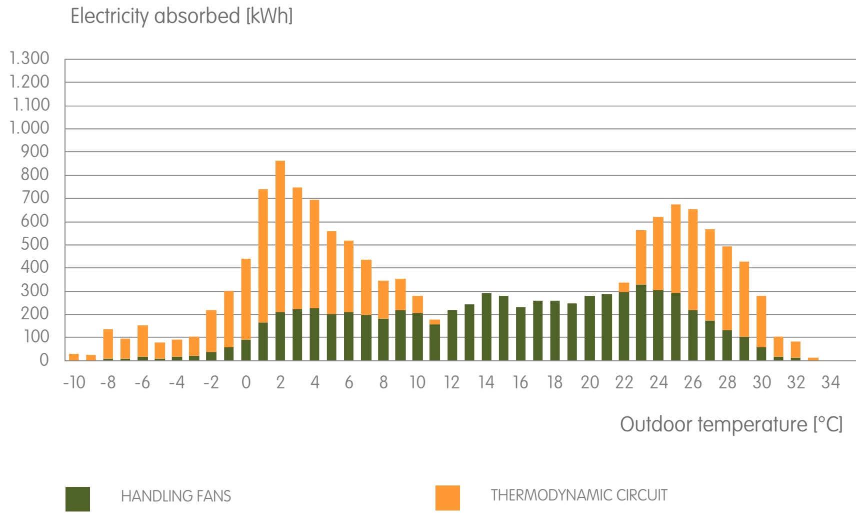


Fig. 8: *For most of the system's operating hours, the electricity absorbed due to ventilation in units with an enthalpy wheel is greater than the electricity used to produce capacity*

This means that during the annual operation cycle, the power absorbed by the thermodynamic recovery unit is less compared to the rooftop unit with the enthalpy wheel recovery unit based on both selection criteria adopted (type 1 compact enthalpy wheel and type 2 enthalpy wheel with low front speed).

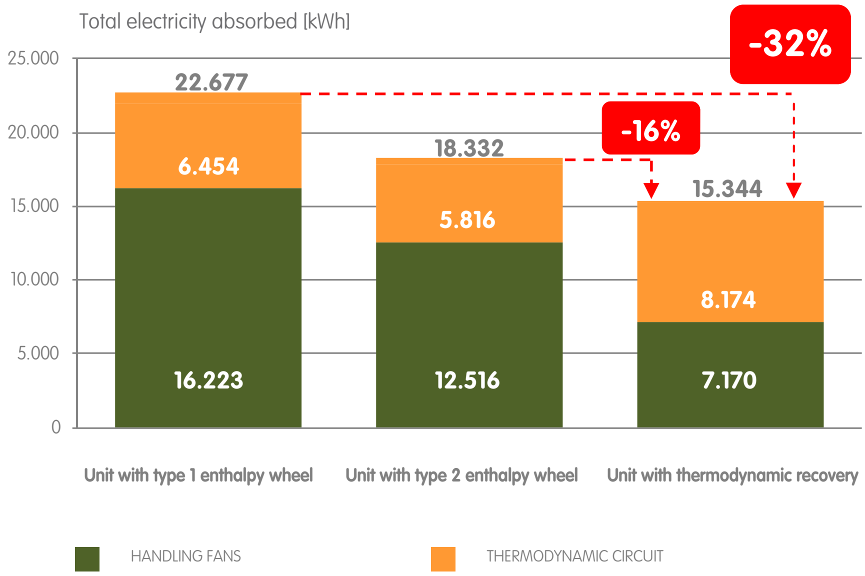


Fig. 9: *Overall energy consumption during the annual operating cycle: thermodynamic recovery technology considerably reduces the building's running costs*

CONCLUSIONS

Thermodynamic recovery units are based on the high-efficiency reversible air-air **heat pump** technology, which uses exhaust air as a source of heat. The innovative thermodynamic cycle and the lack of pressure drops typical in traditional recovery units allow for **high seasonal efficiency**, both in terms of production and ventilation.

The energy analysis on an annual cycle for a typical commercial application in a continental climate for Clivet units with thermodynamic recovery shows the following:

- **32% energy savings** compared with a compact rooftop with enthalpy wheel with a face velocity of 3,2 m/s
- **significant energy saving, equal to 16%**, even compared with a rooftop unit fitted with an enthalpy wheel with a lower face velocity (1,8 m/s) and bigger size.

Therefore, thermodynamic recovery noticeably **reduces the overall running costs** compared to the results of an initial rough comparison based on the design conditions alone.

There are **other benefits** in using thermodynamic recovery compared to the enthalpy wheel:

- **Compact design**: a unit with thermodynamic recovery can be as much as 20% smaller
- **Lower installation costs**: the thermodynamic recovery is fully integrated in the unit and individually tested before shipping. The enthalpy wheel is instead often supplied in a separate module that is assembled on site, with additional costs for handling, mechanical assembly, electrical and control wiring and for performance test.
- **Environmental health**: in all outdoor air applications, thermodynamic recovery does not involve any cross contamination.
- **Reliability**: during operation with low outdoor temperatures, the enthalpy wheel is exposed to the risk of ice forming on the rotor. The resulting slower rotor speed (until it stops) and activation of the additional electrical heaters under particularly severe conditions lead to a considerably lower overall efficiency compared to the nominal value.
- **Performance over time**: the thermodynamic recovery does not require additional features compared with a normal refrigeration circuit. Instead, the deterioration of the hygroscopic surface handling on the enthalpy wheel gradually reduces the actual exchange efficiency and therefore the actual energy recovery capacity.

Fig. 10: *Thanks to the considerably lower overall cost during the system's life cycle, the CLIVETPack rooftop systems with thermodynamic recovery are widely used to provide air-conditioning in supermarkets and shopping centres, cinemas and restaurants, congress centres and trade show venues, industrial buildings and in many other applications.*

APPENDIX

Detail of the analysis with reference to RECOVERY WITH TYPE 1 ENTHALPY WHEEL (diameter 800 mm)

APPLICATION FEATURES

Outdoor dry bulb temperature (median)	°C	-10	-5	0	5	10	15	20	25	30	35
Outdoor relative humidity	%	90	80	70	65	60	58	55	51	45	50
Total load building (environment + fresh air)	kW	-61,2	-47,5	-33,6	-19,3	-4,4	11,4	7,3	17,3	34,1	60,1
No. Hours (Monday Saturday / 8-20)	h	8	43	332	629	569	635	664	680	195	1

ROOFTOP WITH ENTHALPY WHEEL

Temperature / humidity efficiency	% / %	71 / 62	71 / 58	71 / 52	71 / 51	51 / 13 *	OFF	OFF	OFF	68 / 43	68 / 43	
Pressure drop enthalpy wheel	Pa	129	131	134	136	139	377	460	460	152	154	
Filter pressure loss of the enthalpy wheel	Pa	20	20	20	20	20	33	40	40	20	20	
Enthalpy wheel motor power input	kW	0,4	0,4	0,4	0,4	0,4	0	0	0	0,4	0,4	
Enthalpy wheel total capacity output	kW	25,3	21,1	16,6	12,3	5,0	0	0	0	2,9	11,9	
Air outlet enthalpy wheel temperature/humidity (DB/RH)	°C / %	11,3 / 50	12,7 / 46	14,2 / 43	15,6 / 43	15,1 / 44	15,0 / 58	20,0 / 55	25,0 / 51	27,3 / 52	28,8 / 52	
Temperature / humidity air mixture (DB/RH)	°C / %	17,3 / 43	17,8 / 42	18,2 / 41	18,7 / 41	19,1 / 41	16,0 / 54	20,1 / 55	25,7 / 54	26,4 / 54	26,8 / 57	
Thermodynamic system capacity output	kW	35,9	26,4	17,0	7,0	0	0	0	17,3	31,2	48,2	
Compressor power input	kW	10,0	5,6	2,8	1,1	0	0	0	2,4	4,9	12,3	
External fans power input	kW	2,0	1,5	1,0	0,5	0	0	0	0,5	1,0	1,5	
Supply / return - fan power input	kW	2,2	2,2	2,2	2,2	2,2	3,1	3,5	3,5	2,2	2,2	
Exhaust - fan power input	kW	0,4	0,4	0,4	0,4	0,4	2,2	2,7	2,7	0,4	0,4	**Totale**
Electricity absorbed ENTHALPY WHEEL MOTOR	kWh	3,1	16,8	129,8	245,9	222,5	0,0	0,0	0,0	76,2	0,4	**695**
Electricity absorbed COMPRESSORS AND EXTERNAL FANS	kWh	96	307	1.265	981	0	0	0	1.955	1.141	14	**5.759**
Electricity absorbed AIR HANDLING FANS	kWh	21	114	876	1.661	1.502	3.334	4.050	4.148	515	3	**16.223**
TOTAL Electricity absorbed	**kWh**	**121**	**437**	**2.272**	**2.887**	**1.725**	**3.334**	**4.050**	**6.103**	**1.732**	**17**	**22.677**

ROOFTOP WITH THERMODYNAMIC RECOVERY

Temperature / humidity air mixture (DB/RH)	°C / %	10,5 / 56	12,3 / 53	13,9 / 50	15,5 / 47	17,0 / 45	16,0 / 66	20,0 / 55	25,7 / 53	27,2 / 53	28,6 / 54	
Thermodynamic circuit total capacity output	kW	44,9	47,5	33,6	19,3	4,4	0	0	17,3	34,1	60,1	
Compressor power input	kW	9,6	9,9	5,4	2,5	0,6	0	0	2,2	5,1	14,4	
External fans power input	kW	2,0	1,5	1,0	0,5	0,1	0	0	0,5	1,2	1,7	
Integration electric heaters power input	kW	16,3	0	0	0	0	0	0	0	0	0	
Supply / return - fan power input	kW	1,5	1,5	1,5	1,5	1,5	1,2	1,1	1,1	1,5	1,5	
Exhaust - fan power input	kW	0,2	0,2	0,2	0,2	0,2	1,0	1,0	1,0	0,2	0,2	**Totale**
Electricity absorbed INTERGATION ELECTRIC HEATERS	kWh	130	0	0	0	0	0	0	0	0	0	**130**
Electricity absorbed COMPRESSORS AND EXTERNAL FANS	kWh	93	491	2.137	1.874	348	0	0	1.859	1.225	16	**8.044**
Electricity absorbed AIR HANDLING FANS	kWh	13	72	558	1.057	956	1.416	1.368	1.401	328	2	**7.170**
TOTAL Electricity absorbed	**kWh**	**237**	**563**	**2.694**	**2.931**	**1.304**	**1.416**	**1.368**	**3.260**	**1.553**	**18**	**15.344**

Energy saving: 32%

Commercial application, Milan, open from 8am to 8pm from Monday to Saturday based on an annual cycle.

Data summarising by 5°C temperature ranges with an indication of the median value. Frequency in hours, "*bin method*".

* Enthalpy wheel in stepped operation with reduced rotation speed.

APPENDIX

Detail of the analysis with reference to RECOVERY WITH TYPE 2 ENTHALPY WHEEL (diameter 1.100 mm)

APPLICATION FEATURES

Outdoor dry bulb temperature (median)	°C	-10	-5	0	5	10	15	20	25	30	35
Outdoor relative humidity	%	90	80	70	65	60	58	55	51	45	50
Total load building (environment + fresh air)	kW	-61,2	-47,5	-33,6	-19,3	-4,4	11,4	7,3	17,3	34,1	60,1
No. Hours (Monday Saturday / 8-20)	h	8	43	332	629	569	635	664	680	195	1

ROOFTOP WITH ENTHALPY WHEEL

Temperature / humidity efficiency	% / %	77 / 69	77 / 65	77 / 60	77 / 57	55 / 15 *	OFF	OFF	OFF	75 / 53	77 / 53	
Pressure drop enthalpy wheel	Pa	71	73	74	75	76	203	260	260	83	84	
Filter pressure loss of the enthalpy wheel	Pa	20	20	20	20	20	33	40	40	20	20	
Enthalpy wheel motor power input	kW	0,3	0,3	0,3	0,3	0,3	0	0	0	0,3	0,3	
Enthalpy wheel total capacity output	kW	27,7	23,1	18,3	13,5	5,5	0	0	0	3,2	13,8	
Air outlet enthalpy wheel temperature/humidity (DB/RH)	°C / %	12,6 / 47	14,2 / 45	15,4 / 42	16,5 / 41	15,5 / 43	15,0 / 58	20,0 / 55	25,0 / 51	26,4 / 54	28,3 / 60	
Temperature / humidity air mixture (DB/RH)	°C / %	17,7 / 42	18,2 / 42	18,6 / 41	18,9 / 41	18,6 / 41	16,0 / 54	20,0 / 55	25,7 / 54	26,4 / 54	26,7 / 59	
Thermodynamic system total capacity output	kW	33,5	24,4	15,3	5,8	0	0	0	17,3	30,9	46,3	
Compressor power input	kW	8,7	5,0	2,5	0,9	0	0	0	2,1	4,8	11,6	
External fans power input	kW	2,0	1,5	1,0	0,5	0	0	0	0,5	1	1,5	
Supply / return - fan power input	kW	2,0	2,0	2,0	2,0	2,0	2,4	2,4	2,4	2,0	2,0	
Exhaust - fan power input	kW	0,3	0,3	0,3	0,3	0,3	1,6	2,0	2,0	0,3	0,3	**Totale**
Electricity absorbed ENTHALPY WHEEL MOTOR	kWh	2,2	12,0	93,0	176,1	161,0	0	0	0	54,6	0,3	**499**
Electricity absorbed COMPRESSORS AND EXTERNAL FANS	kWh	85	280	1.172	866	0	0	0	1.768	1.132	13	**5.316**
Electricity absorbed AIR HANDLING FANS	kWh	18	99	764	1.447	1.309	2.543	2.908	2.978	449	2	**12.516**
TOTAL Electricity absorbed	**kWh**	**105**	**391**	**2.029**	**2.489**	**1.470**	**2.543**	**2.908**	**4.747**	**1.635**	**16**	**18.332**

ROOFTOP WITH THERMODYNAMIC RECOVERY

Temperature / humidity air mixture (DB/RH)	°C / %	10,5 / 56	12,3 / 53	13,9 / 50	15,5 / 47	17,0 / 45	16,0 / 66	20,0 / 55	25,7 / 53	27,2 / 53	28,6 / 54	
Thermodynamic circuit total capacity output	kW	44,9	47,5	33,6	19,3	4,4	0	0	17,3	34,1	60,1	
Compressor power input	kW	9,6	9,9	5,4	2,5	0,6	0	0	2,2	5,1	14,4	
External fans power input	kW	2,0	1,5	1,0	0,5	0,1	0	0	0,5	1,2	1,7	
Integration electric heaters power input	kW	16,3	0	0	0	0	0	0	0	0	0	
Supply / return - fan power input	kW	1,5	1,5	1,5	1,5	1,5	1,2	1,1	1,1	1,5	1,5	
Exhaust - fan power input	kW	0,2	0,2	0,2	0,2	0,2	1,0	1,0	1,0	0,2	0,2	**Totale**
Electricity absorbed INTERGATION ELECTRIC HEATERS	kWh	130	0	0	0	0	0	0	0	0	0	**130**
Electricity absorbed COMPRESSORS AND EXTERNAL FANS	kWh	93	491	2.137	1.874	348	0	0	1.859	1.225	17	**8.044**
Electricity absorbed AIR HANDLING FANS	kWh	13	72	558	1.057	956	1.416	1.368	1.401	328	2	**7.170**
TOTAL Electricity absorbed	**kWh**	**237**	**563**	**2.694**	**2.931**	**1.304**	**1.416**	**1.368**	**3.260**	**1.553**	**18**	**15.344**

Energy saving: 16%

Commercial application, Milan, open from 8am to 8pm from Monday to Saturday based on an annual cycle.

Data summarising by 5°C temperature ranges with an indication of the median value. Frequency in hours, "*bin method*".

* Enthalpy wheel in stepped operation with reduced rotation speed.

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