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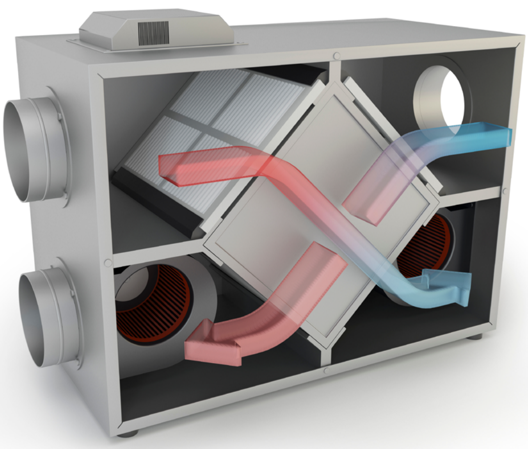
ENERGY RECOVERY IN MECHANICAL VENTILATION SYSTEMS



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43rd Informatory Note on Refrigeration Technologies

“Heat recovery in mechanical ventilation systems may have a very positive environmental impact by reducing the usage of fossil fuel with payback periods of one or two years.”

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Energy recovery in mechanical ventilation systems

The thermal loads of buildings, apart from internal gains, can be classified into two main categories: losses or gains through the envelope and ventilation loads.

Ventilation loads are becoming more important as air purity standards and thus fresh air supply rates are increasing. Heat recovery from the exhaust air can strongly reduce these loads by pre-heating or pre-cooling the fresh inlet air.

Heat recovery in a ventilation system allows significant energy savings, particularly when outdoor conditions differ greatly from the indoor ones. Moreover, when a recovery system is provided, the installed capacity for heating and cooling can be strongly reduced.

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Introduction

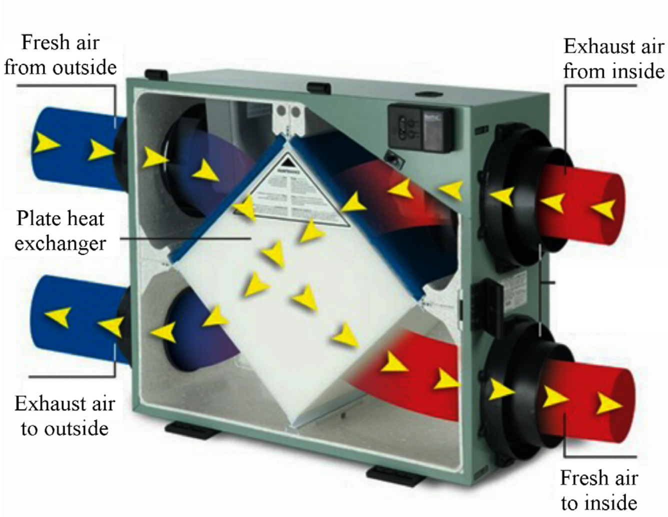
Thermal loads of buildings, apart from internal gains, can be classified into two main categories; losses or gains through the envelope and ventilation loads. Ventilation loads are becoming more important as air purity standards and thus fresh air supply rates are increasing. This trend is accelerated by much improved insulation standards. Insulation is the most common technique for reducing thermal losses or gains; the available technique for reducing ventilation loads is heat recovery, which can be achieved when the building is equipped with a controlled ventilation system [1]. Heat recovery is practically mandatory for near Zero Energy Buildings (nZEBs) [2, 3].

Mechanical ventilation systems are widely used in modern buildings, as improved quality of doors and windows has drastically reduced infiltration; moreover, ventilation allows better control of room conditions.

Heat recovery from exhaust air is a simple process to consider whenever a mechanical ventilation system is available. In fact, there is always an ideal receiver available for the recovered heat: fresh inlet air. The flow rate is similar to that of the exhaust air and its temperature levels (low temperatures in winter and high temperatures in summer) almost always allow the use of heat recovery (Figure 1).

Figure 1:

Scheme of a heat recovery plate exchanger between exhaust and fresh air



Only passive energy recovery will be considered here, then without active control of temperature and humidity. Air to air heat pump energy recovery allows a significant increase in the possible recovery with adequate air control, but it is a complex system that deserves a separate presentation.

The economic advantage of exhaust air heat recovery depends firstly on the volume and duration of ventilation. The payback period decreases as the annual number of hours of use increases. It is, of course, more cost-effective in long, harsh winters or hot summers [4].

Ventilation loads

Ventilation loads (Q_{ven} [W]) depend on fresh air mass flow rate W_{in}[kgs^{-1}] and on the difference between internal (h_i [Jkg^{-1}]) and external (h_e[Jkg^{-1}]) air enthalpy:

$$Q_{ven} = W_{in}(h_i - h_e) \quad (1)$$

Air enthalpy derives from the sum of the dry air and water vapour enthalpies. As heat recovery often concerns only dry air, a sensible ventilation load ($Q_{vensens}$) is considered due to the temperature difference between inside and outside air:

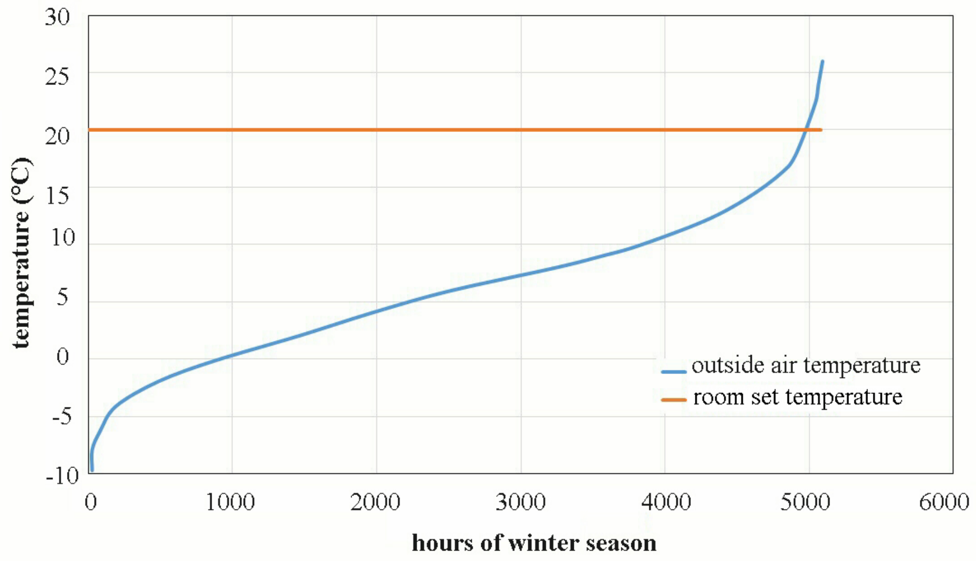
$$Q_{vensens} = c_p W_{in}(t_i - t_e) \quad (2)$$

where cp($Jkg^{-1}K^{-1}$)is the air specific heat and t_i, t_e[°C] the respective temperatures.

The design conditions for a given locality allow for the sizing of heating or cooling equipment. Seasonal cumulative curves are required to estimate the energy required during the season. These are curves based on historical weather data that suggest how many hours the outside enthalpy or temperature are below/above a generic value during a heating or cooling season. Figure 2 represents the cumulative outside temperature curve for a temperate winter climate (Milan) together with the room temperature set at 20°C. Neglecting possible free gains, the sensible energy required for ventilation is proportional to the area between the horizontal line of 20°C and the cumulative curve.

Figure 2:

Cumulative curve of the outside temperature for a typical temperate winter climate (Milan)



Performance of air-to-air energy recovery equipment

A separate Informatory Note will be devoted to a presentation of the heat recovery equipment. For the purposes of this Note, it is sufficient to point out that there are heat exchangers capable of recovering both sensible and latent heat from the air, operating what is known as total heat recovery. However, the most widespread exchangers only recover the sensible heat. An effectiveness is defined for both types [5]:

$$\varepsilon_t = \frac{W_{ex}(h_i - h_u)}{W_{\min}(h_i - h_e)} = \frac{W_{in}(h_{in} - h_e)}{W_{\min}(h_i - h_e)}$$

$$\varepsilon_s = \frac{W_{ex}(t_i - t_u)}{W_{\min}(t_i - t_e)} = \frac{W_{in}(t_{in} - t_e)}{W_{\min}(t_i - t_e)} \qquad (3)$$

- ε_t= total heat exchanger effectiveness.
- ε_s=sensible heat exchanger effectiveness.
- W_{ex} = exhaust air mass flow rate.
- W_{in} = fresh air mass flow rate.
- W_{min}= minimum value of the two flow rates.
- h_i, t_i = room enthalpy/temperature.
- h_e, t_e=outside air enthalpy/temperature.
- h_{in}, t_{in}=supply air enthalpy/temperature after the heat exchanger.
- h_u, t_u=heat exchanger exhaust air enthalpy/temperature.

The exhaust air flow rate is usually lower than the fresh air flow rate, especially to obtain a slight inside overpressure, which eliminates uncontrolled air and dust infiltrations. The fraction is normally around 90%. Even if the effectiveness of an air-to-air heat exchanger can approach 95%, the most common values are between 50% and 70%. Another important parameter of the air-to-air heat exchanger is the pressure drop, which is often between 100 and 200 Pa.

A rough evaluation of the seasonal energy recovered

When cumulative curves are not available, it may be acceptable to assume an average heat recovery equivalent to 50% of the nominal recovery.

The recovered energy is calculated by multiplying the hourly heat recovered, computed as described below, by the operating hours of the plant. This gives only a rough approximation.

Let us take an example. The specific heating capacity required in the typical temperate climate considered here (Milan) is estimated at 47.9 W/(l/s), i.e. the heating power required to supply the enthalpy difference between inside and outside for each litre per second of fresh air for the design conditions. The sensible fraction is less than 60%. A sensible heat recovery with an effectiveness of 0.5 reduces the sensible requirements by about 50% so that the heating capacity is now 33.5 W/(l/s). In fact, 47.9x60%=28.7 (sensible heating capacity) and 28.7x50%=14.4 W/(l/s). The required heating capacity with 50% heat recovery is therefore 47.9-14.4=33.5 W/(l/s). For a heating season of 5000 hours, the heat that can be recovered according to the above rule of thumb is:

$$(47.9 - 33.5) \times 5000 \times 3600 \times 10^{-6} \times 50\% = 129.6 \text{ MJ/(l/s)}$$

Similarly, for a heat exchanger effectiveness of 0.7, the recovered heat can be estimated at 181.0 MJ/(l/s).

A better evaluation of the seasonal energy recovered

When cumulative curves are available, a more accurate evaluation is possible. In fact, for a given heat exchanger effectiveness, a cumulative curve of the inlet air enthalpy or temperature after the heat exchanger can be produced as in figure 3 for temperature, calculating the values with equation (3) for every outside enthalpy/temperature. The hatched area in figure 3 is proportional to the recoverable seasonal heat for a sensible heat exchanger with an effectiveness of 0.5.

In order to go from the maximum recoverable energy to the fraction effectively recoverable,two reduction factors must be accounted for:

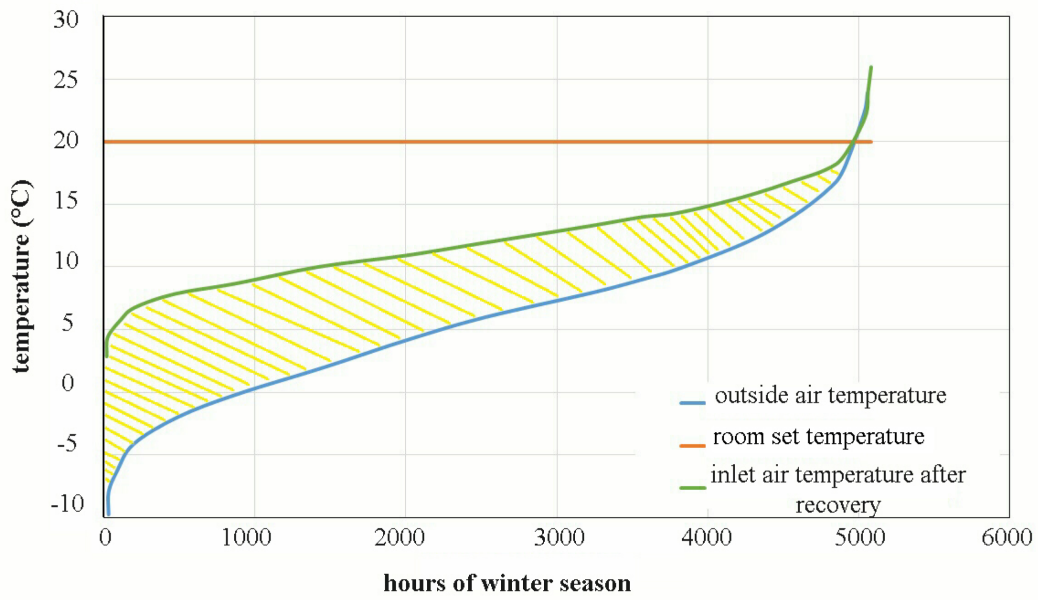
(1) the operating hours of the systems can be a fraction of the 24 hours of the day;

(2) for outside temperatures not very different from room temperatures, mainly in winter, air treatment may not be necessary because, for example, free gains (internal or external) are sufficient to maintain comfortable conditions. It may also happen that mild outdoor temperatures can compensate the internal thermal load by free cooling sending fresh air without any heat recovery.

As far as the first point is concerned, a reduction in the heat recovery proportional to the time fraction of the system inactivity gives an acceptable approximation of the heat recovered, As inactivity occurs mainly during the night, this procedure overestimates the possible energy savings in winter, while it underestimates the savings in summer (night-time temperatures are usually lower than daytime ones). Errors should be small in temperate climates, where day/night temperature differences are generally small. As regards point (2), the heat recovery possible when outside and inside temperatures are close to each other is generally low.

Figure 3:

Sensible heat recovery with a 50% effectiveness for a temperate winter climate (Milan); the hatched area is proportional to the energy recovered.



Evaluation of seasonal sensible heat recovery data

To give an idea of the possible energy recovery and its dependence on climate, three very different climates have been selected [6]:

- a typical temperate continental climate (annual degree-days, DD=2404);
- a mild climate (DD=1415);
- a hot and humid climate (DD=751).

HEATING OPERATIONS

A first analysis is presented in Table 1 and concerns the sensible heat recovery in the three climates during the heating period. The table reports in the first lines the design capacity for the ventilation per unitary fresh air flow rate (W/(l/s)) and the capacities with heat recovery at ε_s=0.5 or 0.7.

As regards the design capacity, it depends on outside design conditions and on the set value for the room (here 20°C, relative humidity – RH=50%). As mentioned previously, a heat recovery system allows a reduction of the specific design heat capacity of the plant for ventilation. As the equipment operates on the sensible fraction of the air enthalpy only, the reduction is not proportional to the heat exchanger effectiveness and is not constant for the various types of climate.

The following lines provide the requested seasonal heat (MJ/(l/s)) without or with heat recovery according to different evaluations as shown in the Table.

It is easy to see that the rule of thumb only gives a rough approximation with over or underestimates according to the climate. The evaluation is carried out for a one-day (24 h) utilisation of the plant. For shorter operating periods, it is possible to estimate a reduction of the fraction of inactivity time by the same amount, as mentioned above. A typical commercial or industrial application could yield about half of the savings listed with a whole day's use in the residential sector.

Table 1:

Sensible heat recovery in the three climates considered during heating period

Climate	Cold and temperate		Mild		Hot and humid	
Degree days	2404		1415		751	
Design heating capacity W/(l/s)						
Heating capacity	47.9		39.8		32.5	
Heating capacity with heat recovery ε=0.5	34.3		28.9		24.3	
Heating capacity with heat recovery ε=0.7	28.9		24.5		21.0	
Heating season heat recovery	MJ/(l/s)	kWh/(l/s)	MJ/(l/s)	kWh/(l/s)	MJ/(l/s)	kWh/(l/s)
Maximum seasonal heat recovery	309.7	86.0	188.2	52.3	86.9	24.1
Maximum seasonal heat recovery (stop at 15 °C)	305.7	84.9	180.4	50.1	76.9	21.4
Seasonal heat recovery ε=0.5 (rule of thumb)	123.0	34.2	84.3	23.4	42.5	11.8
Seasonal heat recovery ε=0.7 (rule of thumb)	172.2	47.8	118.1	32.8	59.5	16.5
Seasonal heat recovery ε=0.5	139.4	38.7	84.7	23.5	39.1	10.9
stop at 15 °C	137.6	38.2	81.2	22.6	34.6	9.6
Seasonal heat recovery ε=0.7	195.1	54.2	118.6	32.9	54.8	15.2
stop at 15 °C	192.6	53.5	113.7	31.6	48.5	13.5

COOLING OPERATIONS

The assessment of air conditioning in summer is similar. Figure 4 shows the cumulative outdoor temperature curve for the temperate continental climate, where the hatched area gives the recoverable heat for a sensible heat exchanger effectiveness of 50%, room conditions 26°C, R.H. 50%. Table 2 summarises the results for the cooling period. The structure of the table is similar to that of the previous table. First, the specific cooling design capacity is considered, depending of course of the outside design conditions and of the room set conditions. This capacity can be reduced by the heat recovery system depending on the heat exchanger effectiveness (as before, two values are considered, 50% and 70%).

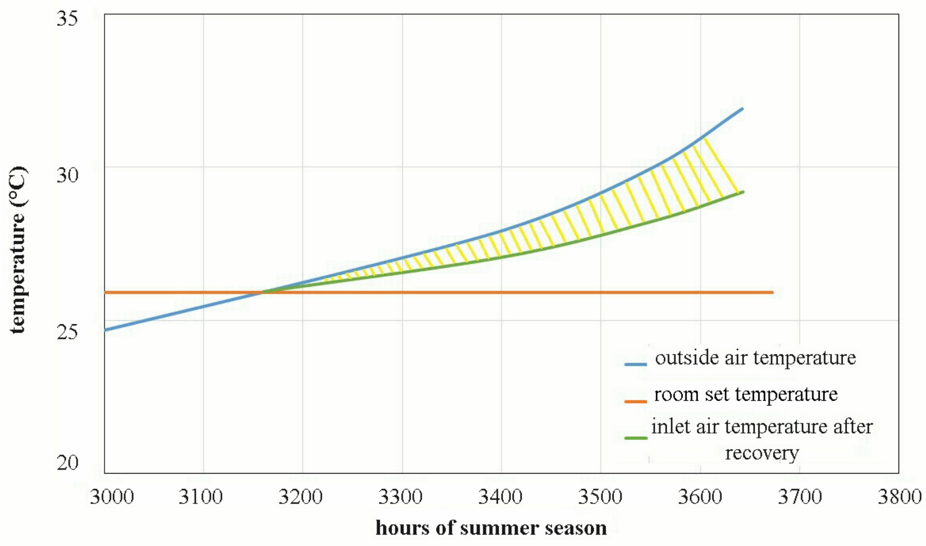
Due to the small temperature differences the possible heat recovery is really modest, even in a hot and humid climate. A simple method is available to improve the recovery: evaporative cooling of the exhaust air before the heat exchanger [7]. For the room conditions already mentioned, evaporative cooling produces an outlet temperature as low as 19°C. As a result,the specific design cooling capacity can be reduced greatly. For the evaporative pad, an effectiveness of 90% is assumed.

Table 2:
Sensible heat recovery in the three climates considered during the cooling period

Climate	Cold and temperate		Mild		Hot and humid	
Design cooling capacity W/(l/s)						
Cooling capacity	19.4		20.0		28.6	
Cooling capacity with heat recovery e=0.5	1.60		16.1		25.5	
Cooling capacity with heat recovery ε=0.7	14.7		14.5		24.3	
Cooling capacity with heat recovery ε=0.5 with evaporative cooling	12.7		12.7		22.1	
Cooling capacity with heat recovery ε=0.7 with evaporative cooling	10.0		19.8		19.5	
Cooling season heat recovery	MJ/(l/s)	kWh/(l/s)	MJ/(l/s)	kWh/(l/s)	MJ/(l/s)	kWh/(l/s)
Maximum seasonal heat recovery	5.8	1.6	10.1	2.8	5.4	1.5
Seasonal heat recovery ε=0.5 (rule of thumb)	3.1	0.9	5.4	1.5	3.8	1.1
Seasonal heat recovery ε=0.7 (rule of thumb)	4.3	1.2	7.6	2.1	5.3	1.5
Seasonal heat recovery ε=0.5	2.6	0.7	4.5	1.2	2.4	0.7
Seasonal heat recovery ε=0.7	3.7	1.0	6.3	1.7	3.4	0.9
Maximum seasonal heat recovery with evaporative cooling	34.3	9.5	48.6	13.5	63.6	17.7
Seasonal specific water consumption kg/(l/s)	28.0		39.3		51.9	
Seasonal heat recovery ε=0.5 with evaporative cooling	15.4	4.3	21.7	6.0	28.6	7.9
Seasonal heat recovery ε=0.7 with evaporative cooling	21.6	6.0	30.3	8.4	40.0	11.1

Figure 4:

Sensible heat recovery with 50% effectiveness for a continental temperate summer climate



Evaporative cooling can improve heat recovery in summer by 2 to 7 times, according to the climate, compared to simple sensible heat exchange. As reported in the table, the energy recovered is greater than the maximum seasonal heat recovery. Thus, heat recovery can alleviate the other cooling loads of the building once the ventilation loads are completely satisfied. Evaporative cooling can therefore be very advantageous: it requires simple and inexpensive equipment. As regards water consumption, estimated in the table at twice the evaporated amount to account for inefficiencies and bleeds, it is estimated at a maximum of 40-50 kg of water per l/s of ventilation air during the cooling season. At the outlet of the heat exchanger, the evaporatively cooled exhaust air, after having pre-cooled the fresh air, still has a lower temperature than the outside air, so that it can be suitable to contribute to the cooling of the condenser of the cooling machine.

Total heat recovery seasonal evaluations

The evaluation of the total seasonal heat recovery can be obtained as before, taking, instead of the temperature cumulative curve, the outside air enthalpy cumulative curve. Of course, the horizontals of the room air enthalpy must be drawn for the set winter and summer conditions.

HEATING OPERATIONS

Energy savings are in principle markedly better than sensible heat recovery: for example, they are about 30% higher in the continental temperate climate for winter. However, the previous evaluation in the diagram can be misleading, as a significant limitation must be taken into account during the heating season.

Latent heat recovery is not effective when the outside air humidity, increased by the water vapour received in the total heat exchanger, reaches values higher than those required by the inlet air, in the presence of internal latent loads. In fact, in doing so, the room air humidity may exceed the design set value, unless an expensive and unjustifiable dehumidification process is provided.

The internal latent load is ΣG_{vi} (presence of people, for example). If we consider only the fresh air inlet W_{in}, the required specific humidity x_{in} at the inlet is given by (x_{room} is the set specific humidity):

$$x_{in} = x_{room} - \frac{\sum G_{vi}}{W_{in}} \quad (4)$$

Total heat recovery must then be excluded when the outside specific humidity is such that the mass recovery in the total heat exchanger takes to values above the limit (4). The limit is more severe when a fraction of the exhaust air is recirculated.

The limit just described frequently exists in temperate climates. This is not only true for areas with high development of latent heat such as swimming pools, kitchens, show rooms, etc., but is also often the case for rooms with little traffic.

The possible heat recovery, keeping this limitation in mind, is represented in Figure 5 for temperate climates: here,no heat recovery is available for an outside temperature above about 9°C (enthalpy 24 kJkg^{-1}).

Figure 5:

Outside air enthalpy cumulative curve and total heat recovery with 50% effectiveness and recovery limitation for the continental temperate winter climate; the hatched area is proportional to the recovered energy.

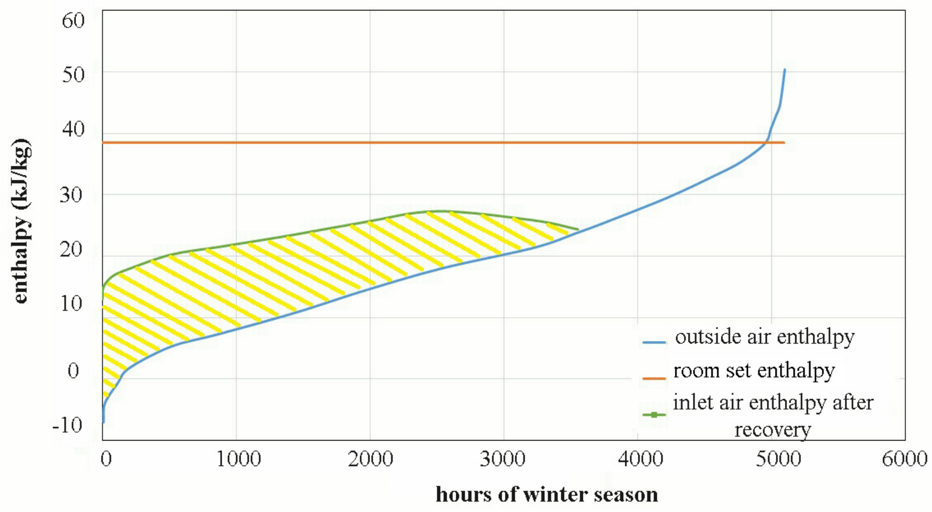


Table 3 provides a summary, for the three climates considered, of the total heat recovery for heating operations. The structure of the table is similar to that of the previous one. The section on energy saving compares the heat recovery values without limitation with the recovery related to the humidity limit.

The reduction is huge, particularly for a hot and humid climate. Sometimes, the actual total heat recovery is of the same order or even lower in some climates than the only sensible recovery for winter conditions.

Table 3:

Total heat recovery in the three climates considered during the heating period

Climate	Cold and temperate		Mild		Hot and humid	
Degree days	2404		1415		751	
Design heating capacity W/(l/s)						
Heating capacity	47.9		39.8		32.5	
Heating capacity with heat recovery ε=0.5	26.4		21.4		17.9	
Heating capacity with heat recovery ε=0.7	17.8		14.8		12.1	
Heating season heat recovery	MJ/(l/s)	kWh/(l/s)	MJ/(l/s)	kWh/(l/s)	MJ/(l/s)	kWh/(l/s)
Maximum seasonal heat recovery	444.1	123.3	265.7	73.8	107.5	29.9
Heating capacity with heat recovery ε=0.5	194.1	53.9	115.7	32.1	43.1	12.0
Seasonal heat recovery without limitation ε=0.7	272.1	75.6	162.1	45.0	60.3	16.7
Seasonal heat recovery with limitation ε=0.5	166.0	46.1	80.4	22.3	16.9	4.7
Seasonal heat recovery with limitation ε=0.7	218.0	60.5	97.3	27.0	17.4	4.8

COOLING OPERATIONS

Table 4 shows the results in terms of design cooling capacity and energy savings in summer. Sometimes the climate that is most disadvantaged during the heating period (hot and humid) benefits from the best performance in summer. A strong increase in heat recovery can take place during cooling operations. Then do not always reject total heat recovery in favour of only sensible recovery when total heat recovery is of the same order or even less than the sensible recovery alone, considering only heating operations. Furthermore, the possible reduction of the installed cooling capacity allows significant cost savings due to the relatively high cost of cooling equipment.

Table 4:

Total heat recovery in the three considered climates during the cooling period

Climate	Cold and temperate		Mild		Hot and humid	
Design cooling capacity W/(l/s)						
Cooling capacity	19.4		20.0		28.6	
Cooling capacity with heat recovery ε=0.5	10.6		11.0		15.7	
Cooling capacity with heat recovery ε=0.7	7.2		10.4		10.6	
Cooling season heat recovery	MJ/(l/s)	kWh/(l/s)	MJ/(l/s)	kWh/(l/s)	MJ/(l/s)	kWh/(l/s)
Maximum seasonal heat recovery	20.3	5.6	24.5	6.8	82.9	23.0
Seasonal heat recovery ε=0.5	9.1	2.5	11.0	3.1	37.3	10.4
Seasonal heat recovery ε=0.7	12.8	3.6	15.4	4.3	52.2	14.5

Some economic evaluations

The cost structure can vary greatly for different users, making it difficult to generalise the results. Costs can be divided into investment and operating costs. As regards the former, not only the cost of the heat recovery system must be considered, but also the marginal cost saving resulting from the possible reduction of the installed heating or cooling capacity that can be achieved by recovering energy from ventilation. Of course, it is not easy to estimate this saving: it depends on the absolute capacity to which the saving is applied, as the marginal cost of the installed heating or cooling capacity is a decreasing function of the capacity itself. Nevertheless, the saving is worth considering, especially for cooling operation. As far as operating costs are concerned, they are essentially two costs: the cost of heating energy (here the use of natural gas is assumed) for the boilers and the cost of electrical energy for the cooling equipment and the fans of the heat recovery system. The picture is complicated by the influence of boiler effectiveness and the COP of the cooling machines in determining the requirements, even neglecting the possible variation in the pressure drop for the different heat exchangers and the effectiveness of the fans.

The reference costs are listed in Table 5 where the marginal cost of a unit (1 kW) of cooling or heating capacity is reported (consider the large difference between the two values due to the higher cost of chillers compared to boilers). The investment cost of the installed heat recovery system is then given, referred to the unit ventilation rate (1 l/s) for three systems: sensible heat recovery with an effectiveness of 0.5 and 0.7 and total heat recovery with an effectiveness of 0.7.

The reported values are highly questionable not only because they depend on the type of equipment and on very different installation costs, but also because they strongly depend on the absolute size of the device, with marginal costs decreasing with it. The selected values are reasonable in developed countries, in the range 800-3000 l/s. Finally, energy costs are given for natural gas and electrical energy.

Table 5:

Reference costs considered for the economic analysis

Marginal specific cost of cooling capacity (€/kW)	300
Marginal specific cost of heating capacity (€/kW)	60
Investment cost of installed heat recovery system €/(l/s)	
Sensible heat recovery equipment with ε=0.5	6
Sensible heat recovery equipment with ε=0.7	10
Total heat recovery equipment with ε=0.7	16
Natural gas tariff c€/m³	90
Electrical energy cost c€/kWh	25

A summary of the costs and savings for yearly operation is reported in Table 6 for the three climates considered.

The first two lines provide the additional specific investment costs for the heat recovery system at both effectiveness of 0.5 and 0.7 (for 0.5, only the sensible recovery and for 0.7, both sensible and total). The costs include the installed equipment, reduced to take into account the capacity savings of the heating and cooling equipment due to heat recovery. This reduction differs from one climate to another. To get an idea, it is around 20%. The total cost of heat recovery equipment is about a 30% higher than that of sensible recovery alone.

Operational costs and savings are listed in the other rows of Table 6.

Table 6:

Costs and savings of heat recovery during yearly operation

Climate	Temperate		Mild		Hot humid	
Additional specific investment cost with heat recovery system €/(l/s)						
	Sensible	Total	Sensible	Total	Sensible	Total
Recovery efficiency ε=0.5	6.2		5.9		6.0	
Recovery efficiency ε=0.7	9.2	13.1	8.9	13.1	9.3	12.0
Operational cost and savings €/(l/s) per year						
Cost without heat recovery	13.3		8.3		5.0	
Cost with heat recovery						
Recovery efficiency ε=0.5	9.3		5.8		4.0	
Recovery efficiency ε=0.7	7.7	6.7	4.8	5.1	3.6	3.3
Pressure drop						
Pressure drop cost ε=0.5	0.6		0.4		0.3	
Pressure drop cost ε=0.7	0.9		0.6		0.5	
Saving with heat recovery						
Recovery efficiency ε=0.5	3.5		2.0		0.7	
Recovery efficiency ε=0.7	4.8	5.7	2.8	2.5	1.0	1.2
Economic and thermodynamic COP						
Economic COP ε=0	5.9		4.9		2.2	
Economic COP ε=0.7	5.4	6.6	4.5	4.1	2.0	2.4
Therm. COP ε=0.5	15.7		13.3		6.7	
Therm. COP ε=0.7	14.6	17.3	12.3	11.5	6.2	8.7

The heating costs correspond to a gas boiler with an efficiency of 0.9 (tariff 90c € m^{-3}), while the cooling cost is based on a COP of 3 with an electricity tariff of 25 c € kWh^{-1}.

Savings with heat recovery are reduced, as due, by the parasitic energy cost of the pressure drop in the heat exchangers. The estimate in the table assumes a pressure drop of 200 Pa for ε=0.5 and 300 Pa for ε=0.7 and a fan efficiency of 40%. Operating times of 7,000, 5,000 and 4,000 hours per year are considered for temperate, mild and hot humid climates respectively. The advantage of the system described here can be evaluated by a sort of economic COP, i.e. the ratio between the specific annual saving allowed by the heat recovery system and the annual cost of electricity to operate the fans. Values reported in Table 6 suggest that each euro spent on driving the fans allows to save from €2 to over €6 per year. Owing to the great tariff variability around the world, it is advisable to have an idea of the thermodynamic COP, i.e. the ratio between the energy recovered and the electricity used to operate the fans. In this way, the passive heat recovery system can be compared to an exhaust air heat pump. The values reported in Table 6 range from 6 in hot climates to 17 in cold climates. Needless to say, the values depend strongly on the pressure drops. It is therefore recommended to carefully analyse this feature of the heat exchanger. Possible savings are strictly climate-related, especially in the heating season, when the seasonal energy cost for ventilation is by far higher than in the cooling season, even in a hot and humid climate. High effectiveness should always be preferred as the additional cost is rapidly repaid by the savings made. It should be noted that specific regulations in many countries require the installation of heat recovery systems with a minimum effectiveness value. The payback period (3% discount rate) increases from only about two years for temperate climates and from two years to three years for mild climates. The payback period is longer for hot and humid climates, increasing up to more than eight years; in this case, evaporative cooling is strongly recommended.

Total heat recovery deserves special attention. The limitations imposed by humidity control during the heating season strongly reduce the possible savings in the temperate climates and, to a greater extent, in mild and hot and humid climates where the influence of humidity can lead to a four-fold reduction in possible savings, from only sensible to total heat recovery. The conclusion is not that sensible heat recovery is always preferable, as total heat recovery allows significant savings in mild and hot humid climates in cooling operations.

A comparison with Present Worth Value (PWV) analysis at a discount rate of 3% over 10 years gives the following results (energy cost increases by 5% per year):

- total heat recovery with an effectiveness of 0.7 is the best choice for a temperate cold climate with a PWV of €47/(l/s);
- sensible heat recovery with an effectiveness of 0.7 is the best choice for a mild climate with a PWV of €21/(l/s);
- only sensible heat recovery with an effectiveness of 0.7 is the best choice for a hot and humid climate with a PWV that amounts only to €2/(l/s).

In general, total heat recovery in a hot and humid climate may or may not be recommended depending on the balance of disadvantages during the heating season and possible benefits in the cooling season in relation to the higher cost of the equipment. Evaporative cooling can allow very significant savings during the cooling season, especially in hot climates.

Conclusion

Mechanical ventilation systems allow a better indoor air quality. The energy cost of fresh air can be strongly reduced by proper heat recovery. The following issues should be carefully considered.

- The energy benefits of heat recovery increase in cold or in very hot climates and of course when the ventilation time is longer.
- Energy recovery in the heating season is generally much higher than in the cooling season (often 5 to 6 times higher).
- The heating and cooling capacities of the plant shall be reduced with respect to the usual design in the presence of a heat recovery system.
- A higher heat exchanger effectiveness should normally be preferred, especially in cold climates.
- The design of the heat recovery system should carefully consider the pressure drops to limit the cost of electricity for the fans.
- The economic advantages depend mostly on the cost of heating energy (e.g. natural gas) and less on the cost of electricity, as the electricity saved to run the chillers is partly balanced by the electricity for the fans.
- The design of heat recovery should allow for the circumvention of the heat exchanger with a by-pass or with appropriate heat exchangers, able to set the exchange to zero, to allow for possible free cooling during the year.
- Total heat exchangers are sometimes less efficient than only sensible ones. A careful analysis of the climate is required.

Evaporative cooling on air exhaust provides very effective cooling of fresh air and should be considered whenever water is available at low cost.

Mechanical ventilation is mandatory in new or retrofitted airtight buildings. The energy and economic costs due to rising air quality standards can be reduced significantly through a well-designed heat recovery system.

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IIR recommendations

Heat recovery in mechanical ventilation systems may have a very positive environmental impact by reducing the usage of fossil fuel with payback periods of one or two years. The IIR therefore emphasises the need to:

- Develop strong worldwide campaigns on the economic and environmental benefits of heat recovery in ventilation systems to raise awareness among potential users, policy makers and industry representatives.
- Organise specific courses for designers and installers on appropriate choice of the heat recovery systems according to climate and building requirements.
- Set up incentive schemes and guidelines to promote the use of heat recovery systems in building ventilation plants.

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