Heat recovery in ventilation systems - waste heat use or renewable energy

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For as long as discussions about renewable energies have been ongoing, definitions and chargeability have been discussed in various technical standards and legal regulations. Practically each document defines something differently and there is no uniform procedure especially in the area of air conditioning and ventilation technologies. This paper shows differences between heat recovery and waste heat use and defines the renewable share of heat and cold recovery in ventilation units. A definition of renewable energies based on a primary energy approach would allow a fully technology neutral calculation of renewable shares and give a clarity to the political direction of travel.

1 Legal framework

The main legal bases for renewable energies in Europe are:

- DIRECTIVE (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2018 on the promotion of the use of energy from renewable sources
- Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency.

Definition in 2018/2001/EU:
(1) 'energy from renewable sources' or 'renewable energy' means energy from renewable non-fossil sources, namely wind, solar (solar thermal and solar photovoltaic) and geothermal energy, ambient energy, tide, wave and other ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas, and biogas;
(2) 'ambient energy' means naturally occurring thermal energy and energy accumulated in the environment with constrained boundaries, which can be stored in the ambient air, excluding in exhaust air, or in surface or sewage water;
(9) 'waste heat and cold' means unavoidable heat or cold generated as by-product in industrial or power generation installations, or in the tertiary sector, which would be dissipated unused in air or water without access to a district heating or cooling system, where a cogeneration process has been used or will be used or where cogeneration is not feasible;

The limitation to ambient air in (2) is not understandable, because ambient air immediately becomes outdoor air when leaving the building or machinery. The definition of waste heat and cold in (9) is also difficult to understand and has no physical base.

We can summarise, that the definition of these items is at any time a question which boundary conditions are selected.

This regulation is amended and supported by national regulations for the promotion of renewable energies in the Member States.
For example in Germany:

- Act on the Promotion of Renewable Energies in the Heat Sector (Renewable Energies Heat Act - EEWärmeG)
- Regional laws such as EWärmeG in Baden-Württemberg

There is no common definition of renewable energy and especially the heat recovery of ventilation system is treated and considered in different ways:

- Excluded
- treated as waste heat use and not counted in statistics
- treated as waste heat use depending on application (residential, tertiary, commercial, process, etc.).

This article and the proposals are limited to building related energies (heating, cooling, ventilation). The regulation itself gives guidance for some technologies but is not following consequently.
The amount of aerothermal, geothermal or hydrothermal energy captured by heat pumps is to be considered as energy from renewable sources for the purposes of Directive [1] shall be calculated according Annex VII.

$$E_{RES} = Q_{usable} * (1 - \frac{1}{SPF}) \qquad (1)$$

Q_{usable}: The estimated total usable heat delivered by heat pumps. Only heat pumps for which SPF > 1.15 * 1/η shall be taken into account,

SPF: The estimated average seasonal performance factor for those heat pumps (in this article mainly used as COP),

η_{is}: The ratio between total gross production of electricity and the primary energy consumption for electricity production. (in this article mainly uses as $1/f_{pr}$)

According guidance [3] the power system efficiency for electrical heat pumps is η_{is}= 0.45 and for thermal heat pumps is η_{is}= 1.0. The minimum SPF for electrical systems is 2.55 and for thermal systems 1.15.

The equation (1) can be used for a fully technology open specification of renewable energy and additionally in heat recovery of ventilation units. This means, if the coefficient of performance based on primary energy is bigger than 1.15, the contribution to renewable energies can be counted (2).

$$SPF * \eta = \frac{SPF}{f_{pri}} = COP_{pri} = SPF_{pri} > 1.15 \qquad (2)$$

It is nothing more than saying: Renewable energy is considered, if the usable energy of the machine is bigger than the primary energy input plus a threshold of 15%.

2 Heat recovery vs. waste heat use

2.1 General

Heat recovery, if at all creditable, is usually treated as waste heat recovery. It should be noted that there are physical differences between waste heat recovery and heat recovery in ventilation systems. The following examples are intended to illustrate this:

2.2 Waste heat use

If the building is heated with a fuel boiler (Fig. 1) then, for example only 75% for the heating is available, 25% passes outwards via the exhaust gas flow. In this example, a waste heat utilisation recovers 80% of the waste gas flow, i.e. 20% of the input, and accordingly only 5% of the waste gas passes outside.
This is a classic waste heat utilisation from a combustion process for a building. The waste heat can be used only one time exactly as the energy of the fuel.

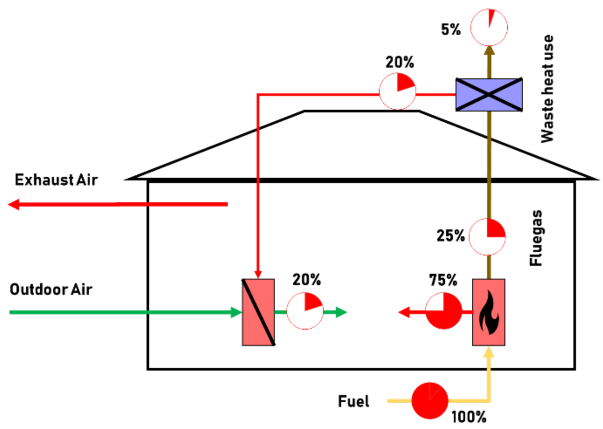

Fig. 1 : Example waste heat use with a boiler

2.3 Heat recovery in a ventilation system

If we now simplify the heat generation and only consider the ventilation system without heat recovery, the entire heat of the heating (including waste heat utilisation if necessary) is lost by the exhaust air (Fig. 2).

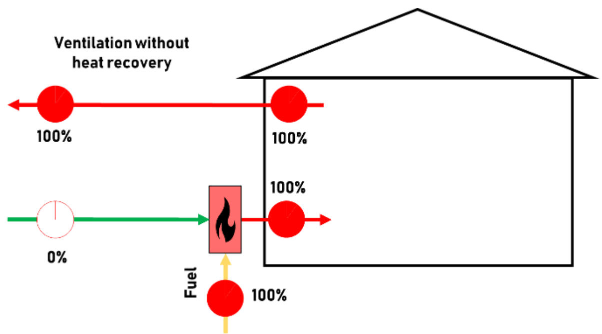

Fig. 2 : Example ventilation unit without heat recovery

With heat recovery in a ventilation system, the recovered heat is now returned to the circuit and is available again for heat recovery.
The installation of a heat recovery system (in our example 50%, Fig. 3) also reduces the heat requirement by 50%. This means that 0.5 kWh is recovered from 1 kWh of input in the first step.

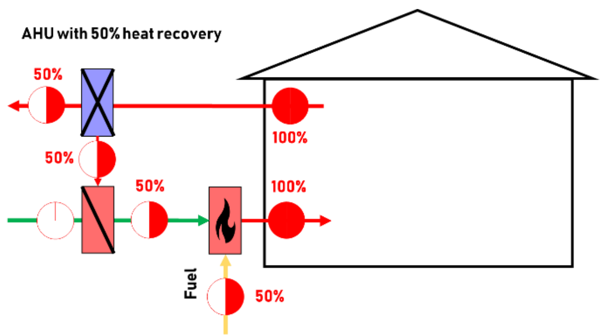

Fig. 3 : Example ventilation unit with 50% heat recovery

In the case of heat recovery in a ventilation system, the recovered heat is now back in the cycle and is again available for heat recovery.

A part of recovered energy thus regenerates again and again (Fig. 4). By definition this share is renewable energy.

If we would have a heat recovery with 100% efficiency, all energy will be recovered and recovered again (**renewing itself**). By definition renewable energy.

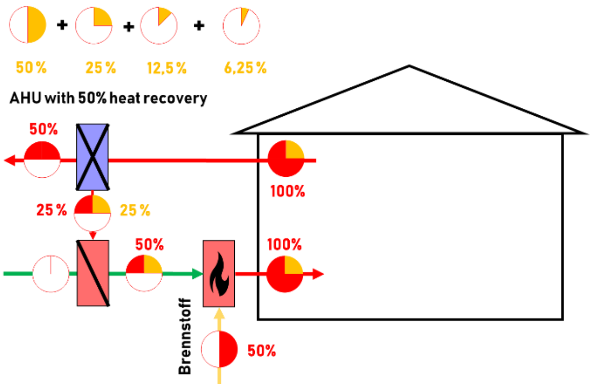

Fig. 4 : Example ventilation unit with 50% heat recovery

This process can be represented by an infinite series (3):

$$Q_{useable} = Q_{end} + Q_{end} \times \left(\frac{1}{2} + \frac{1}{4} + \frac{1}{8} + \cdots\right) \quad (3)$$

2.4 Calculation of renewable share in ventilation heat recovery system

Based on the specifications made in chapter 1 in analogy for the heat pump and using the general equation for a converging geometric series n and the temperature ratio of heat recovery η_t [0..100%]:

$$S_n = \sum_{k=1}^{n} a \times q^{k-1} = a + a \times q + a \times q^2 + \cdots + a \times q^{n-1} = a \times \frac{(1-q^n)}{(1-q)} \quad (4)$$

We get the usable energy for the heat recovery:

$$Q_{usable} = Q_{end} \times \frac{(1-\eta_t{}^n)}{(1-\eta_t)} \quad (5)$$

Or in analogy for a heat pump and furthermore, ventilation is a continuous process and if we consider a non-stop operation, we have an endless period and:

$$COP = \lim_{n\to\infty}\left(\frac{(1-\eta_t{}^n)}{(1-\eta_t)}\right) = \left(\frac{1}{(1-\eta_t)}\right) \quad (6)$$

Typically, a heating (including heat recovery) in ventilation systems is designed to cover ventilation loss. Space heating systems are designed to cover the transmission plus infiltration plus ventilation losses not covered by heat recovery. This means, we can isolate the ventilation and the heating system.

So, for a non-continuous operation (for example ventilation stops during night time) there is no ventilation loss in the stop period (only infiltration and transmission losses). When ventilation starts again, it starts exactly at the same situation where it stoped. Generally speaking, ventilation can be seen as a continuous process and equation (6) is valid in any case.

Using the approach of equation (1) we get:

$$Q_{usable} = Q_{end} + Q_{RES} \quad (7)$$

Or for the renewable energy of the heat recovery

$$Q_{RES} = Q_{usable} - Q_{end} \quad (8)$$

Using (5)

$$Q_{RES,HR} = Q_{usable,WRG} * (1 - \frac{1}{COP}) \quad (9)$$

And using (6):

$$Q_{RES,HR} = Q_{usable,HR} * \eta_t \quad (10)$$

What does is this equation (10) want to tell us? In technical heat recovery systems there is always a part which is waste heat use from the heating device.

$$Q_{Waste,HR} = Q_{usable,HR} * (1 - \eta_t) \quad (11)$$

All the calculations do not consider, that there might be other renewable heat sources in the ventilated building like passive solar gains, human beings or even renewable heating systems which will improve the renewable performance of the heat recovery, by recovering also these sources again.

2.5 Cold recovery

The cold recovery follows exactly the same principle and can be used in the same way. For humidification and dehumidification the same approach can be used based on humidity and enthalpy recovery performance data.

2.6 Examples

The specifications made in chapter 2.4 are valid for a heat recovery based only on thermal energy and not considering the transport energy for the air flow (this will be treated in the following chapter). But this will help to understand the principle.

Using equation (6) for typical heat recovery systems according Ecodesign regulation 1253/2014 (run around coils $\eta_{t,min}$=0.67 and others $\eta_{t,min}$=0.73) or slightly better we find a thermal COP of 3…5, which is in the same range like the electrical performance of a heat pump (Fig. 5).

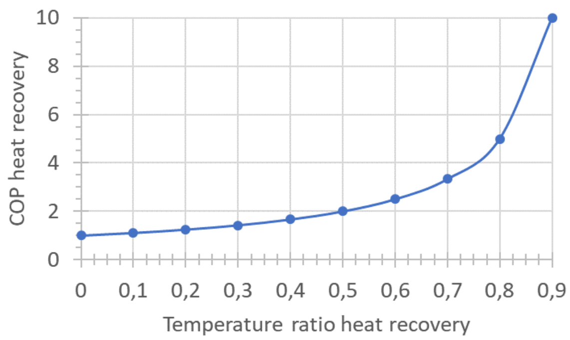

Fig. 5 : Thermal COP of a heat recovery system

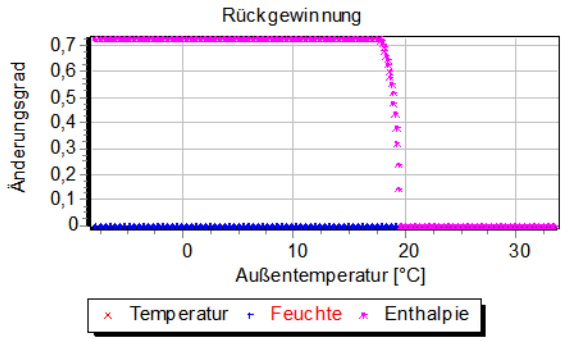

Fig. 6: Hourly temperature ratio of heat recovery supply air temperature 20°C (Frankfurt)

3 Primary energy based approach

3.1 General aspects

The approach in chapter 2 calculates the renewable thermal energy of a heat recovery, but does not cover all the energy aspects needed. A real ventilation system with heat recovery needs electrical energy and depending on heat recovery and outdoor conditions additional thermal energy. Thermal and electrical energy cannot simply be added, so we have to shift to a primary energy based approach.
We can specify a COP based on primary energy for our ventilation system with heat recovery:

$$COP_{pri,\mathrm{HR}} = \frac{Q_{usable,\mathrm{HR}}}{Q_{\mathrm{Waste,HR}} * f_{\mathrm{heat}} + Q_{trans} * f_{\mathrm{elec.}}} \qquad (12)$$

$$Q_{useable,\mathrm{HR}} = Q_{Waste,HR} + Q_{RES,HR} \qquad (13)$$

A primary based COP is a helpful indicator to decide if any system is delivering a renewable energy contribution or not. If for example the COP_{pri} >1 says, that the system is generating more useable energy, than it needs primary energy.
Nothing else is the minimum requirement of RED [1] for heat pumps in with a threshold of 15% based on electrical energy in (1).

Using the equations chapter 2 we get:

$$COP_{pri,\mathrm{HR}} = \frac{1}{\eta_t * f_{heat} + \frac{Q_{trans}}{Q_{useable,\mathrm{HR}}} * f_{\mathrm{elec.}}} \qquad (14)$$

Heat recovery systems shall have a thermal control system. This means, depending on the supply air temperatures needed and the climate conditions, the average temperature ratio operation in operation is lower than the design temperature ratio (Fig. 6). For renewable energy share calculation, the average temperature ratio for heat recovery in operation shall be used.

3.2 Examples

The following simplified examples will demonstrate the options of primary energy based approach.

Ventilation unit according EU 1253/2014 Tier 2:

- V=10.800 m^3/h = 3 m^3/s
- fan consumption including filter, heat recovery, casing = 800 W/(m^3/s) * 3 m^3/s = 2.400 W
  SUP fan 1.400 W und EXT Fan 1000 W
- temperature ratio of heat recovery 0,73
- primary energy factor heat $f_{pri,heat}$=1,0 (η=1)
- primary energy factor electricity $f_{pri,elec}$=2,2 (η=0,45)
- supply air temperature and room temperature min 20°C (no cooling)
- 8760 h operation

The hourly simulation (Table 1) for the different parameters and locations shows, that the COP_{pri} of the ventilation system with heat recovery is around 2 in the northern and around 1.5 in the southern European countries (Table 1, column 3-6) . The fan consumption based on ErP 1253/2014 does not include the additional demand for the transportation inside the building. This is exactly the same approach as the heat pumps with borderline SPFH2 according [3].

Even if we consider a further demand for transportation by doubling the fan power, the COP_{pri} still is 1.33.

If we compare for example with a heat pump COP=3.5 and using $f_{pri,elec}$=2,2 (η=0,45) the COP_{pri} is around 1.59 and in the same range.

4 Other renewable technologies

The primary energy approach as a basis for determining the renewable energy contribution can be applied to other known technologies including:

- Cold generation
- Cooling and enthalpy recovery
- Free cooling with cooling towers
- Evaporative cooling
- Solar systems
- And any combination

If we generalise the equation (12) to:

$$COP_{pri} = \frac{\sum Q_{usable}}{\sum(Q_f * f_{pri,f}) + \sum(W_f * f_{w,f})} \quad (15)$$

Q_{usable}: Generator outgoing energy
Q_f: Generator end energy demand
W_f: Generator auxiliaries demand
f: Primary energy factor for each end energy considered

A political steering aspect is fully implemented by the primary energy factors for each energy considered.

If we furthermore introduce for example a renewable share factor r in equation (16), then we get a simple determination of the contribution of renewable energies. If the factor r is positive ($COP_{pri}>1$), then we have a renewable contribution and if the factor r is negative ($COP_{pri}<1$), we have no.

$$r = \frac{E_{RES}}{Q_{usable}} = (1 - \frac{1}{COP_{pri}}) \quad (16)$$

The examples in Table 2 show some simplified approaches for different technologies.

As stated in the regulation [1], the primary energy approach works with heat pumps (Table 2 line 1 and 2). It works also for a solar water heater (line 3) and thermal heat pumps as well (line 5). If we look at the boilers, we see REG <0 for fossil heated and REG >0 for biogas and wood pellet. Clearly depending on their primary energy factors. (line 4,6,7).

Looking at the cold generators, we see negative contribution for fossil heated absorption chillers (line 9) and the approach is working for any free cooling system (line 11, 12).

Some experts might challenge, whether an electrical chiller can be a contributor to renewable energy shares depending on the efficiency and the primary energy factors.
Some might also highlight, that a chiller is not "producing" energy as such but shifting energy to another level. But also, this is exactly the same with heat pumps and the cold generated in chillers, is usable energy – no doubt.
With this principle a combined generation of heat and cold in a heat pump can be treated by adding the generated energy and considering the primary energy input.

5 Conclusion

This article has shown, that the current political definitions of renewable energies in buildings are complicated and do not adhere to the principle of technological neutrality.

Heat recovery in ventilation systems is comparable with heat pumps and is providing a significant amount of renewable energy in buildings.
A primary energy based coefficient of performance would allow a fully technology neutral calculation of renewable contribution. Specifying individual and/or national primary energy factors would provide clarity to underpin political decision-making and a improve the transparency of recalculation and reporting.

6 Symbols and abbrevations

Q_{usable}: The usable heat or cold delivered by a generator
Q_{end}: The end-energy used by a generator
Q_{RES}: The renewable energy contribution
Q_{Waste}: The waste energy contribution
$Q_{tansport}$: The transport energy demand (typically fan in ventilation systems)
W_f: Auxiliary energy demand for a generator
COP: The seasonal performance factor of a generator (in [2] SPF
COP_{pri}: The seasonal performance factor of a generator based on primary energy
η_{is}: The ratio between total gross production of electricity and the primary energy consumption for electricity production. (in this article mainly uses as $1/f_{pr}$)
f_{pri}: The primary energy factor for each energy used
η_t: The temperature ratio of a ventilation heat recovery system
HR: Heat recovery
SUP: Supply air
EXT: Extract air

7 References

[1] DIRECTIVE (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2018 on the promotion of the use of energy from renewable sources
[2] Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency.
[3] COMMISSION guidelines on calculating renewable energy from heat pumps from different heat pump technologies pursuant to Article 5 of Directive 2009/28/EC of the European Parliament and of the Council (2013/114/EU)

Table 1: Example calculation for the renewable contribution of ventilation heat recovery

1	2	3	4	5	6	3a	
Climate zone		Frankfurt	Helsinki	Barcelona	Athens	Frankfurt	
Operation time [h]		8760	8760	8760	8760	8760	
Temperature ratio η		0.73	0.73	0.73	0.73	0.73	
$P_{SFP,ges}$ [W/(m³/s)]		800	800	800	800	**1600**	
average temperture ratio η_{av}	Sim	0.716	0.721	0.705	0.704	0.698	
COP	(6)	3,52	3,58	3,39	3,39	3,31	
$Q_{usable,HR}$ [kWh]	Sim	203,045	331,519	119,818	129,781	206,366	
$Q_{ren,heat}$ [kWh]	(9)	145,380	239,025	84,472	91,366	144,043	
$Q_{not\ ren,heat}$ [kWh]	(12)	57,665	92,494	35,346	38,415	62,323	
Elec. Fans [kWh]	Sim	21,024	21,024	21,024	21,024	**45,550**	
$COP_{pri,WRG,Wärme,reg}$	**(13)**	**1.954**	**2.389**	**1.468**	**1.533**	**1.333**	
REG	(16)	**49%**	**58%**	**32%**	**35%**	**25%**	

Table 2: Simplified example calculation for the renewable contribution of different technologies

		Q_{outg}	Q_f	ζ	$f_{pri,f}$	W	COP / EER	f_w	**COP_{Pri}**	**REG**
	Heat generation									
1	Air to water heat pump	10000			1	2800	3,57	2,2	**1,62**	**38%**
2	Water to water heat pump	10000			1	2500	4,00	2,2	**1,82**	**45%**
3	Solar water heater	3000			1	300		2,2	**4,55**	**78%**
4	Gas boiler (fossil)	10000	11000	0,91	1	200		2,2	**0,87**	**-14%**
5	Thermal heat pump	10000	8000	1,25	1	30		2,2	**1,24**	**19%**
6	Gas boiler (biogas)	10000	11000	0,91	0,5	30		2,2	**1,80**	**44%**
7	Pellet	10000	12000	0,83	0,2	200		2,2	**3,52**	**72%**
	Cold generation									
8	Chiller (electrical)	10000			1	3000	3,33	2,2	**1,52**	**34%**
9	Absorptions chiller (fossil)	10000	15000	0,67	1	500		2,2	**0,62**	**-61%**
10	Absorptions chiller (biogas)	10000	15000	0,67	0,5	500		2,2	**1,16**	**14%**
11	Free geothermal cooling	5000			0	200	25,00	2,2	**11,36**	**91%**
12	Free cooling tower	5000			0	500	10,00	2,2	**4,55**	**78%**