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Temperature efficiency values: Definitions and requirements

Regulations, standards and guidelines have over time defined various indicators of heat recovery, some of which are also formulated as minimum requirements. Unfortunately, these definitions, e.g. for the temperature efficiency RWZ or the permissible auxiliary energy required for operation, are often different, which confuses the experts concerned and leads to uncertainty. The correct use is additionally made more difficult by the distinction between residential ventilation and non-residential ventilation. Different geographical areas of application (national and international) create further confusion. An analysis of the existing definitions in Europe, especially in the German-speaking countries, should help to bring some order to this confusion and create an overview.

Geographical scope

In practice, the following rules are affected today:

- **European regulation** (e.g. EU 1253 – 2014)
  This must be directly implemented in all EU countries; the scope is therefore the entire EU.
- **National law** (e.g. EEWärmeG in Germany)
  It has legal effect in the respective country.
- **European standard** (e.g. EN 13053)
  This must be converted into a national standard by the CEN members; its scope is therefore larger than that of the EU. Standards normally reflect the state of the art and it is therefore advisable, but not mandatory, to comply with them.
- **National guideline** (e.g. VDI 3803 Sheet 5)
  They apply in the respective country and reflect the state of the art. It is advisable, but not mandatory, to comply with them.

The significance of a regulation/standard/guideline thus depends on its geographical scope and enforceability. From the literature shown above, European regulations (EU) and European standards (EN) are therefore particularly important and must be observed accordingly.

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European Regulation EU 1253 (2014) with regard to the requirements for the environmentally friendly design of ventilation systems

This regulation requires a minimum efficiency (minimum RWZ) of heat recovery. At the same time, the auxiliary energy required for operation is limited.

Minimum temperature efficiency η_{t_NWLA}[1)]

The RWZ is also referred to here as the "thermal transfer rate of a non-residential heat recovery system η_{t_NWLA}":

$$\eta_{t\_NWLA} = (t_2'' - t_2') / (t_1' - t_2') \qquad (01)$$

t_1'	Extract air temperature (before the HRU)
t_2'	Outside air temperature (before the HRU)
t_2''	Supply air temperature (after the HRU)

1) In the German Official Journal of the EU, the designations are not used consistently. There are German and English abbreviations for the same term, which is confusing. For example, the η_{t_NWLA} is also called η_{t_nrvu} (non-residential ventilation unit).

Since 1 January 2018, the minimum RWZ for CV systems has been 68%, for all other HRS 73%.

This is applicable to:

- Non-residential ventilation systems NWLA
- Systems with two directions ZLA → two fans
- Air flow rates q_{nom} of
  → > 1000 m³/h always
  → 250 > q_{nom} > 1000 m³/h, if declared as NWLA

As minimum requirements are imposed on the RWZ (e.g. 73%), boundary conditions are defined for comparability:

- Both mass flows are of equal magnitude → $m_1 = m_2$
- The temperature difference ($t_1' - t_2'$) is 20 K
- There is no condensation → "dry"
- There is no temperature change due to fan heat and leakage

Maximum permitted specific fan power SVL_{int}

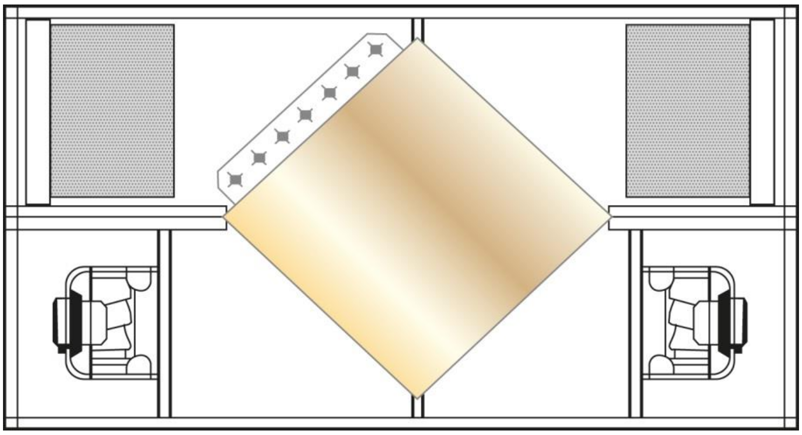

Figure 1: Reference configuration according to EU 1253

The EU 1253 limits the specific fan power of the reference configuration (= HRS and filter), which is determined by the internal pressure loss Δp_{int} and the overall efficiency of the fans η_{fan}.

$SVL_{int} = \Delta p_{int} / \eta_{fan}$ (02)

It is interesting to note that the specification for nominal volume flows is subdivided into larger than and smaller than 2 m³/s. Presumably, this is intended to take account of the lower fan efficiency at low air outputs.

$SVL_{int\ limit} = 1100 – 150 \cdot q_{nom} + E – F$ (03) where $q_{nom} < 2\ m^3/s$

$SVL_{int\ limit} = 800 + E – F$ (04) where $q_{nom} \geq 2\ m^3/s$

The maximum permissible internal specific fan power $SVL_{int\ limit}$ is increased by the efficiency bonus E if the actual RWZ exceeds the minimum value. The reason for this bonus is the assumption that a higher RWZ also causes or requires a higher pressure loss. For this reason, 30 W/m3/s of additional electrical power consumed are granted per percent RWZ increase. With a normal fan efficiency, this is about 20 Pa additional pressure loss for heat recovery, i.e. about 10 Pa per air stream.

$E = (\eta_t – 0.73) \cdot 3000$ (05)

The maximum permissible specific fan power $SVL_{int\ limit}$ can be corrected depending on the filter equipment (→ filter correction F: no filter = less $SVL_{int\ limit}$).

Assessment

With the specification of minimum RWZ and specific drive power, both possibilities of energy saving are used. The following points are important:

- With the minimum RWZ of 0.73 or 0.68, there is a clear requirement that cannot be discussed.
- With the efficiency bonus E, there is some leeway with the $SVL_{int\ limit}$ and higher RWZ. At 30 W/m3/s, however, the incentive is low. The type of primary energy used (water, coal, etc.) is not taken into account.
- For the $SVL_{int\ limit}$ there are several influencing parameters
  - Pressure loss HRS
  - Pressure loss filter
  - Efficiency fan, motor, drive and control

  These values are hardly likely to be known in the planning and in the offer phase. The question therefore arises as to whether the processing would not be facilitated by concrete specifications.
- The subdivision of the $SVL_{int\ limit}$ into two mass flow ranges is astonishing, since the influence or the effect is quite large, especially at < 2 m3/s.
- For RWZ and fan power there are specified boundary conditions which are not always observed in practice. Which values should be used then?
- With the usual design, the permissible pressure loss of the HRS is approx. 300 Pa (for both air streams). This is relatively low – compared to the values of EN 13053.

EN 13053 draft 2017

Ventilation for buildings – Central ventilation systems – Ratings and performance for units, components and sections

In this design, the RWZ η_t is corrected with the required auxiliary energy. The following definitions apply:

$$\eta_t = (t_{22} - t_{21}) / (t_{11} - t_{21}) \qquad (06)$$

η_t	Degree of temperature change (temperature efficiency)
t_{22}	Supply air temperature
t_{21}	Outside air temperature
t_{11}	Extract air temperature

The required electrical power consumption P_{el} can be taken into account with the coefficient of performance ε:

$$\varepsilon = Q_{HRS} / P_{el} \qquad (07)$$

Performance of the HRU Q_{HRS}

$$Q_{HRS} = (t_{22} - t_{21}) \times q_{V2} \times \rho_A \times c_{pA} \qquad (08)$$

Electrical power consumption.

$$P_{el} = (q_v \times \Delta p_{HRS}) / \eta_D + P_{el\ aux} \qquad (09)$$

q_{V2}	Volume flow outside air m^3/s
ρ_A	Air density kg/m3
c_{pA}	spec. Thermal capacity of air J/kg.K
q_v	Air volume flow m^3/s
Δp_{HRS}	Pressure loss HRU (supply and extract air) in Pa
η_D	System efficiency of drive (e.g. fan)
$P_{el\ aux.}$	Additional el. power (e.g. pump)

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Boundary conditions must be defined for a comparison:

- Both mass flows are of equal magnitude → $m_1 = m_2$
- The air density ρ_A is 1.2 kg/m³
- The fresh air temperature t_{21} is 5 °C
- The exhaust air temperature t_{11} is 25 °C
- There is no condensation → "dry"
- The overall efficiency of drive η_D is 0.6

The thermal and electrical powers can now be used to define the efficiency of an HRU, the energy efficiency η_e:

$$\eta_e = \eta_t \times (1 - 1/\varepsilon) = \eta_t \times (1 - P_{el}/Q_{HRS}) \qquad (10)$$

It can now be used to require minimum values for the various classes:

Class	H1	H2	H3	H4
Minimum energy efficiency η_e	0.74	0.70	0.65	0.60

With known pressure loss, the necessary temperature transfer coefficient η_t can be calculated from this:

$$\eta_t = \eta_e + \Delta p_{HRS} / (c_{pA} \times \rho_A \times (t_{11} - t_{21}) \times \eta_D) \qquad (11)$$

Assessment

The combination of thermal and electrical powers is an interesting idea, but the result depends largely on the definition of the boundary conditions. However, the significance of this European standard, which unfortunately is still only published as a draft, has decreased with the entry into force of EU 1253. The following points are also important:

- The energy efficiency η_e of the selected class can be achieved with any combination of the temperature transfer coefficient η_t and the pressure loss of the HRU Δp_{HRS}. The influence of the RWZ clearly outweighs compared to EU 1253. While only approx. 20 Pa pressure loss per % RWZ is available there via the efficiency bonus, the permissible increase for EN 13053 is approx. 140 Pa.

- The coefficient of performance ε gives a value analogous to the power output in relation to power input. This is used in the German Renewable Energies Heat Act (EEWärmeG), which requires an RWZ of at least 0.7 for an allowable HRU with a coefficient of performance of at least 10.
- The scope of validity covers all CEN countries, although EU 1253 probably takes precedence in the EU. Nevertheless, higher demands can be made here as well with class 1. (Class 2 corresponds approximately to EU 1253.)
- The basic values obtained for the pressure loss of the HRU for the comparable classes H1 and H2 are 600 and 480 Pa, respectively, which are considerably more than the approx. 300 Pa in EU 1253.
- The calculation of the RWZ η_t is iterative and therefore somewhat complicated.

VDI 3803 Sheet 5 (2013)

Ventilation technology, requirements on heat recovery units

This guideline is the successor to VDI 2071 and deals exclusively with heat recovery. Characteristic values are only defined; there are no requirements and limits regarding efficiency and necessary auxiliary energy.

Degree of temperature change (temperature efficiency) Φ_t

$$\Phi_t = (t_{22} - t_{21}) / (t_{11} - t_{21}) \qquad (12)$$

Φ_t Degree of temperature change (temperature efficiency)

t_{22} Outside air outlet temperature

t_{21} Outside air inlet temperature

t_{11} Extract air inlet temperature

Coefficient of performance ε

$\varepsilon = Q_{HRU} / P_{el}$ (13)

Performance of the HRU Q_{HRU}

$Q_{HRU} = (t_{22} - t_{21}) \times V_{AU} \times \rho_A \times c_{pA} = (t_{11} - t_{21}) \times \Phi_t \times V_{AU} \times \rho_A \times c_{pA}$ (14)

Electrical power consumption P_{el}

$P_{el} = (V_{AU} \times \Delta p_{HRU.AU}) / \eta_{AU} + (V_{FO} \times \Delta p_{HRU.FO}) / \eta_{FO} + P_{Zus}$ (15)

V_{AU}	Volume flow outside air m^3/s
V_{FO}	Volume flow exhaust air m^3/s
ρ_A	Air density kg/m3
c_{pA}	spec. Thermal capacity of air J/kg.K
q_v	Air volume flow m^3/s
$\Delta p_{HRU.AU}$	Pressure loss HRU outside air Pa
$\Delta p_{HRU.FO}$	Pressure loss HRU exhaust air Pa
η_{AU}	System efficiency drive outside air
η_{FO}	System efficiency drive exhaust air
P_{Zus}	Additional el. power (e.g. pump)

Efficiency η_{HRU}

$\eta_{HRU} = \Phi_t \times (1 - 1/\varepsilon) = \eta_t \times (1 - P_{el}/Q_{HRU})$ (16)

Boundary conditions must be defined for a comparison of the characteristic values:

- Both mass flows are of equal magnitude → $m_1 = m_2$
- The air density ρ_A is 1.2 kg/m^3
- The fresh air temperature t_{21} is 5 °C
- The exhaust air temperature t_{11} is 25 °C
- There is no condensation → "dry"
- No heat input and output

Assessment

This guideline reflects the basic knowledge of heat recovery; this is no wonder, since the original version (VDI 2071) was developed back in the 1970s. Accordingly, the characteristic values defined here can often be found in other rules. The similarity with EN 13053 E is particularly striking.

Looking at the previous issues, there are two main points that stand out:

- Originally there was also an RWZ relating to the extract air. In order to avoid mix-ups, this variant has now been omitted - analogous to EN 308.
- The defined boundary conditions - necessary to enable comparisons and limit values - were not introduced until later. The interpretation of using the characteristic values also outside these boundary conditions is therefore permissible and corresponds to the original meaning.

VDI 3803 Sheet 1 (draft 2018)

Ventilation technology, structural and technical requirements, central ventilation systems

With regard to heat recovery, the draft refers to EN 13053 dated 2017. In addition to the RWZ, the required auxiliary energy is also considered and evaluated. The HRU classes H1 to H4 of EN 13053 are adopted.

EN 308 (1997)

Test methods for determining the power criteria of air/air and air/exhaust gas mixture heat recovery devices

This rule was the first European standard for heat recovery. With regard to characteristic values, their significance lies in the definition of the degree of temperature change and the boundary conditions.

Degree of temperature change η_t

$\eta_t = (t_{22} - t_{21}) / (t_{11} - t_{21})$ (17)

t_{22} Supply air temperature

t_{21} Outside air temperature

t_{11} Extract air temperature

Boundary conditions

- Air density
  It is defined as 1.2 kg/m^3 and is (approximately) correct for air at 20 °C and 50% relative humidity.
- Measuring temperatures
  For dry operation/measurement, the following apply:
  - Extract air inlet 25 °C (wet bulb temperature < 14 °C)
  - Supply air inlet 5 °C
  These values have (unfortunately) been adopted as boundary conditions for the coefficient of performance ε. The consequence is that – seen over the year – the rating of the HRU performance is too high. The influence of the pressure loss is too small, which leads to incorrect RWZ/Δp equivalents.

EN 16798-3 (2017)

Energy performance of buildings. Ventilation for buildings.
Part 3: For non-residential buildings. Performance requirements
for ventilation and room-conditioning systems

In this standard, heat recovery is only a small subchapter which refers primarily to EN 13053. The SFP is granted the generous value of 300 W/m3/s for the heat recovery classes H1 and H2. The RWZ here is called temperature ratio and is not related to the outside air but – contrary to all other rules – to the cold air flow.

Temperature ratio (temperature efficiency) Φ_t ***at*** $m_1 = m_2$

$\Phi_t = (\theta_{22} - \theta_{21}) / (\theta_{11} - \theta_{21})$ (18)

θ_{22} Outlet temperature HRU cold air flow

θ_{21} Inlet temperature HRU cold air flow

θ_{11} Inlet temperature HRU hot air flow

Specific fan power P_{SFP}

$P_{SFP} = P / q_v = \Delta p_{tot} / \eta_{tot} = \Delta p_{stat} / \eta_{stat}$ (19)

P El. power consumption of the fan

q_V Design volume flow of the fan

Δp_{tot} Total pressure differential across the fan

η_{tot} Total fan efficiency based on the total pressure

Δp_{stat} Static pressure differential across the fan

η_{stat} Total fan efficiency based on the static pressure

Considering that this European standard was only published in 2017, it is astonishing that – compared to the existing rules – new terms and abbreviations have been introduced/used. This makes the topic even more confusing!

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Summary

In almost all rules, the logic for defining the RWZ is the same. (EN 16798 is an exception, in that the heating of the cold air and not that of the outside air is used.) It is therefore all the more surprising that the same term and the same abbreviations are not used for this. The auxiliary energy required for the operation of the HRU is generally represented by the additional electrical power consumed. If a combination of thermal efficiency and pressure loss is attempted, the necessary equivalent is determined relatively arbitrarily; the permissible Pascal pressure loss per percent temperature efficiency fluctuates between approx. 20 and 140. The question is whether two independent limit values - one for the temperature efficiency and one for the auxiliary energy - would not be clearer and easier to use.

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