Condensation in the plate heat exchanger increases efficiency and pressure loss

A great advantage of plate heat exchangers is the separation of the supply and extract air flows. This means impurities, odours as well as moisture cannot be transferred. Nevertheless, a part of the latent heat of humid extract air can also be used in the plate heat exchanger due to condensation. This increases the temperature efficiency RWZ of the heat recovery. How large this increase is, however, has long been controversial. Only the results of a joint series of measurements[1] with six exchangers from different manufacturers provided generally valid findings. These are described and interpreted below.

[1] Test reports HP 9/1, 10, 12 and 18/1 of the HVAC testing laboratory of the Lucerne University of Applied Sciences and Arts (HTA), 2000

Condensation in the extract air

At low outside temperatures – when there is a high heat demand – moist extract air is cooled down by the outside air to such a degree that the saturation temperature is reached and condensate is formed. This releases the condensation heat (= heat of evaporation). The condensation not only increases the heat output, but also the pressure loss of the heat exchanger. This applies in principle to all types of heat recovery – i.e. recuperative and regenerative systems. The following details are important for the plate heat exchanger.

Temperature efficiency RWZ

In Germany, according to VDI 3803 Sheet 5, a temperature efficiency Φ_t is defined for the outside air, which is also referred to as the degree of temperature change:

$$\Phi_t = (t_{22} – t_{21}) / (t_{11} - t_{21}) \qquad (01)$$

The RWZ applies in "dry conditions", i.e. without condensation. This is different with condensation in the extract air. Condensation heat is released, i.e. the cooling of the extract air flow is reduced (Fig. 1). This increases the temperature difference between extract air and supply air; more heat is transferred.

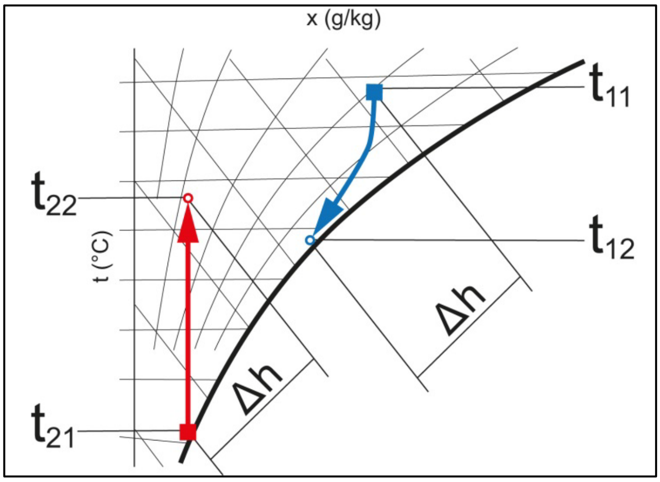

Figure 1: Condensation in the hx diagram

Condensation also increases the heat transfer between the extract air and the plate. This also improves heat transfer. For two reasons, the cold air is heated more than in dry operation and the temperature efficiency Φ increases accordingly.

$$\Phi = \Phi_t + \Delta\Phi_K \qquad (2)$$

The extent of this increase $\Delta\Phi_K$ depends primarily on the dry temperature efficiency of the plate heat exchanger and on the amount of condensate, i.e. the air conditions of outside air and extract air. Since in practice the heating of the outside air is important for the dimensioning of the reheater, the effective temperature efficiency Φ is almost exclusively used in planning. This is therefore considered in the following, in which case the mass flows (m1 = m2) are assumed to be the same. Diagram 1 shows the basic course of the temperature efficiency increase $\Delta\Phi_K$ as a function of the extract air humidity and the dry temperature efficiency (at an extract air temperature of 20 °C and an outside air temperature of -10 °C). This reveals the following:

- The increase in the temperature efficiency is strongly dependent on the humidity of the extract air. The higher the humidity, i.e. the more condensate, the greater the increase in the temperature efficiency $\Delta\Phi_K$.
- The curve for 100% relative humidity reflects the physical limits; in practice, however, it is not important.
- It can be seen that the increase in the temperature efficiency first increases with the dry temperature efficiency and then decreases again. This is the only way to ensure that the efficiency Φ does not exceed 100%.

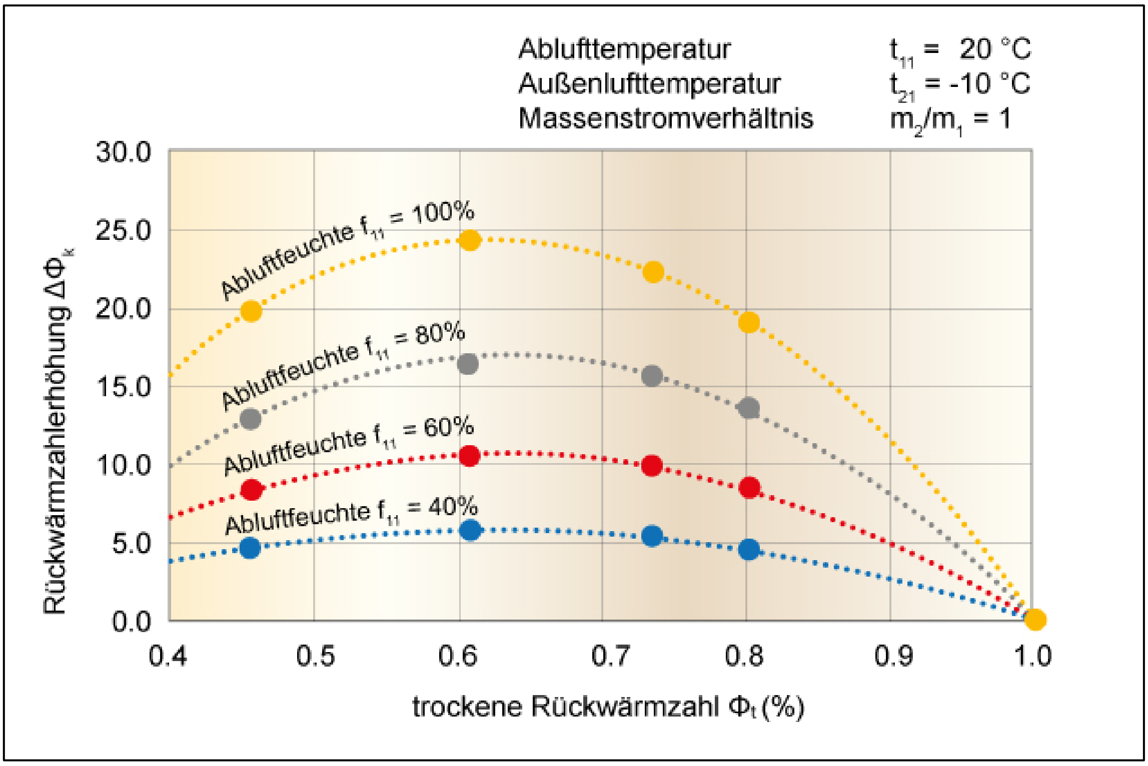

Diagram 1: Temperature efficiency increase with condensation

- Low temperature efficiency cannot always be improved, and cannot be improved at will. In other words: For maximum utilisation of the condensation heat, dry temperature efficiencies of approx. 60% are required.
- All measured plate heat exchangers show the same characteristics and (within the measuring tolerance) the same values. This means that the increase in the temperature efficiency during condensation is the same for all exchanger designs (plate profiles).

Pressure loss with condensation

In the plate heat exchanger, condensate occurs primarily in the "cold corner" due to uneven cooling (Fig. 2); condensate can only be expected on the entire plate under extreme conditions (high humidity and low outside temperature). Condensation creates droplets or a water film on the extract air side. This reduces the free cross-section. As a result, the splitting speed and thus also the pressure loss increase. This is usually not taken into account in design, although under normal extract air conditions this increase may well be 50% of the pressure loss in dry operation.

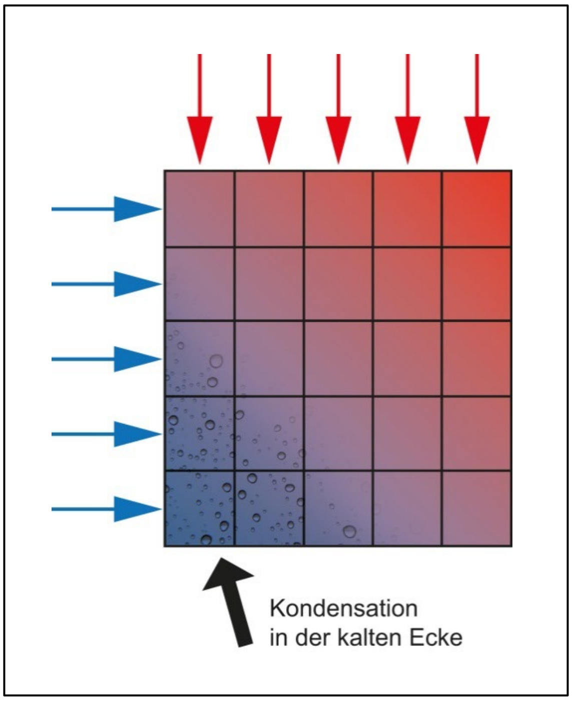

Figure 2: Condensation first occurs in the "cold corner"

For all measured plate heat exchangers, the pressure loss has increased during condensation; a trend curve is given in diagram 2. In contrast to the temperature efficiency, however, the increase in pressure loss cannot be specified independently of the product, as this is determined

- from the plate spacing,
- from the pressure loss in dry condition,
- from the mounting position of the exchanger
  (Where is the cold corner? How does the condensate drain off?),
- from the design principle.

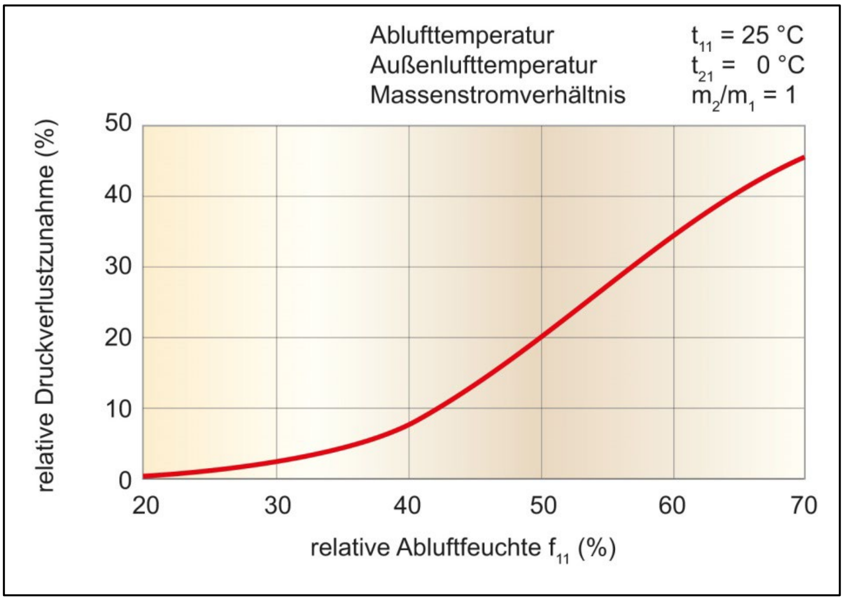

Diagram 2: Pressure loss increase with condensation

In the measurements, the relative increase in the pressure loss of the extract air Δp1 at 70% relative humidity was between 20% and 50%; it is strongly dependent on the extract air humidity. Practical experience has shown that with high extract air humidity and low outside air temperatures, i.e. with large condensate volumes, the pressure loss can even rise to twice the initial value.

Frost hazard

Under extreme conditions, i.e. at very low outside temperatures, the condensate produced – starting at the cold corner – can freeze and thus possibly put the heat recovery unit out of operation. Manufacturer information and technical literature on this subject is available in sufficient quantity.

Design

In ventilation units, it is important that the condensate produced is separated from the air stream, collected and discharged. This may require droplet separators, but in any case collection trays with inclination (if possible on both sides) and appropriately dimensioned discharge pipes with siphon. In order to avoid the transfer of condensate from the extract air to the supply air, a pressure drop towards the extract air should be planned in addition to a tight design. A good condensate discharge is achieved when the extract air flow with the condensate flows vertically downwards, i.e. in the direction of gravity. Special measures are required for "horizontal installation" (= horizontal plates), as the condensate drains off uncontrolled. A droplet separator is recommended; there is an increased risk of icing.

Configuration

An important reason for excessively high values of temperature efficiency concerns the initial conditions of the extract air. Despite dry outside air at low outside temperatures, the extract air humidity is usually set too high. The result is that too much condensate is calculated to be in the extract air and thus a too high (theoretical) temperature efficiency.

(A reliable dimensioning of the reheater is therefore obtained by using the dry temperature efficiency. This recommendation also applies to conservative profitability calculations.)

Conclusions

- The increase in the temperature efficiency with condensation is independent of the design principle (plate profiling).
- Calculation programs for temperature efficiency must still function correctly even with extreme values. Controls are therefore useful:
    - for very low temperature efficiencies (does this achieve condensation at all?)
    - for very high temperature efficiencies and high air humidities (can even values above 100% be obtained?)
- In addition to the dry temperature efficiency Φt, the wet temperature efficiency Φ can also be specified in the design documents so that the influence of condensation becomes apparent.
- The recommendations regarding design and installation position must be observed.
- It is important that no condensate is transferred to the outside air side. The demands for a tight design are correspondingly high.
- An indication of the increase in pressure loss due to condensation in the design documents is recommended (→ fan design).
- The extract air conditions must be critically scrutinized during planning.
- Such non-proprietary measurements are not (yet) known for plate heat exchangers with a countercurrent proportion; however, a similar behaviour is to be expected.

Formula symbols used

Symbol	Explanation	Unit
Φ_t	Temperature efficiency (dry)	– or %
t	Temperature	K or °C
m	Mass flow	kg/h or kg/s
x	Absolute humidity	g/kg
f	Relative humidity	%
$\Delta\Phi_K$	Temperature efficiency increase	%
Δp	Pressure drop	Pa

Indices:

1. Index: 1 Extract air/exhaust air
2 Outside air/supply air

2. Index 1 Inlet plate heat exchanger
2 Outlet plate heat exchanger

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