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Heat exchanger – also for cooling

The usefulness of conventional heat recovery systems in animal houses during heating periods tends to be restricted to times when the perceptible heat given off by the animals is not sufficient to generate a heat output that is desirable for the pens. Once the temperature in the animal house exceeds this setpoint temperature, control valves are deployed to channel the incoming/outgoing air flow past the heat exchanger via a bypass valve, thus preventing any further exchange of heat between the incoming and outgoing air. By humidifying the outgoing air prior to entry into the heat exchanger, this is cool and can escape the fresh air heat. Because of the separate streams of air (Supply and exhaust air) it affects the water content is not the stable air. Using a dynamic calculation model, the fall in temperature inside the stable can be predicted depending on the thermal efficiency of the heat exchanger, the air flow and ventilation rate and the amount of water vaporised. The report deals with the theoretical principles and the effect of heat exchangers featuring adiabatic cooling of the incoming and/or outgoing air on the climate in animal houses. On the basis of an example, the cooling effect of different variants is compared and assessed. The results presented are based on a dynamic calculation model. The technical and economic feasibility of heat recovery systems of this kind will be examined later in a pilot plant.

Keywords
Heat recovery, adiabatic and diabatic cooling, climatization of animal houses

Abstract
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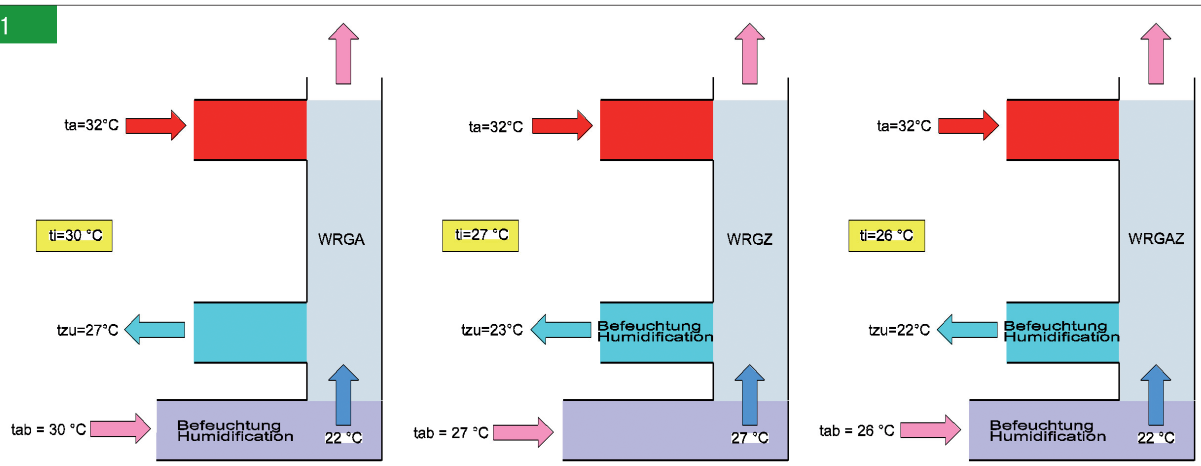
The report deals with the theoretical principles and the effect of heat exchangers featuring adiabatic cooling of the incoming and/or outgoing air on the climate in animal houses. On the basis of an example, the cooling effect of different variants is compared and assessed. The results presented are based on a dynamic calculation model. The technical and economic feasibility of heat recovery systems of this kind will be examined later in a pilot plant.

Operating Principle

Depending on where the humidification of the air takes place, in the outgoing or in the incoming air flow, three possible variations may be identified. Where the outgoing air is subject to humidification (variant WRGA, **Figure 1**, left), fully diabatic cooling of the incoming air takes place through the exchange

Fig. 1



Schematic representation of different heat recovery possibilities, with adiabatic and/or diabatic cooling (ti: the temperature in the stable, ta: the outside temperature, tzu: the temperature of the incoming air, ta: the temperature of the exhaust air) of heat in the heat exchanger. The advantage of this is that the water content of the air in the stable is not increased. The outgoing air can, therefore, be enriched with water up to its saturation point (100 % relative humidity). The extent to which the outgoing air cools is dependent on the relative humidity of the air inside the stable. This in turn depends on the external climatic conditions, the livestock and the ventilation rate. A reduction in temperature of up to 10 °C is possible.

It is also possible to humidify the incoming instead of the outgoing air (variant WRGZ, **Figure. 1**, centre). By contrast to variant WRGA, humidification of the incoming air increases the water content of the air in the stable. In order to ensure that the relative humidity of the air in the stable does not rise above the threshold value (for instance, 70 %), the vaporised quantity of water in the incoming air must necessarily be restricted. Instead of vaporising the water in the incoming air, it can also be atomised over a wide area in the stable by means of high pressure nozzles. The WRGZ variant differs from the usual high pressure atomisation of the air in the stable by virtue of the fact that the incoming air is diabetically pre-cooled in the heat exchanger, subject to the temperature inside the stable being below the outside temperature.

In a plant featuring humidification of the outgoing and incoming air (WRGAZ, Fig. 1, right) the relative humidity of the outgoing air was increased to 100 %. However, the relative humidity of the incoming air cannot in most cases be increased to 100 % because otherwise there would be an excessive rise in the relative humidity of the air in the stable. The use of this variant enables the maximum adiabatic and diabatic cooling potential of the heat recovery unit to be fully utilized.

Principles of Calculation

With the help of a simulation model in which all the control variables – discharge of sensible and latent heat on the part of the animals, external and internal climatic conditions, heat losses as a result of transmission and ventilation, thermal efficiency of the heat recovery system – are dynamically linked, the effect of humidification of the outgoing and incoming air in the heat recovery system on the climatic conditions in the stable can be examined. The cooling process may be compared with that of other cooling processes such as subsoil heat exchangers (EWT) and high pressure atomising (HDV) in the stable.

Because the temperature of the stable is both a command variable and an influencing variable, an iteration procedure is used in the calculation process. The maximum permitted relative humidity in the stable, the saturation point of the air and the thermal efficiency of the heat recovery system are all determining factors when it comes to cooling. Within the range of 10 to 20°C, the temperature of the atomised water exerts only a very minor effect on the stable temperature (< 0.1°C).

Sample Calculation

The sample calculation relates to a stable housing 600 fattening pigs at a live weight of 100 kg. The outside temperature is 32 °C, the relative humidity outside is 40 % (**Table 1**). The maximum permitted relative humidity in the stable air is limited to 70 %. The transmission losses amount to 257 W/°C. The thermal inertia of the building is not taken into account in the calculations (stationary heat flow).

$$t_{i,referenz} = \frac{H_s + q_T \cdot t_a + V \cdot 0.28 \cdot \rho \cdot t_a}{q_T + V \cdot 0.28 \cdot \rho} \quad \text{(Eq. 1)}$$

$$t_{i,WRGA} = \frac{H_s + q_T \cdot t_a + V \cdot 0.28 \cdot \rho \cdot [t_a - \eta_{WRG} \cdot (t_a - (t_i - \frac{W_{ab} \cdot 680}{V \cdot 0.28 \cdot \rho}))] - \eta_{WRG} \cdot W_{ab} \cdot 1.16 \cdot (t_i - t_w)}{q_T + V \cdot 0.28 \cdot \rho} \quad \text{(Eq. 2)}$$

$$t_{i,WRGZ} = \frac{H_s + q_T \cdot t_a + V \cdot 0.28 \cdot \rho \cdot [t_a - \eta_{WRG} \cdot (t_a - t_i) - \frac{W_{zu} \cdot 680}{V \cdot 0.28 \cdot \rho}] - W_{zu} \cdot 1.16 \cdot (t_i - t_w)}{q_T + V \cdot 0.28 \cdot \rho} \quad \text{(Eq. 3)}$$

$$t_{i,WRGAZ} = \frac{H_s + q_T \cdot t_a + V \cdot 0.28 \cdot \rho \cdot [t_a - \eta_{WRG} \cdot (t_a - (t_i - \frac{W_{ab} \cdot 680}{V \cdot 0.28 \cdot \rho})) - \frac{W_{zu} \cdot 680}{V \cdot 0.28 \cdot \rho}] - (\eta_{WRG} \cdot W_{ab} + W_{zu}) \cdot 1.16 \cdot (t_i - t_w)}{q_T + V \cdot 0.28 \cdot \rho} \quad \text{(Eq. 4)}$$

$$t_{i,HDV} = \frac{H_s + q_T \cdot t_a + V \cdot 0.28 \cdot \rho \cdot t_a - W_{HDV} \cdot 680 - W_{HDV} \cdot 1.16 \cdot (t_i - t_w)}{q_T + V \cdot 0.28 \cdot \rho} \quad \text{(Eq. 5)}$$

$$t_{i,EWT} = \frac{H_s + q_T \cdot t_a + V \cdot 0.28 \cdot \rho \cdot (t_a - \eta_{EWT} \cdot (t_a - t_b))}{q_T + V \cdot 0.28 \cdot \rho} \quad \text{(Eq. 6)}$$

$t_{i,reference}$: Temperature in reference stable (with no treatment of incoming air) °C
$t_{i,WRGA}$: Temperature in stable with WRGA (adiabatic cooling of outgoing air) °C
$t_{i,WRGZ}$: Temperature in stable with WRGZ (adiabatic cooling of incoming air) °C
$t_{i,WRGAZ}$: Temp. in stable with WRGAZ (adiabatic cooling of incoming and outgoing air)°C
$t_{i,HDV}$: Temperature in stable with HDV (high pressure atomising) °C
$t_{i,EWT}$: Temperature in stable with EWT (subsoil heat exchanger) °C
H_S: Sensible heat discharge from animals (as a function of ti) W
t_a: Outside temperature °C
t_b: Temperature in earth mantel around tube fin heat exchanger °C
t_w: Water temperature of humidification plant °C
q_T: Transmission losses W/°C
V: Air flow and ventilation rate m³/h
r: Air density kg/m³
W_{ab}: Amount of atomised water in the outgoing air kg/h
W_{zu}: Amount of atomised water in the incoming air kg/h
W_{HDV}: Amount of atomised water in the stable air kg/h
η_{WRG}: Thermal efficiency of heat recovery system %
h_{EWT}: Thermal efficiency of subsoil heat exchanger %

Humidification of Outgoing and Incoming Air in the Comparison

In the case of the WRGA variant, the temperature of the outgoing air, assuming an air flow and ventilation rate of 60 000 m³/h, can be reduced to 21.8 °C provided that the relative humidity of the outgoing air is increased to 100 %. Assuming that the efficiency of the heat exchanger is 50 %, the incoming air temperature will fall from 32 °C (outside temperature) to 26.9 °C. Thanks to this cooling the stable temperature (30.5 °C) will be about 1.5 °C below the outside temperature (**Figure 2**). Without WRGA the stable temperature would be 34.5 °C. The relative humidity of the air in the stable will be 48.3 % at 60 000 m³/h (**Figure 3**).

The humidification of the incoming air (WRGZ) is, on the one hand, limited by the maximum water absorption capability of the incoming air and, on the other, by the maximum permitted relative humidity in the stable (70 %). With a ventilation rate of 60 000 m³/h, the incoming air temperature will be 22.8 °C and the temperature in the stable 27.0 °C (**Figure 2**). The temperature in the stable will be 3.5 °C lower by comparison to WRGA, but the relative humidity will be 21.7 % higher (**Figure 3**). In order to ensure that the relative humidity of the stable air does not rise above the limit value (70 %), the relative humidity of the incoming air at 60 0000 m³/h must not exceed 83.5 %.

If both the outgoing air and the incoming air are adiabatically cooled (WRGAZ), assuming an air flow and ventilation rate of 60 000 m³/h, the temperature in the stable will fall to 26.2°C (**Figure 2**). This variant also incorporates the need to restrict the relative humidity of the incoming air as the air flow and ventilation rate increase so that the air in the stable does not become too moist.

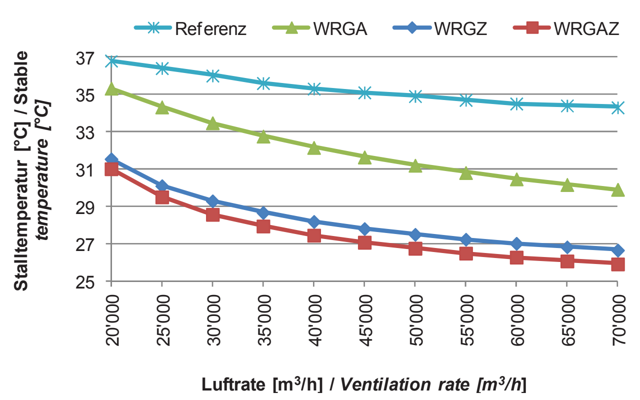
Effect of the Thermal Efficiency of the Heat Exchanger

The effect of thermal efficiency on the stable temperature is most apparent in the case of the variant WRGA (**Figure 4**). As regards the variant WRGZ, the difference in temperature between an efficiency factor of 40 % and one of 80 % is only around 0.7 °C (ventilation rate 40 000 m³/h) whilst, by contrast, for the WRGA variant it is 4.2 °C and for the WRGAZ variant it is 1.5 °C.

Comparison with high pressure atomizing in the stable and the subsoil heat exchanger

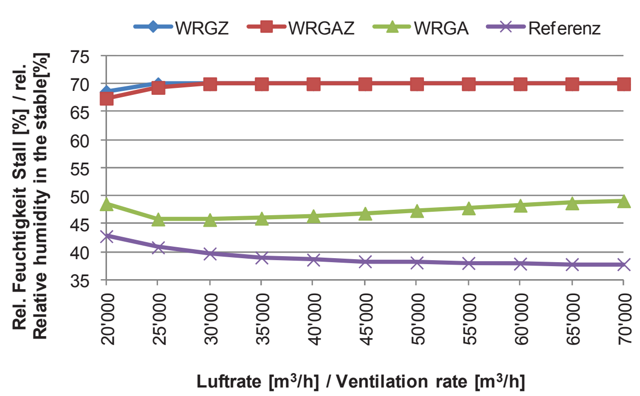
For this comparison the following assumptions have been made. The relative humidity (70 %) of the air in the stable has a limiting effect on the high pressure atomizing (HDV) in the stable as well as on the humidification of the incoming air in the WRGAZ. The thermal efficiency factor of the heat exchanger is 50 %. The temperature of the incoming air as regards the

Fig. 2



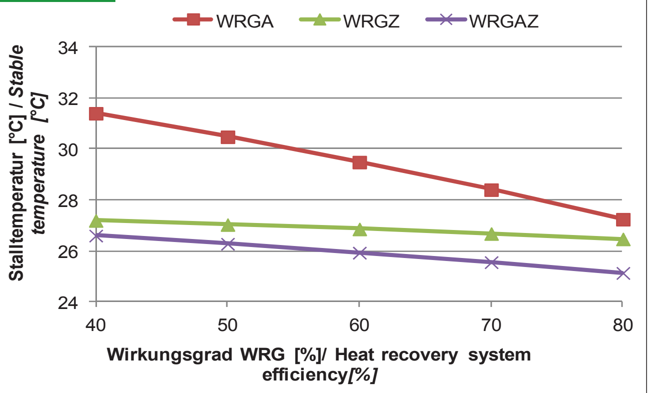
Stable temperature for the 3 types of heat recovery systems in comparison with the reference stable 50 % thermal efficiency of the heat exchanger

Fig. 3



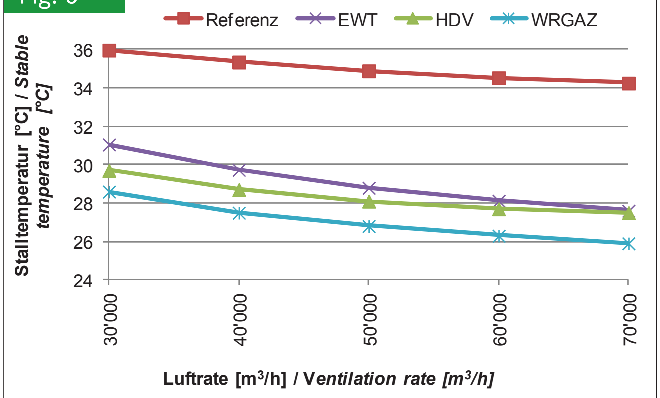
The relative humidity of the reference stable and of the WRGA is considerably lower than in the case of the other two options. 50 % thermal efficiency of the heat exchanger

Fig. 4



The influence of the thermal efficiency of the heat exchanger on the stable temperature in the case of the three heat recovery systems. Ventilation rate 40 000 m³/h

Fig. 5



With the increase of the ventilation rate the temperature difference in the stable between WRGAZ and HDV is also increasing

subsoil heat exchanger variant (EWT) is 24 °C at an outside temperature of 32 °C.

As regards high pressure atomizing in the stable, the whole of the cooling process for the incoming air takes place adiabatically. In the case of a WRGAZ, the reduction in temperature is in part achieved diabatically by means of an exchange of heat between the outgoing and the incoming air. This means that a stable temperature that is 1 to 1.5 °C lower is possible (**Figure 5**). The cooling effect of the subsoil heat exchanger is, with a ventilation rate of 70 000 m^3/h, about the same as with high pressure atomizing in the stable, but at a relative humidity that is actually 15 % lower.

Economic Aspects

In the case of the WRG variants with adiabatic cooling and by contrast to traditional heat recovery systems, fixed additional costs will be incurred due to the humidification system and the larger heat exchanger which also needs to be sufficient to cope with the summer ventilation rate. As regards the operating costs, allowance has to be made for the water and power requirements of the pumps.

On the other hand, cost savings are also possible by comparison to traditional heat recovery systems. There will no longer be any need for a bypass on the incoming and outgoing air side (valves, chimney) and the control system is more straightforward. An additional reduction in costs will be possible if (thanks to the cooling) the air flow and ventilation rate can be reduced in the summer. In the example the stable temperature with a WRGAZ is 28.6 °C at a ventilation rate of 30 000 m^3/h by comparison to 34.5 °C at a ventilation rate of 60 000 m^3/h in the reference stable.

If incoming air is flowing through the heat exchanger all the year round, then higher power costs for the fans will need to be factored in due to the additional air resistance. On the other hand, the requirement for power will be reduced if, when the outside temperatures are higher, the air flow and ventilation rate can be reduced thanks to the cooling arrangement. The more generously dimensioned the heat recovery unit, the less the air resistance will necessarily be with the same air flow and ventilation rate and the greater the thermal efficiency, both in winter and also in summer. On the other hand, the investment costs will rise as the size of the plant grows. Further research and practical trials are needed to pinpoint the economic optimum.

Conclusions

As a result of the integration of an adiabatic cooling system on the outgoing and/or incoming air side, the heat recovery system will contribute throughout the year towards regulating the climate inside the stable. The saturation of the outgoing air with vapour upstream of the heat exchanger will have a dramatic cooling effect. The cooling of the incoming air takes place diabatically and for this reason has no effect on the water content of the air in the stable. The better the thermal efficiency of the heat exchanger, the more heat will be extracted from the incoming air. By comparison to the outgoing air, humidifying the incoming air gives an enhanced cooling effect. However, it is restricted by the relative humidity of the air in the stable. By contrast to the high pressure atomizing in the stable, when a heat recovery system with incoming air humidification is used, the cooling process does not take place totally adiabatically but also to an extent diabatically as a result of the exchange of heat between the outgoing and the incoming air.

On the one hand, the deployment of heat recovery systems all the year round generates a higher power requirement for the fans due to the air resistance in the heat exchanger whilst, on the other, the energy requirement can also be reduced thanks to the ventilation rate required in the summer.

With increased global warming, there is also likely to be an increase in the need for cooling facilities in pig and poultry rearing stations. Heat exchangers with integrated adiabatic cooling of the outgoing and incoming air may be seen as an energetically justifiable solution both for reducing and for increasing the temperature in stables.

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