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Thermotechnical Characteristics of a Modular Stable

The Aco Funki company has a new housing concept for pig husbandry, where the house climate parameters of temperature and air volume flow was measured for one whole day under winter conditions. The speciality of this housing concept is the type of supply air ducting. Through a channel underneath the underground slurry pit and through the control passage into the insulated loft before entering the animal compartment through perforated ceiling plates. This ducting design is connected with very low thermal losses because – as this text shows – the supply air absorbs the transmission heat losses in the building, which leads to an almost neutral heat balance without the necessity of additional heating.

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Keywords

Heat balance, volume flow rate, pig fattening

In times of rising heating costs, energy saving is a demand frequently voiced in connection with new designs of livestock houses. One-day measurements of indoor climate parameters in a livestock house based on a new design by the company Aco Funki were carried out to answer the following questions:

- Does a heat flow balance based on short-term measurements provide realistic values for determining the thermotechnical characteristics of individual livestock houses?
- Can the supply-air ducting be designed in such a way as to recirculate transmission heat back into the interior of a barn (in the sense of heat recovery)?

In order to ascertain if the indoor temperature can be kept at the required level in winter, it is necessary to draw up a balance of the different heat flows. The DIN 18910-1 construction standard gives specifications on how to draw up such a balance for livestock houses (*Fig. 1*) [1].

$$\dot{Q}_{Heizung} = \dot{Q}_{Tiere} - (\dot{Q}_{Bauteile} + \dot{Q}_{Lüftung}) \quad (1)$$

Under normal circumstances the animals are the only heat source in a livestock house [2]. Auxiliary heating sources or heat recovery instruments are frequently used in stables for growing animals or in stables operated according to the allin-allout method. The heating systems are designed according to equation 1, in which the physical formula sign 'Q' stands for the heat flows.

The thermal transmittance of an entire wall or a single building component (e.g. a door) is expressed by its u-value (formerly k-value). The u-value is a factor in the calculation of the heat losses (cf. equation 2). A low u-value is regarded as favourable, whereas a high value is a sign of poor thermal insulation. Experience shows that in livestock houses it is primarily the walls and the ceiling that are responsible for the greatest heat losses. Accordingly, their u-values should be kept particularly low.

$$\dot{Q}_{Bauteile} = Fläche_{Bauteil} \cdot u_{Bauteile} \cdot (\vartheta_{Innenseite} - \vartheta_{Außenseite}) \quad (2)$$

The special characteristic of the modular stable is the heat recovery effect of the supply-

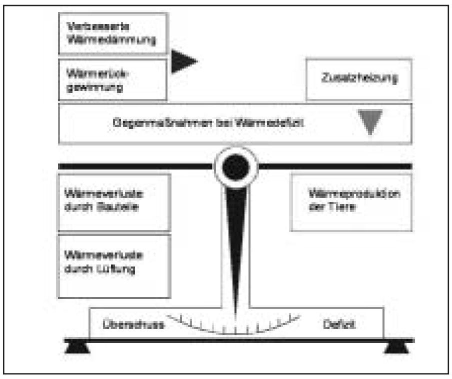

Fig. 1: Heat balance priciple

air ducting system including the perforated ceiling (Fig. 2). This design is intended to recover nearly all transmission heat losses of enclosing building components (floor, wall towards the central passage, ceiling).

The test stable

Figure 2 is a cross-section of the stable in which the measurements were carried out. The numbers indicate the positions of the temperature loggers from the point of entry of the supply air into the building to where it enters the animal compartment through the perforated ceiling.

The temperature development (*Fig. 3*) of the outside air (1) on 7 March 2007 and of the supply air in the feeding passage (2) clearly show the buffering effect of the ground heat exchanger. The supply air system has a heating effect at exterior temperatures below 11°C, whilst having a cooling effect at temperatures above 11°C. Thus, variations between night and day are effectively reduced. Another temperature increase by up to 0.5 K can be observed between the feeding passage and the loft. This increase is higher when the sun is shining on the roof, than in cloudy weather or at night. There was a constant temperature difference of 0.5 K

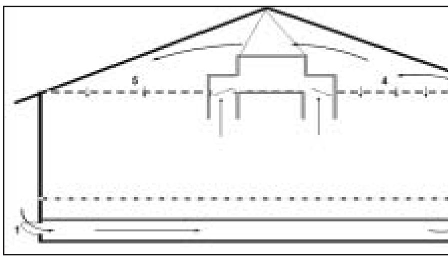

Fig. 2: Profile of the barn; numbers show the positions of the temperature data recording

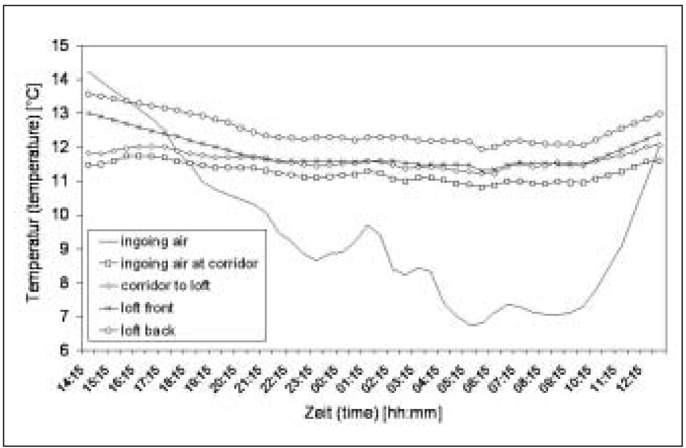

Fig. 3: Temperature profile at specific measuring points

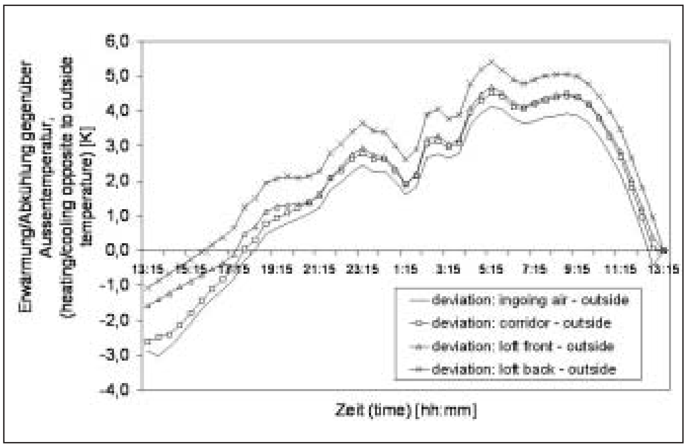

Fig. 4: Heating and cooling of air at different measuring points in relation to outside temperature

between the temperature loggers at the front (4) of the loft and at the back (5). The higher temperature in the back part of the loft is due to the fact that the air in that part of the loft has had a longer time to heat up than the air still in the front part of the loft. The air may heat up, for example, while passing the exhaust air shaft. In order to further substantiate the data in *Fig. 3*, *Fig. 4* shows the temperature differences based on the supply air temperature on the exterior of the building.

Volume flow rate measurements (carried out using the SF_6 concentration decay method) [3] produced conclusive results. At low outside temperatures, the volume flow rate was almost constant ($\bar{x}$ = 3700 m^3 h^{-1} with σ = 860 m^3 h^{-1}). Temporary increases in the air rate occurred at feeding time, when the indoor temperature rose as a result of increased animal activity. The air quality was typical of winter conditions, too. On average, the carbon dioxide concentration was approximately 2300 ppm and the ammonia concentration was around 18.5 ppm.

Heat balance

A heat balance of the animal compartment under consideration was drawn up according to DIN 18910-1 (2004) for the purpose of determining its heat flows. The measurements were carried out on 7 March 2007 at 6 a.m., because at that time of day the temperature difference between inside and outside was greatest. Moreover, the air volume flow rates had been constant for several hours so that the external conditions were stable. The temperature and air humidity data acquired at this point of time were used to calculate the heat flows in the building. *Table 1* presents the individual parameters and the calculation of the heat balance.

The front wall being the only exterior wall of the animal compartment under study, it was consequently the only wall to be taken into consideration in calculating the heat losses through the building envelope. The transmission losses into the floor, the central passage and the ceiling were initially disregarded because for physical reasons it was expected that these losses – due to the special supply air ducting design – would be recirculated into the animal compartment through the supply air that they serve to heat up.

The result of the heat balance proves this assumption to be correct. The heat balance for the compartment in question has a surplus of only 903 W. This value is very low and must be regarded as realistic since the following minimal heat losses had not been taken into consideration:

- Transmissions heat losses to the ground through the isolated single footing of the building
- Transmission heat losses to neighbouring compartments, with temperature differences being very low.

Conclusion

The short-term measurements described above were successfully used to answer both questions asked at the beginning of this paper. On the one hand, it was shown that under winter conditions, when the exterior conditions are nearly constant, it is possible to draw up a heat balance for livestock houses even during normal operation.

Moreover, it was shown that if enclosing building components are ventilated like in the building under study, there are practically no heat losses because the transmission heat losses are transferred back into the supply air by convection.

All in all, these results are confirmed by results from long-term measurements carried out by the Baden Wurttemberg State Institute for Agriculture. Those investigations also confirmed that at low outside temperatures the supply-air ducting layout and the material used in the ceiling contributed to the heating up of the supply air. The heat recovery effect of areas in contact with supply air (floor, wall towards central passage, ventilation ceiling) was confirmed by long-term measurements in the same building under winter conditions, too.

Literature

[1] DIN 18910-1 : Wärmeschutz geschlossener Ställe - Wärmedämmung und Lüftung - Teil 1: Planungs- und Berechnungsgrundlagen für geschlossene zwangsbelüftete Ställe. Beuth Verlag, Berlin, 2004

[2] CIGR : Report I of Working Group on Climatization of Animal Houses. Scottish Farm Building Investigation Unit, Aberdeen, 1984

[3] *Schneider, T., W. Büscher und O. Wallenfang* : Validierung der Tracergasmethode zur Luftvolumenstrombestimmung. Landtechnik, 60 (2005), H. 6, S. 344 - 345

Table 1: Calculation of heat balance

Parameter	Value	
Heat produced by the animals		
Number of animals (with 40 kg lw)[1]:	256	
Sensible heat flow / animal (at 24°C)[2]:	76	
Total [W]		19456
Infiltration heat losses		
Inlet air temperature [°C]:	6.0	
Exhaust air temperature [°C]:	24.0	
Air volume flow rate [m^3/h]	3000	
Air density (24°C) [kg/m^3]	1,21	
Air mass flow [kg/h]	3630	
spec. heat capacity [W/kg K^{-1}]	0.28	
Total [W]		18,295
Heat losses through building components (front wall)		
Wall height [m]	3.0	
Wall width [m]	10.4	
U-value [W/(K m^2)]	0.4	
Net area (excluding windows) [m^2]	26.7	
Wall losses [W]		181.6
Number of windows	3.0	
Window width [m]	1.5	
Window height [m]	1.0	
U-value [W/(K m^2)]	1.0	
Window losses [W]		76.5
Temperature difference [K]	17.0	
Interior temperature [°C]	24.0	
Exterior temperature [°C]	7.0	
Total [W]		258
Overall balance:		
Heat produced by animals [W]		**+19,456**
Infiltration heat losses [W]		**-18,295**
Heat losses through building components (front wall) [W]		**-258**
Heat surplus [W]		**+903**

[1]Stocking on 7 March 2007
[2]acc. to 1984 CIGR calculations