Comparison of Room- and Floor Heating in Piglet Houses

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After two years of investigations, different ventilation- and heating systems for piglet houses can now be evaluated comprehensively. In addition to the economic viability of the variants, the lying behaviour, indoor air quality, and the emission of noxious gases have been taken into account. As compared with standard fans, low-energy „EC fans“ allow electricity consumption to be reduced by an average of more than 50%. With regard to heating energy, gas burners instead of hot-water floor heating with gas boilers also enabled consumption to be reduced by more than 50%. Floor heating, however, is advantageous for the lying behaviour of young piglets and the air quality parameters.

Keywords
Heating, stall climate, ventilation technology

Introduction and Goals

When planning piglet rearing stalls, counsellors and farmers interested in construction are very insecure with regard to the appropriate heating system and animal-friendly floor design. In order to confront this planning insecurity and to obtain reliable data at the stall level, a long-term trial was set up at the agricultural operation Barnstädt (Querfurt county, Saxony-Anhalt) with the support of the AEL and six different ventilation- and heating companies.
The goal of these long-term investigations, which are now complete, was the comparison of different heating techniques for piglet rearing as well as exhaust air fans in view of the consumption of heating- and electric energy. Animal performance and the lying behaviour of the piglets were registered in order to guarantee comprehensive consideration.

Material and Method

The investigations were supposed to provide an energetic comparison of piglet rearing compartments with different technical equipment. Not only the electric energy required for process technology (especially ventilation), but also the necessary heating energy were integral parts of this comparison. Since different measurement-technological requirements must be met for the registration of both energy flows, separate measurement methods are necessary.

Measurement of the Energy Required for Ventilation

The electricity required by the control unit and the fans of a stall compartment can be measured using conventional current meters, which does not cause any problems from the viewpoint of electrical engineering. Illumination and other compartment-specific circuits can also be registered this way. Peak loads are important for the connection power of the system. They can be established with the aid of proven technology for load course registration using the already necessary current meters.
The determination of the specific energy consumption of the entire system [kWh/1,000 m^3 of delivered air] also requires the continuous measurement of the air volume flow. At present, this is only possible with calibrated measuring fans. These sensors consist of a two-winged fan blade which covers the entire cross section of the canal. Above the inertia limit, the rotating frequency, which is measured with the aid of contactless approximation sensors, is directly proportional to the amount of the air volume flow [2].

Measurement of the Energy Required for Heating

The heat requirements of a room to be covered by heating can be calculated based on the heat deficit, which is established through heat balance calculation (thermal balance). This planning step is necessary in order to maintain the minimum temperatures for piglet rearing which are required by animal-protection legislation [8]. In these calculations, the heat generated by the animals (sensitive heat) is set off against the heat loss. Heat losses comprise transmission heat losses through room-enclosing construction elements and ventilation heat losses due to the air exchange required for the discharge of indoor air pollutants according to the DIN 18910 standard (cf. equation 1) [4].

$$\dot{Q}_{heating} = \dot{Q}_{animals} - (\dot{Q}_{parts} + \dot{Q}_{ventilation}) \quad (1)$$

The heat losses due to room-enclosing construction elements are calculated according to equation 2:

$$\dot{Q}_{part} = Area_{animals} \cdot k\text{-}value_{part} \cdot (\upsilon_{indoors} - \upsilon_{outdoors}) \quad (2)$$

The k-value (equation 3) describes the heat flow through one square metre of wall per kelvin of temperature difference in [W/m^2 * K] from the high to the low temperature level.

$$k = \frac{1}{\frac{1}{\alpha_i} + \frac{d_1}{\lambda_1} + \frac{d_2}{\lambda_2} + \cdot + \cdot + \frac{d_n}{\lambda_n} + \frac{1}{\alpha_a}} \quad (3)$$

with:
α_i = indoor heat transition coefficient = 5
α_a = outdoor heat transition coefficient = 25

The heat losses caused by the room-enclosing construction elements can be calculated taking the temperature difference ($\upsilon_{indoor} - \upsilon_{outdoor}$) into account. The design calculation of the heat losses due to air exchange is also based on the DIN 18910 standard. For a comparison of the systems under practical conditions, however, the ventilation heat losses of the compartments must be measured continuously. The air volume flows are registered with the aid of the above-described measuring fans. The difference in the heat contents of inlet- and exhaust air is established through temperature- and humidity measurement in both air flows.
Since, under system-theoretical aspects, a stall is only in a state of energetic balance

equilibrium if the energy bound in the feed and the animal body is taken into account, the establishment of the actual heating energy demand requires direct calorimetric measurements at the heating systems to be carried out while maintaining the desired room temperature. This requires a „heat quantity meter“ for hot water systems and a „gas volume meter“ for gas heating systems. These measuring instruments were installed at the heating systems and read weekly.

Lying Behaviour and Air Quality
During the second trial period (winter 1999/2000), additional measurements were conducted to establish the lying behaviour of the piglets, the air quality in the different stall compartments, and the environmental pollution caused by them.
The lying behaviour of the piglets was registered parallel with the aid of stationary video cameras in two compartments with and without floor heating. The footage was interpreted using the aid of software for ethological investigations („Observer“). The duration and the frequency of the behavioural characteristics „lying“ and „non-lying“ were part of the behavioural comparison.
The air quality and the emission behaviour of the compared variants were measured using proven instruments for gas analysis (Brüel and Kjaer multi-gas monitor, measuring point switch, measuring fan in the round exhaust air chimneys). Moreover, measurements of dust concentration, odour concentration, and the homogeneity of climatic factors in the room were carried out.

Variants and Schedule
Together with the cooperating farms, the trial variants were chosen according to the criteria „investigation requirements“ and „energy savings potential“. **Table 1** shows the comparative variants of the investigations. After three trial periods, the techniques which provided the best results were due to be varied further for the second part of the investigations in order to obtain energetic comparisons between different products (which were often classified as equally good).

Table 1: Description of the trial variants (perforated ceiling as air inlet)

Reference system 1 gas burner & axial fan + phase control	**Variant 1** gas burner & EC low-energy fan + measuring fan and throttling system
Reference system 2 gas burner & axial fan + phase control	**Variant 2** Hot-water floor heating in the lying area + delta pipes for room heating & axial fan + phase control
Reference system 3 gas burner & axial fan + phase control	**Variant 3** Hot-water floor heating in the lying area + delta pipes for room heating & EC low-energy fan + measuring fan and throttling system

Results

In order to obtain realistic planning results, the usual engineering techniques for mass- and energy balancing were employed. For the stall to work even under extreme conditions, livestock density was assumed to be highest in the summer and lowest in the winter. Under winter conditions, the heat flows of the comb compartments for 200 rearing piglets with one and two outer walls which were to be examined at the location under investigation were balanced according to DIN 18910. According to this balance, the heat deficits (and, consequently, the heating requirements) amount to 5.6 kW (comb compartment with two outer walls) and 4.8 kW (compartment with only one outer wall). **Table 2** shows the results of the air rate calculation. The 5 kg animals were assumed to be reared in the winter. The air volume flow calculation (mass balancing) shows that the normal ratio of the summer- and the winter air rate is more than 30:1. These demands with regard to the minimum and maximum air volume flow result in the system having to meet the highest control-technological requirements [6]. The adjustment of the experimental system did not prove to be entirely unproblematical in the winter months. In the practical trial, the precise control of the winter air rate influenced ventilation heat losses considerably.
Despite good heat insulation, the balancing of the heat flows according to DIN 18910 [4] (as usual) showed great deficits also in the examined piglet rearing compartments. For systematic planning and counselling, the goal was to provide an overview which distinguishes what energy source is used at the stall level, how the heat reaches the compartment, and on which physical principle the main effect for the animals is based. For this purpose, a distinction between room heating (**table 3**) and section heating (**table 4**) will be made.
For the economic evaluation of the examined heating systems, purchasing- and operating costs had to be taken into account equally. In addition, the following arguments regarding hot water floor heating systems, which were part of the investigations, were to be examined:

- As the temporal utilization rate of the heating systems and the herd sizes increase, hot water section heating systems gain in economic preferability. The possibility of utilizing waste heat (e.g. from block-type thermal power stations) is also an important pro-argument given the mounting energy prices and the payments to farmers who feed electricity into the mains.
- The structuring of the pen allows (comfort) heat to be offered in the lying area. Room temperature can be reduced, which leads to better air quality (content of noxious gases). The prerequisite for homogeneous growth of the animal group is a sufficient size of the lying area and homogeneous heat distribution. In order to adapt the heat supply to the demand, it is possible to follow lying area temperature curves.

Costs of Electric and Heating Energy
The examined variants did not show any differences in piglet performance which could be proven statistically. Therefore, the most important economic parameters in the comparison of the systems are the expenses for the purchasing and the operation of the ventilation- and heating system per reared piglet. According to the

Table 2: Ventilation rates for the examined pig house under summer and winter conditions

Planning conditions	m^3/h per animal	m^3/h per pen	Normal ratio
summer: 30 kg piglets	62	12 400	31
winter: 5 kg piglets	2	400	1

Table 3: Room heating systems for pig houses

Energy source	Heating oil (burner) Natural gas (burner) Liquid gas (burner) Waste heat (e.g. block-type thermal power station[1])	Direct combustion of gas without discharge of the residues	Combustion of gas or heating oil with discharge of the residues
Transport and distribution medium	**Hot water** - Delta pipes - Iron pipes - Radiators	**Air** - Gas burner - Gas convector	**Air** - Gas convector - Hot-air blower
Main principle	**Convection**	**Direct heating of air** (increase in enthalpy)	

1) Block-type thermal power plant on the basis of biogas, heating oil, rapeseed oil, straw

Table 4: Section heating systems for pig houses

Energy source	Heating oil (burner) Natural gas (burner) Liquid gas (burner) Waste heat (e.g. block-type thermal power plant [1])	Electricity	Electricity - Infrared radiator Liquid gas - Gas radiator **Radiation**
Transport and distribution medium	**Hot water** → floor	**Electricity** → floor	
Main principle	**Heat conduction**		**Heat radiation**

1) Block-type thermal power plant on the basis of biogas, heating oil, rapeseed oil, straw

period cost method, the winter-, transition-, and summer periods are weighted temporally for cost calculation. With regard to energy consumption, altered settings allowed the results of the first investigation period to be improved further in the second period.
The cost calculations show that in all variants energy accounts for more than 50% of the entire special cost of ventilation and heating. Floor heating requires significantly higher investment, which exerts a very negative influence on the total cost per piglet. As compared with plastic floor heating, room heating (gas burner) provided an unexpectedly high heating cost advantage of more than DM 1.00 per reared piglet under the above-described trial conditions (cf. **table 5**). The low- energy EC fans used needed only 50% of the energy required by standard axial fans. Depending on the price of electricity, the payoff period ranges between three and five years (cf. **table 6**).

Behaviour and Air Quality

The behavioural observations also yielded an unexpected result. Over the entire rearing period, floor- and room heating did not lead to any significant difference in lying duration and -frequency on the examined plastic floor. Only on the first days after stalling up did the piglets lie slightly more often in the closed lying area with heat supply (**table 7**). The supposition that this reduces the stress of stall change for the animals can neither be proven through higher growth performance nor improved feed conversion nor lower animal losses. When the hot-water heating elements were shut off, these areas were soiled with the effect that the piglets were dirtier as well. This phenomenon was confirmed by investigations in stalls with comparable floor heating systems.
As compared with the variants with direct gas combustion in the room, hot-water floor heating systems provided far better air quality. As expected, the CO_2 concentrations very clearly exceeded the limit of 3,000 ppm set by the Pig Husbandry Ordinance [8]. Unexpectedly, the use of gas burners led to a larger quantity of methane being released from the slurry and emitted through the exhaust air chimneys (cf. **figure 1**). The reasons for this result must be examined further.

Consequences for Counselling and Practice

Heat flow balancing remains an essential prerequisite for the planning of a demand-oriented heating system. The planning values for the heating power to be installed per piglet place (200 W) which are stated in the literature are often far too high. According to investigations by the author, 40 W per piglet place were sufficient in comb compartments with good heat insulation. It is generally recommended that the following criteria be taken into account when purchasing heating systems and giving advice on heat-technological problems:

- How can the thermal-physiological requirements of the piglets be met?
- Which technology fits logically into the energetic concept of operation (gas, oil, electric energy)?
- Which system results in the lowest full cost (fixed + variable cost!)?

Recommendations Regarding the Economical Use of Electric Energy

In order to save electric energy, it is equally sensible to avoid high flow resistance and to check the efficiency of the control implements and fans used [1, 7]. The public „cost discussion", however, focuses on fans [6]. The use of the new Etavent low-energy EC fans is often discussed controversially. Long-term measurements by the author yielded clear results in this respect as well. With regard

Table 5: Economic results of a two-year system comparison with different heating- and ventilation designs
(Basic parameters: kWh thermal: DM 0.07, electric: DM 0.28)

	Variant 1	Variant 2
Description of the heating system	Gas burner for room heating (liquid gas)	Delta pipes for room heating + hot-water plastic floor heating (liquid gas + hot water)
Consumption of heating energy	4,2 kWh/piglet	22 kWh/piglet
Description of the ventilation system	Perforated ceiling + overfloor suction with EC low-energy fans	Perforated ceiling + overfloor suction with standard axial fans
Consumption of electric energy	0,9 kWh/piglet	2,5 kWh/piglet
Full cost per piglet	**1,40 DM /piglet**	**3,76 DM /piglet**

Table 6: Example of a payoff calculation for the low-energy fan (prices according to the manufacturer Ziehl-Abegg)

	Unit	Standard axial fan 50 cm / 230 volts		Low-energy fan 50 cm / 230 volts	
Purchasing price including control system and motor protection	DM	1350,-		1860,-	
Annual payment given an interest rate of 5% and 10 years of use	DM	175,-		241,-	
Electricity consumption at a utilization rate of average 60%	kWh	2630		1314	
Electricity price per kWh	DM	0. 28	0.14	0.28	0.14
Electricity cost per year	DM	736,-	368,-	368,-	184
Total annual cost	DM	911,-	543,-	609,-	425,-
Cost difference	DM	——————→		- 305,-	
			——————→		- 118,-

Table 7: Intensity of the behavioural characteristic „lying“ on a fully perforated floor (as a reference system) and a partially perforated floor with hot-water floor heating

	Time percentage of the behavioural characteristic „lying“	
Reference time: Day after stalling up	Reference system (fully perforated)	Variant (partially perforated with heating elements)
Stalling-up day	84 %	80 %
2nd day after stalling up	82 %	83 %
3rd day after stalling up	82 %	85 %

to electric energy consumption, the average savings provided by these low-energy EC fans amounted to more than 50%. If the higher acquisition cost is taken into account, the purchase pays off within only three to five years. Virtually no acquisition in the pool of ventilation costs is currently as cost-effective as this fan technology.

The difference in energy consumption lies in the altered drive technology as compared with the standard axial fan. **Figure 2** shows the effect in a diagram. Under full load, a standard- and a low-energy fan with the same diameter require approximately the same power. In the governed speed range, i.e. below the rated speed, the advantages of the low-energy fan become obvious.

Recommendations Regarding the Economical Use of Heating Energy

Despite all considerations with regard to saving energy, it cannot be questioned that the heating system must be able to cover the heat requirements of the piglets. The lying behaviour of the piglets is the most important indicator of the correct temperature setting. The observation of the lying behaviour during daily work in the stall enables the current demand to be checked and the setting of the control implement to be altered accordingly. Figures 3 and 4 show the lying behaviour at a room temperature too low (**figure 3**) and at an appropriate temperature in the lying area (**figure 4**). If the piglets lie on their stomachs or in a relaxed position on their sides, this is a sign of well-being; if they lie in a cluster, there is need for action, i.e. heating.

The above-described heat-technological connections show that only the following possibilities allow heat losses to be reduced:

- Reduction of the k-value through improved heat insulation (walls, stall ceiling, floor)
- Minimization of the ventilation heat losses through precise setting of the minimum air rate
- Heat recycling from exhaust air with the aid of heat exchangers
- Supply of heat only in the lying area of the animals

The presented results show that only full-cost calculations which take the purchasing- and operation cost into account reflect the actual economic preferability of different alternative solutions [3]. Table 5 summarizes the results of the two-year investigation in the form of a full-cost comparison in DM of the special cost of heating and ventilation per reared piglet in the most favourable and the most unfavourable combination. A fair comparison between alternative solutions requires identical energy sources and energy supply costs (in DM per kWh). Many comparisons contain serious mistakes in this respect.

This merely economic comparison, however, does not show the following advantages of variant 2:

- The restriction of heat supply to certain spots allows the lying- and excretion behaviour of the animals to be influenced positively.
- If hot-water floor heating systems are used, air quality is not impaired by combustion products (carbon dioxide and water).

An economic evaluation of other floor-heating systems is impossible at present

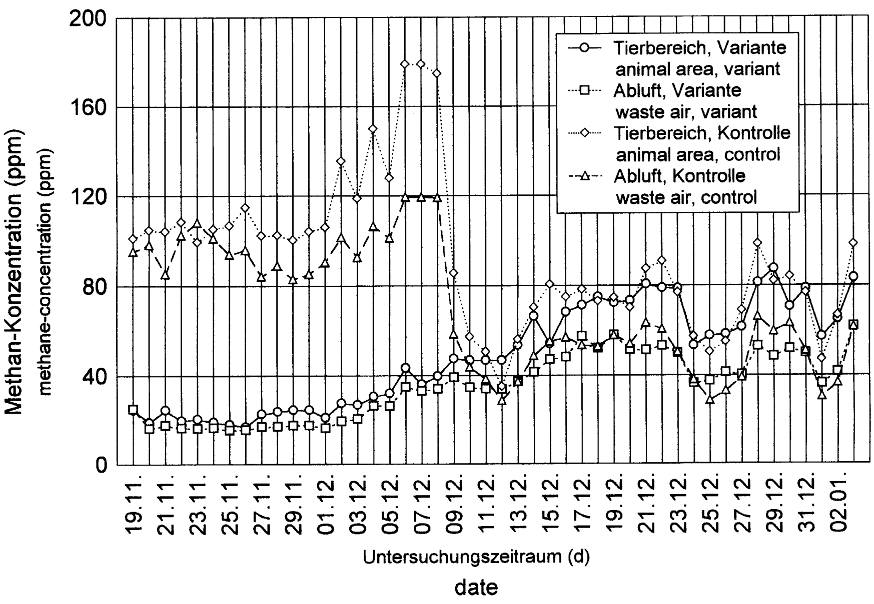

Figure 1: Comparison of the methane release from slurry in stalls with gas burners (reference system) and hot-water floor heating (variant) for piglet rearing during a typical winter period (winter 1999/2000)

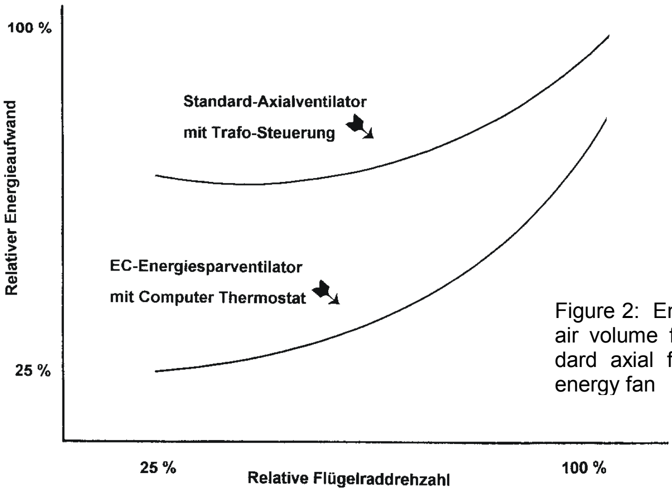

Figure 2: Energy requirements for the air volume flow delivered by a standard axial fan and an Etavent low-energy fan

Figure 3: Lying behaviour of young rearing piglets (ca. 7 kg) at an indoor temperature too low (room heating)

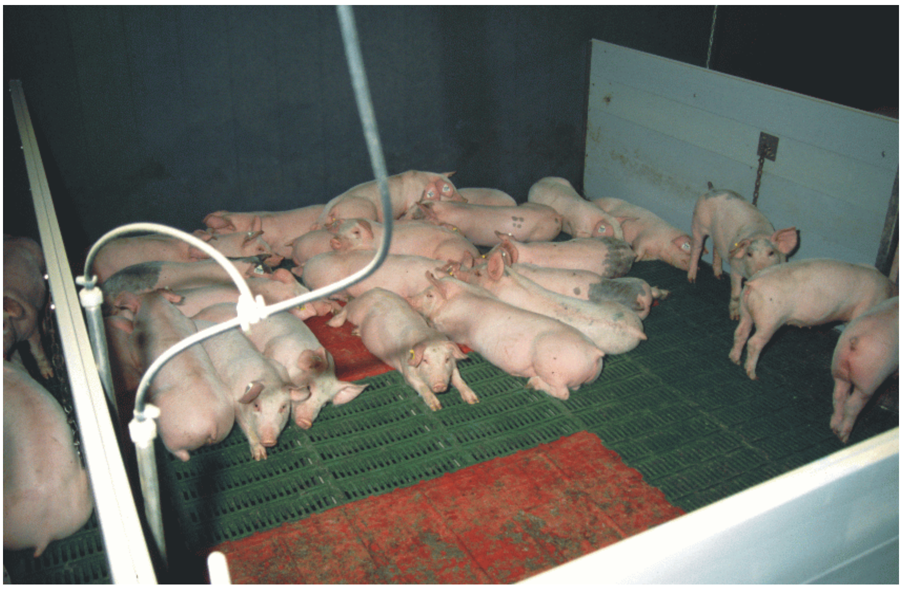

Figure 4: Lying behaviour of older rearing piglets (ca. 15 kg) at an appropriate floor temperature (floor heating)

because the resource requirements are unknown and comparability with the creep area in the farrowing pen is limited [5]. The investigations did not confirm a general savings effect due to reduced room temperatures in stalls with floor heating. Obviously, this effect can only be expected if, in addition, convection and radiation from the heating surfaces into the room are eliminated by means of covers or housings.

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