Environmentally Compatible Fattening Pig Husbandry III

Daytime-Related Effects

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As part of continuous emission measurements in the experimental stall for fattening pigs in Hohenheim, a conventional stall with fully slatted floor and forced ventilation (FSF) was compared with a naturally ventilated kennel housing system (KN) during four fattening periods from October 1999 until April 2001. The third contribution to the article series about environmentally compatible fattening pig housing focuses on the description and analysis of daytime-related effects and the course of emissions.

The courses of three measuring periods during the second fattening period which were chosen as examples as well as multiple regression analyses were studied to answer the question of what variables mainly determine the different daily courses of NH_3- and CO_2-emission and to what extent emission reduction strategies may influence the daily course. In accordance with the literature, the FSF housing system largely showed a positive correlation between temperature, volume flow, and emission. In the KN housing system, however, a reduction in emissions was observed combined with increasing volume flows, which generally occurred in particular at low temperatures. Animal activity, which was strongly influenced by the feeding times, was reflected by significant peaks of CO_2 concentration and –emission as well as NH_3 emission.

In the FSF housing system, the percentage of variance in the daily course of the emission rates during the selected measuring periods which can be explained through variables able to be used for practicable stall climate recording and –control and able to be influenced through measures of emission reduction ranged between 12 % and 75 % for NH_3 and between 39 % and 47 % for CO_2. In the KN housing system, the percentage of explainable variance is lower at 52 % to 64 % (NH_3) and 18 % to 28 % (CO_2).

Keywords
Fattening pig husbandry, environmental compatibility, emissions, ammonia and greenhouse gases

Introduction and Problem

In the discussion about environmental policy, the agricultural sector and animal housing are attributed a significant role both with regard to their contribution towards the emission of climatically and environmentally relevant gases and their reduction potential. Animal housing alone accounts for ca. 84 % of German ammonia (NH_3) emission, for example, and the contribution of agriculture towards methane (CH_4) emission amounts to approximately 44 % [1].

Gaseous emissions from animal housing which contain nitrogen (N) and carbon (C) are produced during the degradation of organic substance (mainly excrement) and by the metabolic activity of the animals themselves. The release of N-compounds causes various detrimental effects on the environment and directly or indirectly affects numerous processes and control functions in the balance of materials in soils, plants, and water [2]. The additional release of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) which exceeds natural emission leads to the accumulation of these gases in the atmosphere and contributes to an undesirable additional (anthropogenic) greenhouse effect. The feared ecological consequences are the gradual warming of the earth´s atmosphere, the possible shifting of the climate zones, and an increase in climatic anomalies [3].
The compelling national and international necessity to reduce the emission of climatically and environmentally relevant gases and to implement the relevant measures is taken into account in the IPPC[1] directive, the article law from 3 August 2001, or the Göteborg multi-pollutant protocol, for example.
The development and derivation of efficient reduction strategies requires knowledge about the factors which influence the release, amount, and dynamics of the source-specific emissions of climatically and environmentally relevant gases. Especially in animal housing, however, the availability of data regarding newer and, in particular, naturally ventilated housing systems in comparison with so-called conventional systems on the one hand and climatically relevant gases such as methane and nitrous oxide on the other hand is still low [4]. Finally, the question arises as to what extent the dynamics of stall-specific gas emissions can be influenced over the course of the day, for example, and whether this can be used for reduction measures.

Goals

A system comparison of two different housing systems for fattening pigs with regard to the emissions of ammonia (NH_3), carbon dioxide (CO_2), and methane (CH_4) was formulated as the main goal of the studies on environmentally compatible fattening pig housing. The housing systems to be compared were a conventional stall with fully slatted floor as a reference system and a conversion solution with natural

[1] IPPC: Integrated Pollution Prevention and Control

ventilation, level concrete areas, and kennel housing.

The main goal was intended to be reached by achieving the following individual goals:

- Collection of reliable data with high temporal resolution from two housing systems in simultaneous parallel operation,
- Comparison of the emission rates for the evaluation of the environmental effects of the housing systems,
- Comparison of daily effects and sensitivity towards different factors which influence emission,
- Comparison of indoor air quality and stall climate parameters for the assessment of the individual housing environment of the animals.

In accordance with the first goal, the results regarding the sensitivity and the reliability of the measuring system as well as the methodology have been described in the first part of the article series about environmentally compatible fattening pig husbandry [5]. The second part [6] focused on the results of the emission rate comparison based on daily mean values. The description and discussion of selected, exemplary daytime-related effects is the focus of the third part of this article series.

Housing Systems and Measured Variables

The system comparison of the housing systems “kennel housing, natural ventilation” (KN) and “fully slatted floor, forced ventilation” (FSF) was carried out in the experimental stall for fattening pigs in Hohenheim in two spatially separated compartments. The examinations extended over four consecutive 16 week fattening periods in different seasons from October 1999 until April 2001.

The ground plan in **Figure 1** shows the division of the FSF system into 6 pens with 9 animals each and the division of the KN system into two pens with 24 animals each as well as the subdivision in each pen into an activity area with perforated floor and a covered, level concrete resting area. The FSF housing system had underfloor extraction with pore channels for fresh air supply. The natural ventilation system in the KN housing system was designed as gravity shaft ventilation with an additional solar-powered, temperature-controlled fan in the eastern chimney for supporting ventilation if wind pressure and temperature difference as natural forces were insufficient for air exchange. Fresh air was supplied on the west side of the stall. The cross section of the fresh air opening could be varied using a temperature-controlled rolling blind. The KN system was developed as a conversion solution for an existing stall with a fully slatted floor and realized as a conversion measure in the experimental stall in the summer of 1999 [7].

Both housing systems featured a sensor liquid feeding system with 16 feeding times between 6:00 a.m. and 10:00 p.m. For demanuring in both systems, the liquid manure was collected in two containers each on both sides of the feeding passage over the entire fattening period and drained only after stalling out. Both compartments were stocked at the same time using the all in-all out method. Average stalling-in- and stalling-out weight per animal amounted to 25 kg and 110 kg respectively. This corresponded to approximately 3 to 10 livestock units per stall. Fattening duration was approximately 110 days. Further information and details regarding the experimental stall for fattening pigs and the design of the housing systems can be found in [5, 7]

For the registration of the measured variables relevant for emission calculation, i.e. gas concentration and volume flows as well as different influencing factors, the highest possible temporal resolution was striven for. The volume flow was measured in all exhaust air shafts using calibrated measuring fans. One specific gas analyzer each served to determine the concentration of NH_3, CO_2, and CH_4. These instruments worked according to the principle of non-dispersive infrared spectroscopy. Depending on the order of the different measuring points and the level adjustment- and sampling times per measuring point which needed to be considered during gas concentration measurement, the emissions and the factors which influenced them were compared three times per hour. The trial concept, the measuring methods, the measuring process, the characteristics of the measuring instruments, and the method of data processing and -selection are described in detail in [5, 6].

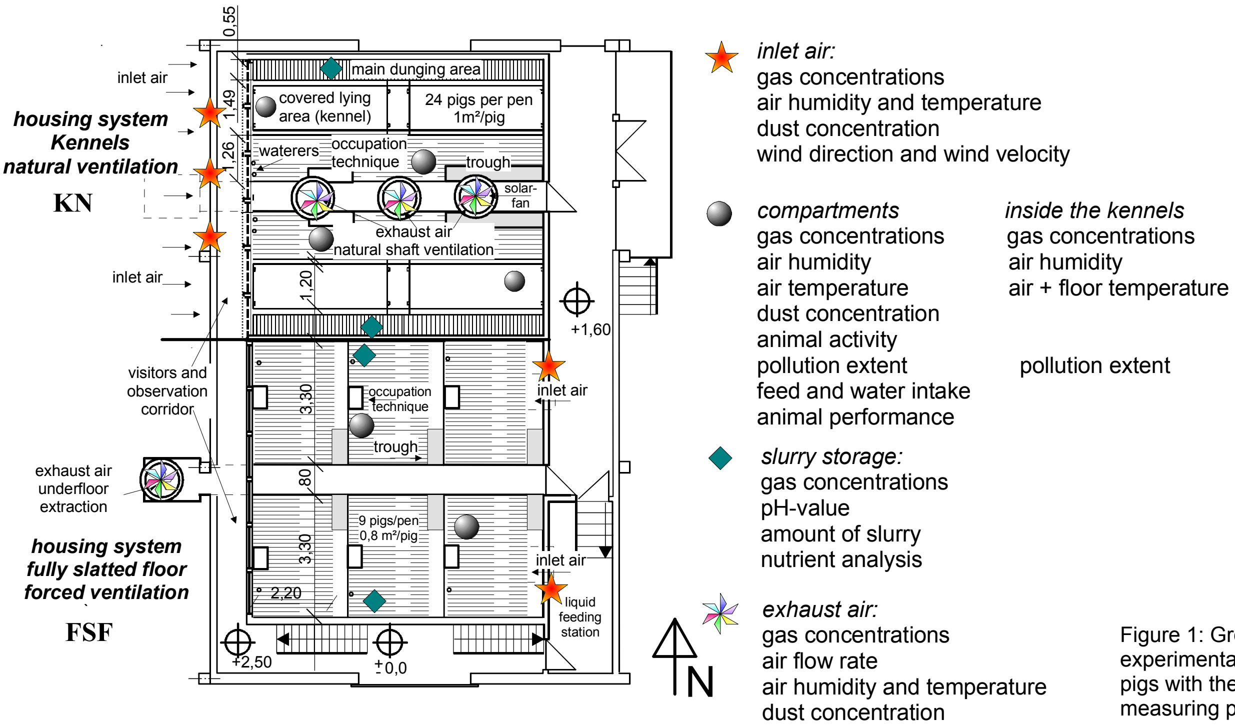

Figure 1: Ground plan of the experimental stall for fattening pigs with the arrangement of the measuring points

Description and Selection of the Results

An exemplary analysis of daily courses was carried out during three selected, representative 4 to 5 day measuring periods in the second fattening period (March to June 2000), which allow typical correlations between values such as temperature, volume flow, gas concentration, and emission for different situations to be shown. For better comparability of the results, the volume flow- and emission values refer to one livestock unit (LU).

The calculation of mean daily courses over longer periods did not provide a satisfactory result because in individual situations visible effects were damped too much by this method of representation, which reduced the meaningfulness of the results. Below, only the dynamics of the concentrations and the emissions of NH_3 and CO_2 are discussed because no clear daily course could be shown for CH_4 emissions in various constellations.

The graphic representation and the visual examination of numerous daily courses of emission and different marginal conditions as well as the evaluation of the literature led to the selection of factors which are likely to influence the course of NH_3- and CO_2-emission. In order to examine the complexity of the correlations and the amount of influence on emission, separate variables were established for each housing system, which were employed for a multiple, linear regression analysis (separate for each measuring period).

When choosing and limiting the variables to be examined, the continuous measurability of the variable and the question of whether it could be used for stall climate recording and –control while keeping expenditures within reasonable limits was also considered for practical reasons with regard to the derivation of emission reduction strategies. These variables were tested in a second analysis of reduced regression models. **Table 1** lists the choice of variables for each housing system.

Multiple linear regression analysis was carried out according to the “stepwise method” using the statistics software SPSS 11.0 for Windows™. One after the other, the explaining variables with the highest partial correlation coefficient with the dependent variable (here: gas emission) were integrated into the equation if the related regression coefficient was significant (significance level 0.1). The explaining variables may be correlated among each other, which is taken into account when estimating the coefficients in order to exclude false correlations. Determinateness r^2 shows the percentage of variance which is explained by the regression equation. A general restriction to be mentioned is that the conditions linearity and normal distribution of the experimental data were not always met. Even data transformation, however, did not result in an improved normal distribution of the data. High determinateness and the normal distribution of the standardized residues allow the assumption to be made that the given correlation can be considered linear [8]. If the prerequisite of normal distribution is not met, this is not considered very serious in this case [9, 10]. The regression models enabled the significant explaining variables for the daily course of emission in the different housing systems and measuring periods to be determined.

Results

The results will be described separately for each housing- and ventilation system. In particular basic relationships between temperature, volume flow, gas concentration, and day/night dynamics will be discussed, and differences between the housing systems will be shown. The description of the results of regression analysis will be limited to the explaining variables with the greatest influence (determinateness) and the course of emission.

Fully Slatted Floor, Forced Ventilation

The marginal conditions, mean gas concentrations, and emissions during the three measuring periods of the second fattening period which were chosen as examples are listed in **Table 2**. In **Figure 2** (c.f. page E 74), the course of indoor- and outdoor temperature, volume flow, exhaust air concentration, and the emission rates of the gases NH_3 and CO_2 in the selected measuring periods are shown on top of each other.

Table 1: Choice of variables for multiple regression analysis in the examination of determination factors for the daytime-related course of emission

	System FSF (Fully slatted floor, forced ventilation)		**System KN (Kennel housing, natural ventilation)**	
	NH_3-emission [g h^{-1} LU^{-1}]	**CO_2-emission [g h^{-1} LU^{-1}]**	**NH_3-emission [g h^{-1} LU^{-1}]**	**CO_2-emission [g h^{-1} LU^{-1}]**
Day (6:00 - 22:00) or Night (22:00 bis 6:00) *	X R	X R	X R	X R
Indoor temperature [°C]	X R	X R	X R	X R
Outside temperature [°C]	X R	X R	X R	X R
Temperature difference [K]	X R	X R	X R	X R
Air flow rate [m³h^{-1} LU^{-1}]	X R	X R	X R	X R
Indoor air concentration of NH_3 and CO_2 [ppm]	X R (only CO_2)	X R (only CO_2)	X R (only CO_2)	X R (only CO_2)
Exhaust air concentration of NH_3 and CO_2 [ppm]	X	X	X	X
Gas concentration below the slats of NH_3 and CO_2 [ppm] **			X	X
Solar fan in use (Yes/No)			X	X
NH_3-emission [g h^{-1} LU^{-1}] ***		X		X
CO_2-emission [g h^{-1} LU^{-1}] ***	X		X	

* Day/Night rhythm defined in dependence of the feeding times (appr. every 1,5 h between 6:00 until 22:00)
** Influence of an air exchange through the slats during night (decreasing gas concentrations) on the emission? [11]
*** Correlation between NH_3 and CO_2-Emission [15, 14, 9]
X: General regression model
R: Reduced regression model

Table 2: List of the marginal conditions, mean gas concentrations, and emission rates of NH_3 and CO_2 for the three measuring periods of a fattening period (March until June 2000) in the FSF housing system “fully slatted floor, forced ventilation” (mean value and standard deviation)

Measuring period	1		2		3	
Date Fattening day	16.03.-19.03.00 Fattening days: 17-20		30.03.-03.04.00 Fattening days: 31-35		04.05.-07.05.00 Fattening days: 66-69	
Number of values	283		351		288	
Stall occupation [LU]	4.6	+/- 0.1	6	+/- 0.2	10.8	+/- 0.06
Outside temperature [°C]	6.8	+/- 1.4	9.1	+/- 5.5	18.5	+/- 4.5
Indoor temperature [°C]	19.2	+/- 0.9	20.6	+/- 1.3	23.0	+/- 1.9
Temperature difference [K]	12	+/- 1.1	11.5	+/- 4.4	4.5	+/- 2.8
Air flow rate [m^3 h^{-1} LU^{-1}]	404	+/- 19	396	+/- 122	504	+/- 92
NH_3-exhaust air concentration [ppm]	23.2	+/- 1.7	25.3	+/- 3.4	22	+/- 2.8
NH_3-emission rate [g h^{-1} LU^{-1}]	6.0	+/- 0.37	6.2	+/- 0.78	7.3	+/- 1.0
CO_2-exhaust air concentration [ppm]	1941	+/- 240	1895	+/- 342	1352	+/- 166
CO_2-emission rate [g h^{-1} LU^{-1}]	1131	+/- 168	1027	+/- 178	850	+/- 166

The course of temperature and volume flow very clearly shows the dependence of the volume flow on the indoor temperature-dependent stall climate control of forced ventilation. In measuring period 1, the volume flow is largely constant and corresponds to the minimum air rate. Measuring periods 2 and 3 exhibited a clear day-night rhythm, which was also dependent upon outdoor temperature. NH_3 exhaust air concentration runs counter to fluctuating volume flows, which indicates a dilution effect of gas concentration due to higher volume flows. NH_3 emission (the product of volume flow and gas concentration) largely runs parallel to the volume flow and therefore shows increased values if the volume flow is increased. In **Figure 3**, these connections are shown in more detail with a temporal resolution of 2 days in measuring period 3. Especially the example of the second day shows that the steep increase in the volume flow as of 6:00 a.m. is first combined with a significant increase in NH_3 emission and a reduction in NH_3 concentration, which is increased at night. After the maximum air rate has been reached, however, a decrease in NH_3-emission and -concentration is recorded at first. However, when the indoor temperature increases further over the course of the day despite the maximum air rate and when it has reached its delayed maximum during the day, gas concentration and emission increase again.

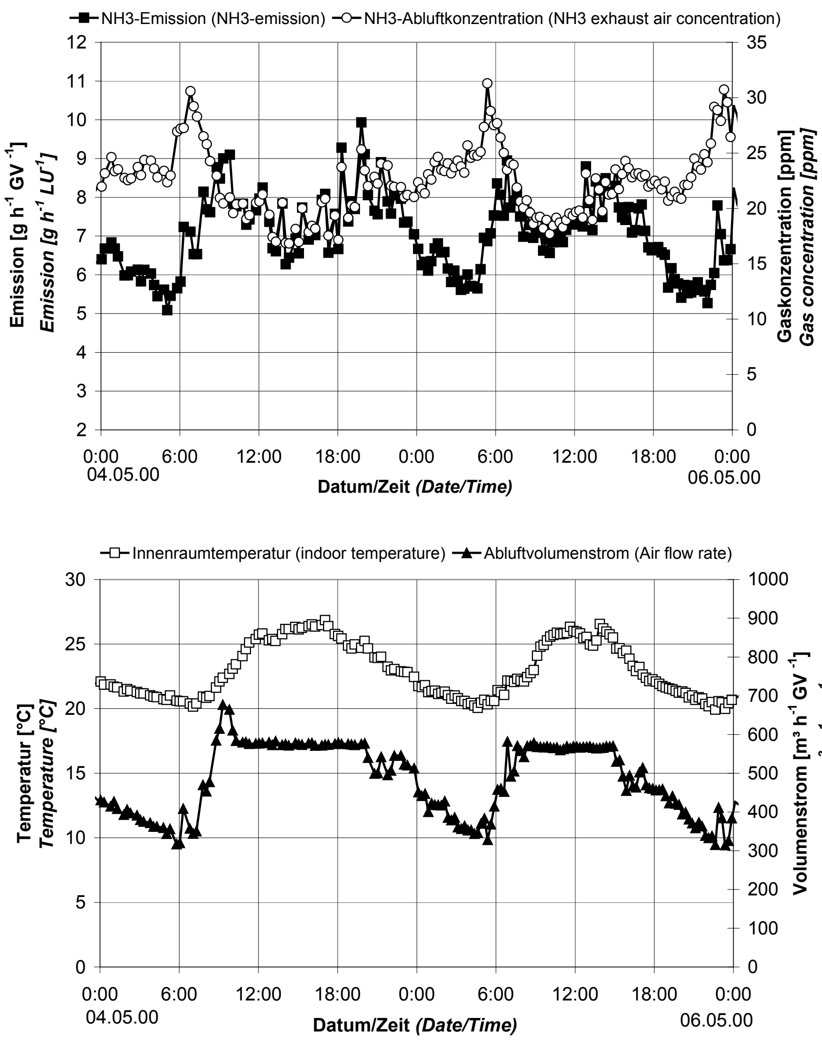

Figure 3: Course of indoor temperature, volume flow, NH_3 exhaust air concentration and -emission rate on two days in May (66th to 68th fattening day) in the FSF housing system “fully slatted floor, forced ventilation”

According to the results of regression analysis, 97 % of the variance of NH_3 emission alone can be explained through exhaust air concentration (r^2=0.61) and volume flow (r^2=0.36) in measuring period 1 with relatively constant volume flows. Exhaust air concentration exhibits a strongly positive correlation with NH_3 emission, while the correlation of the volume flow and NH_3 emission is slightly negative. In measuring periods 2 and 3 with fluctuating volume flows, the importance and the direction of effect of the factors are inverted. In measuring period 3, 95 % of the variance of NH_3 emission is explained by the volume flow (r^2=0.55; positively correlated) and exhaust air concentration (r^2=0.4; negatively correlated).

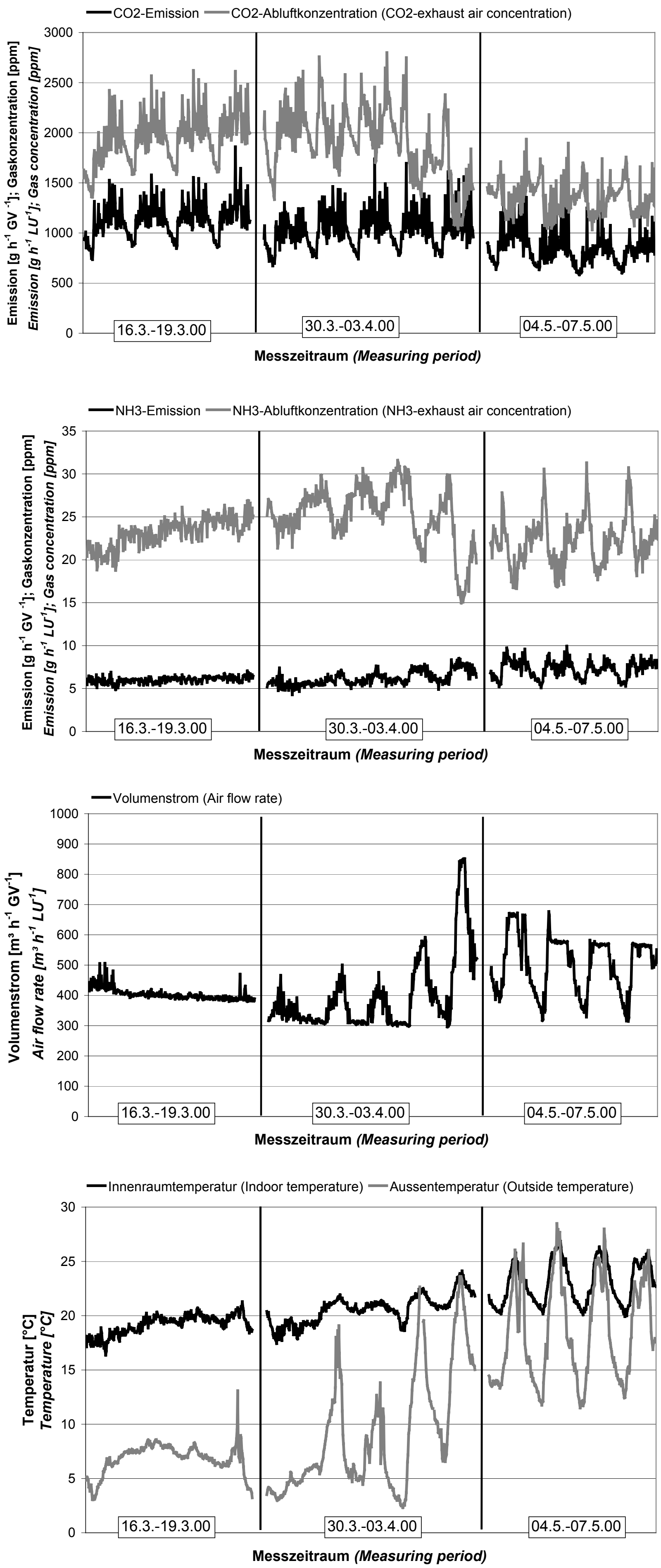

Figure 2: Courses of indoor and outdoor temperature, volume flow, exhaust air concentration, and the emission rates of the gases NH_3 and CO_2 in the selected measuring periods of a fattening period in the FSF housing system “fully slatted floor, forced ventilation”

The course of largely animal-specific CO_2 concentration and -emission (figure 2) shows clear day/night dynamics and heavy fluctuations during the day. Especially in measuring period 1 with constant volume flows and in comparison with NH_3 emission, this value proves to be largely independent of the volume flow. **Figure 4** shows the course of indoor temperature, CO_2 concentration, and –emission rate for three days in measuring period 1.

The heavy fluctuations in CO_2 concentration and –emission during the day are mainly attributed to the frequent feeding times in 1.5 hour intervals in the time from 6:00 a.m. until 10 p.m. At the beginning of feed distribution, strong activity and agitation among the animals are recorded, which are combined with a short-time increase in heat release (cf. course of the temperature) and CO_2 production. The daily courses of NH_3 emission shown in Figure 3 also provide an explanation for short-term emission peaks during the feeding periods.

In measuring period 1, the regression analysis for CO_2 emission showed an explained variance of 91 % due to CO_2 exhaust air concentration alone. 50 % of this variance can be explained as a consequence of indoor temperature and the variable day/night. In measuring period 2, the volume flow (r^2=0.5), day/night (r^2=0.2), and exhaust air concentration (r^2=0.1) have a positive effect. In the regression model for the CO_2 emission of measuring period 3, however, the explaining variables NH_3 emission (r^2=0.4; positively correlated), NH_3 exhaust air concentration (r^2=0.3; negatively correlated), and CO_2 exhaust air concentration (r^2=0.18; positively correlated) are attributed the greatest importance for the explained variance of 88 %. It must be taken into account that NH_3 emission and –concentration are in turn strongly determined by the volume flow.

Kennel Housing, Natural Ventilation

Table 3 provides an overview of the marginal conditions, mean gas concentrations, and emissions during the three measuring periods of the second fattening period, which were chosen as examples. **Figure 5** shows the courses of indoor- and outdoor temperatures, volume flows, exhaust air concentration, and the emission of the gases NH_3, and CO_2 in the selected measuring periods on top of each other.

When the marginal conditions (table 3) and the courses (figure 5) are considered, basic differences in comparison with the

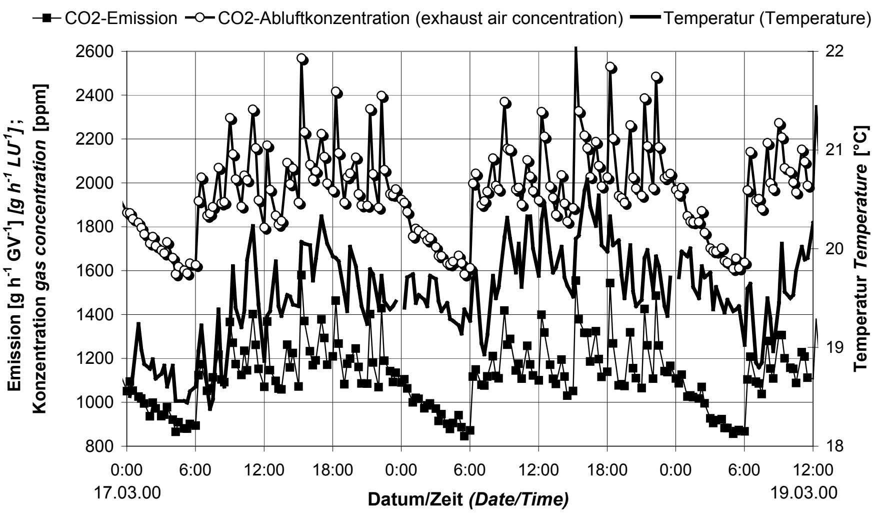

Figure 4: Course of indoor temperature, CO_2 exhaust air concentration and –emission rate on three days in March (fattening day 18-20) in the FSF housing system "fully slatted floor, forced ventilation"

FSF housing system (table 2; figure 2) become clear first. A summary of the results shows that lower temperatures (corresponding to the outdoor temperatures), larger volume flows (especially on cool days) as well as lower gas concentrations and emissions were observed throughout in the naturally ventilated KN housing system. Other results regarding system- and emission rate comparison are described in detail in [6].

In measuring periods 1 and 2, the volume flow is influenced less by the course of the temperature than by the wind conditions. Measuring period 3 shows that on windless days with small temperature difference natural air exchange is heavily restricted and that a sufficient air rate would not have been achieved without the use of the temperature-controlled solar fan. De facto, the volume flow courses in measuring period 3 therefore exhibit great similarity with those registered during forced ventilation. However, differences remain with regard to the lower indoor temperatures and the pronounced day/night temperature amplitudes.

As regards the correlations between the volume flow and NH_3 emission, the effects of the KN system are opposed to those of the FSF system. An increase in the volume flow causes both NH_3 exhaust air concentration and NH_3 emission to diminish. This effect still appeared in measuring period 3 (**figure 6**) although here the volume flows show similarities with forced ventilation.

Regression analysis for the NH_3 emission of the KN system showed very similar results for measuring periods 1 and 2 with an explained variance of 90 % due to the variables NH_3 exhaust air concentration (r^2=0.4; positively correlated), volume flow (r^2=0.2; negatively correlated), CO_2 emission (r^2=0.15; positively correlated), and CO_2 exhaust air concentration (r^2=0.15; positively correlated). In measuring period 3, only the variables temperature difference (r^2=0.3; positively correlated) and CO_2 emission (r^2=0.4; positively correlated) with an explainable variance percentage of 70 % were integrated into the regression model. However, the negative correlation between volume flow and emission remained.

An effect of nightly air exchange through the slatted floor on the course of emission [11] which can be demonstrated by significant alterations of gas concentration under the slats could not be proven.

As in the case of the FSF system, the daily courses of both CO_2 concentration and -emission are significantly determined by activity peaks during feeding. In the regression model of measuring period 1,85 % of the variance of CO_2 emission is explained by the positively correlated variables CO_2 exhaust air concentration (r^2=0.4), NH_3 exhaust air concentration (r^2=0.23), NH_3 emission (r^2=0.2), and outdoor temperature (r^2=0.12). In the regression model for measuring period 2, the variable day/night is additionally taken into account, and the variable NH_3 emission is weighted more. In measuring period 3, only 50 % of the variance of CO_2 emission can be explained using the variables NH_3 emission (r^2=0.35; positively correlated) and temperature difference (r^2=0.15). Another 20 % of the variance is explained through CO_2- and NH_3 gas concentrations, day/night differences, volume flow, and temperature.

Reduced Regression Model

With regard to possible strategies of emission reduction, the selected measuring periods should be used to carry out supplementary examinations as to

Table 3: List of the marginal conditions, mean gas concentrations, and emission rates of NH_3 and CO_2 for three measuring periods of a fattening period (March until June 2000) in the KN housing system "kennel housing, natural ventilation" (mean value and standard deviation).

Measuring period	**1**		**2**		**3**	
Date Fattening day	16.03.-19.03.00 Fattening days: 17-20		30.03.-03.04.00 Fattening days: 31-35		04.05.-07.05.00 Fattening days: 66-69	
Number of values	283		351		288	
Stall occupation [LU]	4.2	+/- 0.1	5.4	+/- 0.12	9.9	+/- 0.05
Outside temperature [°C]	6.8	+/- 1.4	9.1	+/- 5.5	18.5	+/- 4.5
Indoor temperature [°C]	8.0	+/- 1.2	11.2	+/- 4.5	18	+/- 3
Temperature difference [K]	1.2	+/- 0.8	2	+/- 1.8	0.5	+/- 1.8
Air flow rate [m^3 h^{-1} GV^{-1}]	1182	+/- 340	876	+/- 346	564	+/- 95
NH_3-exhaust air concentration [ppm]	7.4	+/- 1.5	9.6	+/- 2.6	7.3	+/- 2
NH_3-emission rate [g h^{-1} LU^{-1}]	4.2	+/- 0.6	4.0	+/- 0.8	3.8	+/- 0.6
CO_2-exhaust air concentration [ppm]	740	+/- 96	828	+/- 135	840	+/- 98
CO_2-emission rate [g h^{-1} LU^{-1}]	675	+/- 150	607	+/- 120	460	+/- 72

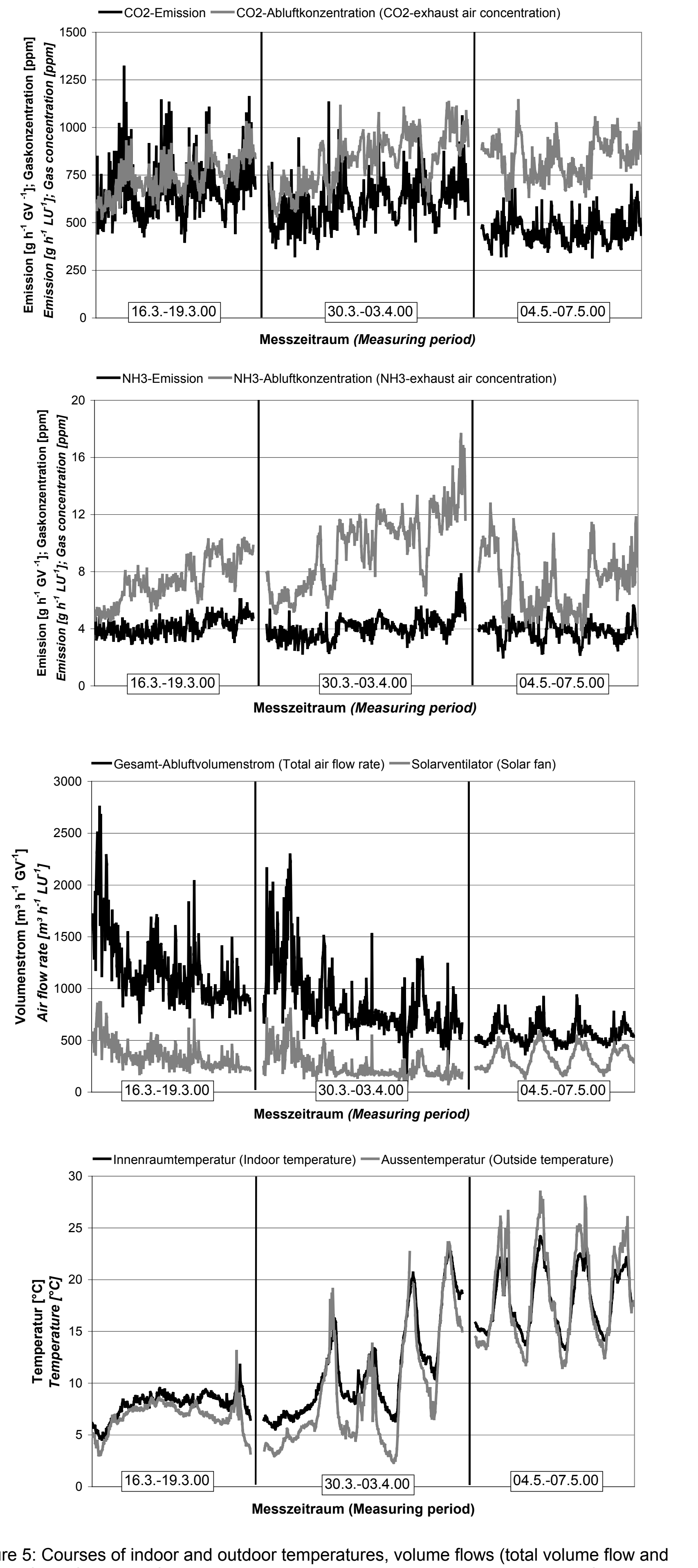

Figure 5: Courses of indoor and outdoor temperatures, volume flows (total volume flow and volume flow of the solar fan), exhaust air concentration, and the emission rates of the gases NH_3 and CO_2 in the selected measuring periods of a fattening period in the KN housing system "kennel housing, natural ventilation"

what percentage of the emissions can solely be explained using variables which could be recorded and employed in stall climate control and thus offer the possibility of influencing the daily course of emission. For this purpose, the variables day/night, indoor- and outdoor temperature, temperature difference, volume flow, and CO_2 indoor concentration (table 1) were examined in the reduced regression model. The results are very different depending upon the measuring period and the housing system, as well as the gas emission to be examined. They are listed in **Table 4**.

The direction of effect of the variables which could be influenced by an emission reduction strategy expresses itself in the sign of the individual correlation coefficient. With the exception of measuring period 1, gas emission as well as volume flow and temperature were positively correlated in the FSF housing system. Correlation with temperature difference was negative. In the KN housing system, however, the correlation of gas emission with the volume flow was negative. Measuring periods 1 and 2 showed a positive correlation of indoor temperature and temperature difference.

Discussion

In the models, only the variables day/night and CO_2 indoor concentration have so far been used as indirect indicators of animal activity. It remains to be examined whether the meaningfulness of these variables can be improved by adding a temporally highly resolved activity signal. With regard to the derivation of emission reduction strategies, it must be taken into account that the interaction of influencing factors such as volume flow, temperature, temperature difference, stocking, and animal activity, as well as their effects on emission in different constellations may be very different.

Due to natural ventilation and the structuring of the room, the possibilities of influencing the KN housing system are generally smaller. The models can probably be improved using further parameters, which particularly take factors influencing the volume flow, i.e. wind flow and temperature difference as well as their interaction more into account.

At very high volume flows and low temperatures, exhaust air concentration in the KN system often differed only slightly from background concentration. It is assumed that the NH_3 supply potential of

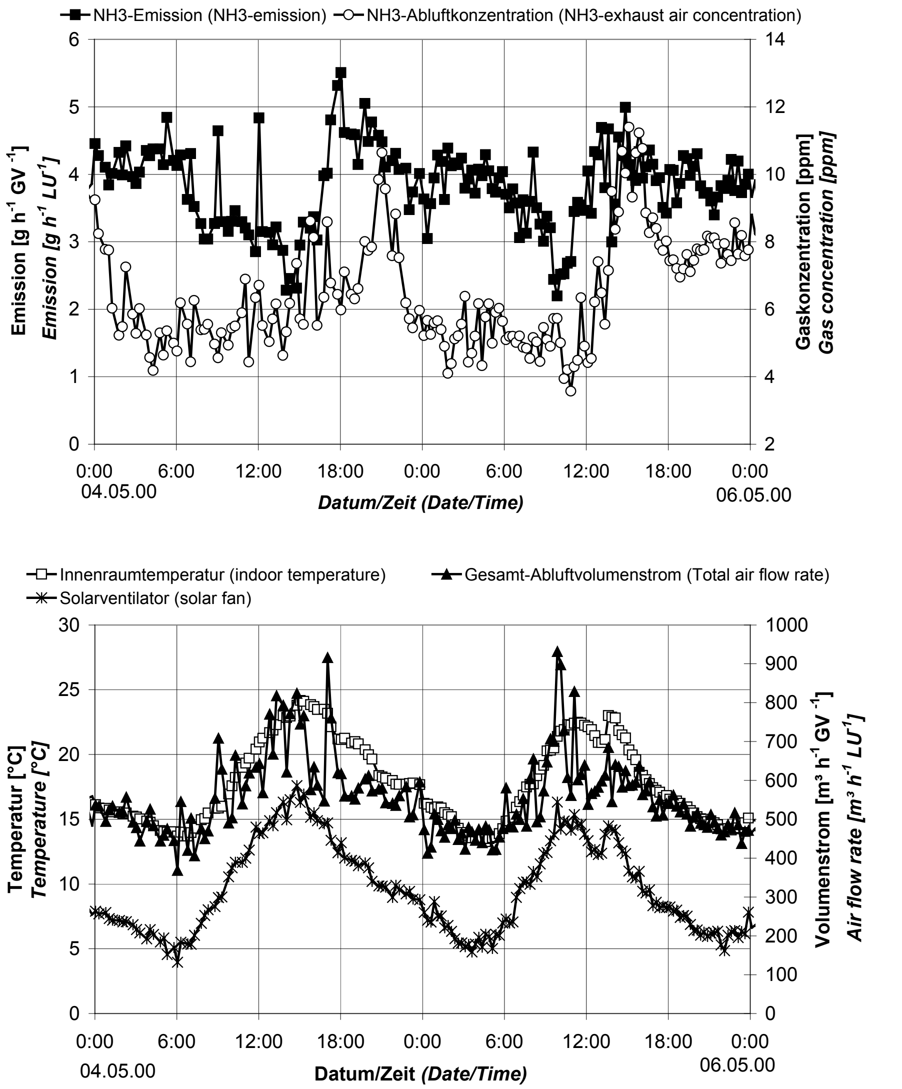

Figure 6: Course of indoor temperature, volume flow, NH_3 exhaust air concentration and -emission rate on two days in May (66^{th}-68^{th} fattening day) in the KN housing system "kennel housing, natural ventilation"

Table 4: Percentage of the explainable variance of the emission rate due to the explaining variables day/night, indoor- and outdoor temperature, temperature difference, volume flow, and CO_2 indoor concentration in the reduced linear, multiple regression model

Housing system	Fully slatted floor forced ventilation (FSF)			Kennel housing natural ventilation (KN)		
Measuring period	1	2	3	1	2	3
NH_3-emissions rate [g h^{-1} GV^{-1}]	12 %	75 %	68 %	52 %	59 %	64 %
CO_2-emissions rate [g h^{-1} GV^{-1}]	46 %	47 %	39 %	21 %	28 %	18 %

the KN stall system is lower and slower due to cooler temperatures and that, owing to the structuring of the housing system and the arrangement of the exhaust shafts, the emitting surfaces were not flowed over evenly despite large volume flows. In addition, it must be taken into account that at cool temperatures (i.e. large volume flows and low emissions) the animals largely stayed in the covered resting areas. However, the contribution of gas concentrations in the covered resting areas towards emission is unclear.

The literature provides only very little information about the daily course of emission from pig stalls with kennel housing and natural ventilation. Niebaum [9] also observed a decrease in gas concentration at large volume flows. However, this author does not give any information about the course of the emission. Rathmer [10] also describes lower NH_3 exhaust air concentrations for the examined experimental outdoor climate stalls due to the dilution effect of the volume flow and the assumed lower formation and release caused by lower temperatures. On the basis of daily mean values, the NH_3 emission of the experimental outdoor climate compartments was positively correlated with both temperature and, deviating from the authors´ own results, volume flow during the entire trial period. However, daily courses are not shown.

For warm stalls with forced ventilation, generally positive correlations between volume flow, temperature, and emission, as well as decreasing gas concentrations combined with a volume flow increase are described [12, 13, 14, 10], however, Keck [13] observed differences in the averaged daily course depending upon fresh air temperature. At fresh air temperatures above 20 °C, NH_3 emission reached its maximum already some time before the maximum of the volume flow. At fresh air temperatures below 20 °C, a largely parallel sinus-shaped course of volume flow and emission was described. Aarnink [12] describes a clear dependence of the daily course on animal activity with differences between day and night as well as plausible emission peaks during phases of increased animal activity, which caused the heat production of the animals and, hence, indoor temperature and volume flow to increase.

Conclusions

The evaluation of exemplary daily courses of NH_3- and CO_2 emission and different influencing factors has provided the following main results for the FSF housing system with forced ventilation:

- NH_3 emissions at fluctuating volume flows are mainly explained using the factors volume flow (positively correlated) and exhaust air concentration (negatively correlated).
- The day/night dynamics of NH_3 emission are mainly determined by the dynamics of the temperature course and, hence, the volume flow. Short-term peaks can be attributed to feeding-related animal activity.
- The day/night dynamics of CO_2 emission, however, can mainly be explained using feeding-related animal activity, which leads to an increase in CO_2 exhaust air concentration and temperature (both positively correlated). At a secondary level, they can be attributed to volume flows running parallel over the course of the day, which cause alterations of gas concentration and NH_3 emission.

As compared with the FSF system, the most important observations for the KN housing system with natural ventilation are:

- The amount and the fluctuation of the volume flows are significantly larger. Temperatures, gas concentrations and -emissions are generally considerably lower than in the FSF system.
- In contrast to the FSF system, the volume flow is negatively correlated with NH_3 emission. This means that increasing volume flows cause emission to diminish.
- In contrast to temperature-controlled forced ventilation, the volume flow of natural ventilation is considerably influenced by the wind conditions. In addition, it is correlated positively with temperature difference and negatively with indoor temperature.

The potential of emission reduction measures which are based on the limitation of short-term emission peaks over the course of the day with the aid of adapted stall climate recording and –control is given due to the clear dynamics of stall-specific emissions. The choice of potential control variables, however, must be adapted to the individual housing- and ventilation system and the different factors which determine the dynamics of emissions. In addition, the different sources as well as the conditions of formation and release of stall-specific emissions must be considered.

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