Ammonia Emission from Fattening Pig Houses in Relation to Animal Activity and Carbon Dioxide Production

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ABSTRACT

Ammonia emission from animal facilities is a world-wide research focus area, because ammonia is a nuisance for the external environment. It is therefore important to know how ammonia emissions depend on various factors, such as animal activity and ventilation rate. The objective of this paper is to show the impact of animal activity on the variation of the diurnal ammonia emission in controlled environment with low variation in indoor temperature. The investigation, comprising three trials with a total of 57 24-hour measuring periods, has been dealing with animal activity, ventilation rate and ammonia emission. In order to show how precisely the ventilation rate can be measured on the basis of the easier measurable carbon dioxide concentration, investigations of the ventilation rate have been made both when measured by means of measuring fans and indirectly on the basis of the carbon dioxide concentration. Hourly ammonia emissions, where the ventilation rate is based on carbon dioxide concentrations, have been investigated both with standard sinusoidal corrections for diurnal variations in carbon dioxide productions and adjusted by measured animal activity. The investigation carried out at a conventional farm shows that the diurnal variation in animal activity can be approximated by a sinusoidal model, where about 3/4 of the diurnal variation in activity can be explained ($R^2 \approx 0.75$). The investigations also show that the ventilation rate as daily average can be approximated on the basis of measurements of the carbon dioxide concentration in the animal house, using a carbon dioxide production in accordance with the CIGR (2002) of 0.185 m^3/h per heat producing unit (1 hpu = 1000 W in animal total heat production). The ratio between ventilation rate on a carbon dioxide basis and measured as 24 hour average varied from 1.02 to 1.17. On hourly basis, the relation between ventilation rate based on carbon dioxide concentration and measured by fans, very much depends on whether adjustments for animal activity are taken into account. Without adjustment for animal activity, the correlation is in the worst case close to zero. When using a standard adjustment for activity, the correlation R^2 between calculated and measured ventilation rates will be 0.80 or above. The correlation between animal activity and ammonia emission was between 0.15 and 0.56.

Keywords: Animal, Activity, Ventilation rate, Ammonia, Carbon dioxide, Emission.

INTRODUCTION

Ammonia emission from animal facilities depends on various factors, e.g. housing type, feeding strategy, management, indoor temperature and animal activity. Jacobson *et al.* (2003) showed that the ammonia concentration in a gestation house for pigs will be highest in the early morning. Taking the ventilation rate into account, the ammonia release will also be highest in the morning.

Aarnink *et al.* (1995), investigated ammonia emission variations from fattening pig buildings with partially slatted floors. He found that the ammonia emission was 7 % higher during the day than during the night. The diurnal variation seemed to be related to the activity of pigs. Ni *et al.* (1999) found that the so called floor factor quoting the floor from clean to dirty status has a big impact on the ammonia emission and also that increasing ammonia emission occurs when the airflow rate and the inside room temperature increases. Guarino *et al.* (2003) showed that the ammonia emission varies diurnally with a small peak in the morning and is at maximum in the afternoon. Haeussermann *et al.* (2003) also showed that the animal activity is highest in the day-time. Another important factor is the indoor temperature. Andersson (1995) conducted an experiment on ammonia evaporation from pig and cattle slurry and found that the evaporation increased about four times and progressively when the slurry temperature was increased from 10 to 25^{o}C. In an experiment of Rom and Dahl (2002), the emission increased three times and progressively when the temperature in the pig house increased from 10 to 20 ^{o}C. In later experiments, Rom (2004) found that the emission from pig houses increased by 2.3 times when the temperature in the pig house increased from 10 to 20 ^{o}C.
Ammonia emission is the product of ventilation rate and the difference between ammonia concentration in the inlet and outlet air. For precise ammonia emission measurements it is therefore necessary to perform precise measurements of both ventilation rate and ammonia concentrations. Neglecting the normally low concentration of ammonia in incoming air, the ammonia emission is the product of the ventilation rate and the ammonia concentration in the animal house. So-called measuring fans mounted in connection with conventional fans can be used for measuring ventilation rates properly, but in facilities with several fans this is costly and time-consuming. For some housing types with natural ventilation, it can be very complicated or even impossible to measure the ventilation rate. Therefore, it is of great interest to know if the ventilation rate can be estimated by indirect methods, taking into account any easily measured parameters, as for instance the use of tracer gases. The most popular type of tracer gas has been SF_6, (sulphur-hexa-fluoride), but it is no longer allowed to use it, due to its serious contribution to the greenhouse gas emission. Another way would be to use carbon dioxide produced by the animal itself as a tracer gas, because the carbon dioxide production is correlated to the animal heat production and the ventilation rate. Ventilation rate is calculated by making a mass balance, using the difference between the carbon dioxide concentration in incoming and outgoing air. The carbon dioxide production in animal houses depends on body weight, feed composition, feeding and production level, and carbon dioxide production from manure. For animal houses without deep litter, the carbon dioxide production from manure will normally be below 4 % of the total carbon dioxide production (Aarnink *et al.* 1992) and nearly negligible. For deep litter houses, the carbon dioxide production can be as high as the production from the animals (Jeppsson, 2000). The carbon dioxide production from animals is closely related to the respiratory quotient, RQ, defined as volume of the CO_2 produced, divided by the volume of the O_2 consumed. In practice, RQ ranges from about 0.8 for low-fed animals to 1.2 for heavily fed animals. For high RQ values (1.0-1.2), the carbon dioxide production ranges from 0.175 to 0.200 $m^3h^{-1}hpu^{-1}$ (1 hpu = 1000 W in total heat production), (Ouwerkerk & Pedersen 1994). Investigations of heat, moisture and carbon dioxide balances for

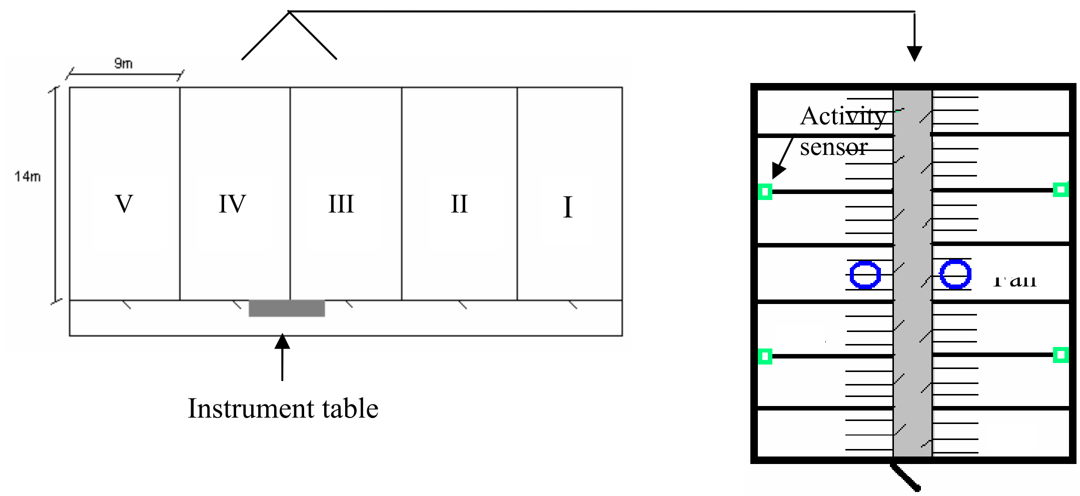
growers showed a carbon dioxide production of 0.185 $m^3h^{-1}hpu^{-1}$ (Pedersen *et al.*, 1998). That production level is also suggested as design figure (CIGR, 2002) and used in the present work. The carbon dioxide and heat production varies during the 24-hour cycle. Therefore, the estimation of ventilation rate, based on carbon dioxide measurements, can be further improved by taking the animal activity into account. The animal activity can, e.g., be measured by an activity measuring system based on infrared detectors in combination with an appropriate interface (Pedersen & Pedersen, 1995). The activity which is measured in mV, is normally converted to non-dimensional relative values in respect to e.g. daily or weekly mean. Different research work (CIGR 2002) has proven a high correlation between animal activity measured in this way and animal heat and carbon dioxide production.

For traditional pig housing, there is typically one activity peak in the morning and one in the afternoon, e.g. for fattening pigs on slatted floors, corresponding to two feeding times a day. Pedersen *et al.*(1998), showed the relation between animal activity and carbon dioxide production. Measurements on animal activity, carbon dioxide and animal heat production from a climatic laboratory with fattening pigs on partly slatted floor showed that 55 % of the diurnal variation in carbon dioxide could be explained by variations in the animal activity (Pedersen & Rom, 1998). The present work has the following main objectives: (1) to examine the agreement between measured animal activity and a standard activity model; (2) to examine the agreement between measured ventilation rate and estimates based on the carbon dioxide concentration; (3) to improve the calculation procedure for estimation of the ventilation rate, based on carbon dioxide measurements, by taking into account the measured animal activity or as a standard adjustment (dromedary model); and (4) to calculate the ammonia emission using such adjustments. While there is physiological relation between animal activity and animal heat and carbon dioxide production, the relation between animal activity and ammonia emission is much more complex and influenced by e.g. urination behaviour, increased air movement, due to active pigs and increased ventilation rate, as a consequence of increased heat production.

MATERIALS AND METHODS

The research was carried out in two different sections (III and IV) in a mechanically ventilated house for fattening pigs with partially slatted floor (Figure 1). The ventilation system consists of inlets through porous ceiling and outlet units, controlled by a combination of a damper and a voltage controlled fan. The indoor climate was monitored by a temperature sensor aiming to keep a constant temperature in the sections of 17 ^oC. The pigs were fed on liquid feeding four times a day, namely at 6.00 and 10.00 a.m. and at 2.00 and 6.00 p.m. The slurry channel below the slats in Section III, with vertical walls, was emptied regularly when filled up, and in Section IV the slurry channel was V-shaped and emptied every morning. Figure 1 shows the facility with 14 pens per section, proportioned to 15 pigs per pen. The actual number has been app. 14 per pen. For each section, measurements of indoor and outdoor air temperatures, carbon dioxide concentration, ammonia concentration, ventilation rate and animal activity were taken on an hourly basis. In the data analysis, is used datasets based on the average of identical hours for the whole trial. The animal activity was measured with passive infrared detectors (PID) and an analogue signal-processing interface (Pedersen & Pedersen, 1995). The sensors were placed 3 m above

floor level in four different positions in each section in conventional buildings, covering all pens in each room. Mean values of the signals for the four sensors measured continuously were used in the analysis.
The carbon dioxide and ammonia concentrations were measured in the exhaust air by sucking air samples continuously through Teflon tubes to the analysers, which was controlled by a computer. The Carbon dioxide concentration was measured by means of a Dräger Polytron transmitter IR CO_2 and the NH_3 was measured by means of a Dräger Polytron messkopf NH_3. Both measuring systems were modified and improved in accuracy by VengSystem, Denmark, with repeatability better than +/- 5% of measured value. The ventilation rate was measured with measuring fans (Fancom) with a free-running impeller with recording of impeller rotations. The measuring fan together with the outlet fans were calibrated in a test rig at Research Centre Bygholm with an accuracy of +/- 4 percent. The ventilation rate was furthermore calculated from measurements of indoor and outdoor carbon dioxide concentration by the following equation:



(a) (b)

Figure 1. Experimental facilities, with investigations in Sections III and IV
(a) shows the entire animal house and (b) one of the two experimental sections.

$$VF = \frac{C}{\Delta C \times 10^{-6}} \quad (1)$$

where:
VF = ventilation rate, m^3/h per hpu
C = carbon dioxide production (0.185 m^3h^{-1} per hpu)
ΔC = difference in carbon dioxide content between indoor and outdoor air, ppm.

Figure 2 shows the relation between ventilation rate and indoor carbon dioxide concentrations, where the outside carbon dioxide concentration is 350 ppm, and the carbon dioxide production is set at 0.185 $m^3h^{-1}hpu^{-1}$.

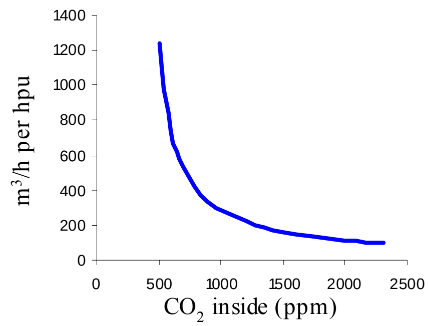


Figure 2 Relation between ventilation rate and carbon dioxide concentration, based on a CO_2 production of 0.185 m^3 per hour per hpu.

Equation (1) for C = 0.185 $m^3h^{-1}hpu^{-1}$, is only suitable for calculations based on a 24-hour average. It gives too low ventilation rates, e.g. in the daytime, where the carbon dioxide production due to high animal activity is normally high and visa versa during the night. Adjustment for diurnal variation in animal activity is carried out by means of Equation (2)

$$R_{act} = 1 - a \times \sin[(2 \times \pi /24) \times (h + 6 - h_{min})] \qquad (2)$$

Where:
R_{act} = relative activity (average of 24 hours = 1)
a = constant expressing the amplitude with respect to the constant 1 (typically of the size 0.1-0.4)
h = time of the day (hours after midnight)
h_{min} = time of the day with minimum activity (hours after midnight)

Figure 3 shows an example of the correlation between animal activity measured and calculated by a standard equation (dromedary model, CIGR 2002).

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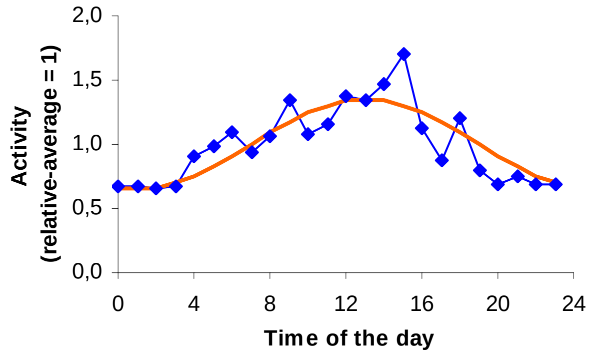


Figure 3. Correlation between measured animal activity and calculated activity (dromedary model)

The ventilation rate adjusted by the dromedary model is shown in Equation (3)

$$VF = \frac{C \times R_{act}}{\Delta C \times 10^{-6}} \tag{3}$$

The ammonia emission was calculated by Equation (4) according to CIGR (2002):

$$AE = VF \times AC \times [(17/29) \times (273.13/(273.13+t))] \times 1.293 \tag{4}$$

Where:

AE = ammonia emission, g/h
AC = ammonia concentration, ppm
17/29 = Ratio between molecular weight of ammonia and the mean "molecule" weight of atmospheric air
t = temperature, °C

In Equation (1), the ventilation rate is expressed per hpu, which can be calculated as the total heat production per animal multiplied by the number of pigs. For fattening pigs, the heat production can be calculated by CIGR (2002) equations, based on the body weight of pigs and the feed intake.

$$\Phi_{tot} = 5.09\ m^{0.75} + [1 - (0.47 + 0.003m)][n\ x\ 5.09\ m^{0.75} - 5.09\ m^{0.75}],\ W \tag{5}$$

Where

Φ_{tot} total animal heat dissipation in animal houses, W
m body mass of the animal, kg
n daily feed energy intake in relation to maintenance ($5.09\ m^{0.75}$, W)

The experiments referred to in this paper cover measurements from three trials in two sections, with in total 57 24-hours measuring periods as shown in Table 1.

Table 1. Overview of measurements

Trial	Period of the year	Number of days	Housing Conditions	Number of pigs	Body weight (kg)	Measured parameters			
						Activity (relative)	Ammonia (ppm)	Carbon dioxide (ppm)	Ventilation rate (m^3/h)
1	Autumn (20.09 - 15.10.2002)	25	Convent.	196	90	×	×	×	
2	Winter (19.02 - 02.03.2003)	11	Convent.	196	48	×	×	×	×
3	Spring (04/04 - 25/04/2003)	21	Convent.	196	88	×	×	×	×

RESULTS AND DISCUSSION

This work comprises Trial 1, where the ventilation rate is calculated on the basis of the carbon dioxide concentration, only, and Trials 2 and 3, where the ventilation rate is both calculated and measured. Trial 1 is carried out in the autumn with pigs averaging 90 kg and investigated in respect to animal activity and ammonia emission. Trials 2 and 3 comprise measurements in winter and spring for pigs of 48 and 88 kg, respectively and include ventilation rate measured with measuring fans.

Because it is aimed by the automatic climate control system to keep the indoor temperature as constant as possible and close to 17 ^oC, the variation in indoor temperature in each trial and section is limited. Expressed by the standard deviation s, on hourly measurement for the whole trials, s is below 0.5 ^oC in Trial 1, below 1.3 ^oC in Trial 2 and below 2.4 ^oC in Trial 3. The reason to a higher standard deviation in Trial 3 than in Trial 1 and 2, is some hot days in the spring 2003.

Due to good management with clean pens together with efficient ventilation, the indoor ammonia concentration was always low, and in average for Trial 1; 2.2 and 2.4 ppm for Section III and IV, respectively. For Trial 2; 2.2 and 1.9 ppm in Section III and IV, respectively and. for Trial 3; 4.4 and 3.5 ppm for Section III and IV, respectively. The maximum measured ammonia concentration was 10.3 ppm measured in Trial 3, Section III.

The average ventilation flow for Trial 2 and 3, with ventilation rate measured with measuring fans, was in Trial 2; 1350 and 2800 m^3/h for Section III and IV, respectively and, in Trial 3; 10400 and 11000 m^3/h for Section III and IV, respectively.

Trial 1

Correlation between measured and calculated animal activity

As shown by CIGR (2002), the animal heat and carbon dioxide production is closely correlated to the animal activity, with high daytime values and low night time values. When using animal carbon dioxide production as basis for calculation of ventilation rate by Equation (1), it is therefore important to know the diurnal variation in the carbon dioxide production. Using an average carbon dioxide value during the day will normally result in too low calculated ventilation rate and visa versa at night. Only for special production strategies as with *ad lib.* feeding and constant lighting, the diurnal variation in animal activity can be negligible. A simple way of adjusting for diurnal variation will be to use a standard sinusoidal model like Equation (2) (dromedary model), including one parameter for amplitude and one for the time of the day with minimum activity.

Table 2 shows which parameters fit best with the dromedary model in each case, calculated as a least square correlation between measured and calculated activity. Furthermore, the correlation is also calculated by fixed, $a = 0.35$ and $h_{min} = 2.0$, respectively.

The table shows that the parameter value a for the sinusoidal (dromedary) model is within the range of 0.24 to 0.41, corresponding to an activity of app. 35 % above the average in daytime and 35 % below the average at night. Table 2 also shows that ¾ of the diurnal variation can be explained by the dromedary model, and the results will only be about 3 % poorer when using the fixed parameters $a = 0.35$ and $h_{min} = 2.0$. The table shows that for pig houses like Sections III and IV, the diurnal variation in animal activity can be expected to be between 65 % in the night and 135 % in the daytime ($a = 0.35$), or nearly with a variation of a factor two.

Table 2. Parameters and correlations for the dromedary model on animal activity (Trial 1)

Week	Section III				Section IV			
	Dromedary model optimized in respect to the parameters a and h_{min}			R^2 Fixed to a = 0.35 h_{min} = 2.0	Dromedary model optimized in respect to the parameters a and h_{min}			R^2 Fixed to a = 0.35 h_{min} = 2.0
	a	h_{min}	R^2		a	h_{min}	R^2	
1	0.37	2.1	0.75	0.75	0.36	2.3	0.77	0.76
2	0.33	2.2	0.77	0.76	0.28	2.8	0.76	0.73
3	0.27	2.5	0.80	0.79	0.24	3.5	0.79	0.67
4	0.41	1.1	0.74	0.70	0.38	1.5	0.72	0.71
Average	0.35	2.0	0.77	0.75	0.32	2.5	0.76	0.72

Diurnal variation in ammonia emission

Ammonia emission from animal houses is the product of ammonia concentration and ventilation rate. It is therefore necessary to have reliable figures of both parameters, when calculating the ammonia emission. As mentioned above, the ammonia concentrations were in general very low. Table 3 shows how the ammonia emission is statistically correlated with the animal activity, expressed by the correlation coefficient R^2 for four succeeding weeks in trial 1.

Table 3 Correlation (R^2) between animal activity and ammonia emission (Trial 1)

Trial	Week	Section III		Section IV		Average of III and IV	
		Eqn. (1) CO_2	Eqn. (3) CO_2 + dromedary	Eqn. (1) CO_2	Eqn. (3) CO_2 + dromedary	Eqn. (1) CO_2	Eqn. (3) CO_2 + dromedary
1	1	0.50	0.79	0.27	0.69	0.39	0.74
1	2	0.38	0.65	0.10	0.38	0.24	0.52
1	3	0.11	0.47	0.04	0.44	0.08	0.46
1	4	0.03	0.62	0.03	0.38	0.03	0.50
	Average					0.19	0.56

As shown in the table, the correlation between animal activity and ammonia emission will be low if the ventilation rate is based on the carbon dioxide concentration, only. In the worst case, there will be no correlation at all. By adjustment with the dromedary model, the R^2 was improved to 0.56, showing that more than half the variation in ammonia emission can be explained by variations in the animal activity. The correlation between animal activity and ammonia emission based on carbon dioxide measurements adjusted by measured animal activity is not included in the table, because the ammonia emission and the activity had then been inter-correlated. An example of the relation between animal activity and ammonia emission, only based on the carbon dioxide concentration is shown in Figure 4. This figure is in good agreement with other investigations, which also indicate that the ammonia emission in the morning is relatively high, compared to the animal activity.

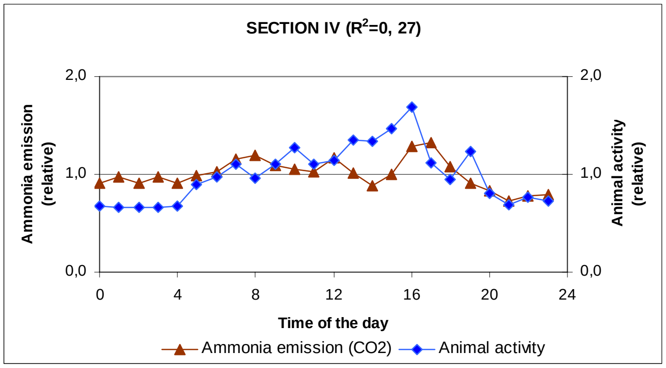


Figure 4. **Animal activity and ammonia emission based on carbon dioxide concentrations, only (trial 1, week 1, section IV)**

Figure 5 shows the ammonia emission, when the ventilation rate is adjusted with the dromedary model, Equation (3), versus the activity.

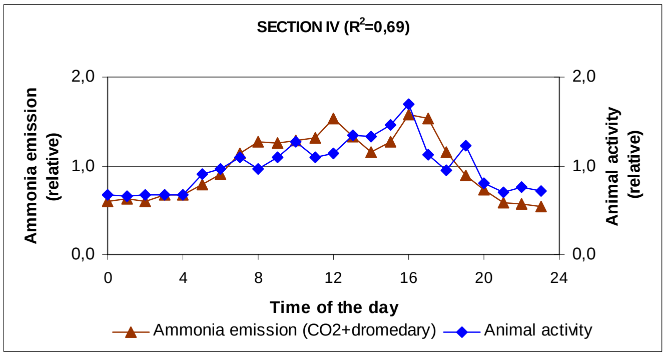


Figure 5. **Animal activity and ammonia emission based on carbon dioxide concentrations, adjusted by the dromedary model (trial 1, week 1, section IV)**

As shown in Figure 5, adjustment with the dromedary model gives a much better approach, due to a better estimate of the ventilation rate.

Trials 2 and 3

Ventilation rate – measured and calculated

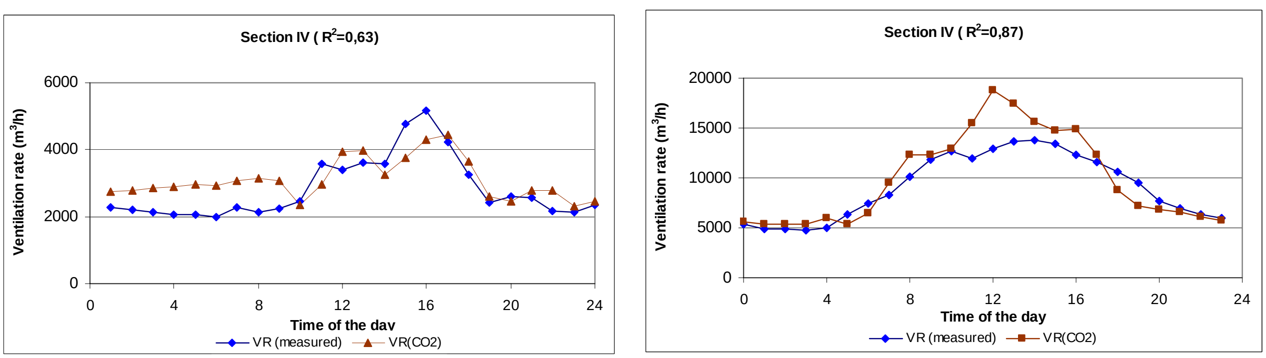
In Trials 2 and 3, the ventilation rate is both measured by measuring fans and based on carbon dioxide concentrations with and without adjustments for diurnal variations in animal activity. Table 4 shows the correlation between measured and calculated ventilation rates, where the ventilation rate is based on:

- Carbon dioxide concentration, only (Strategy 1)
- Carbon dioxide concentration, adjusted for activity by the dromedary model. (Strategy 2)
- Carbon dioxide concentration, adjusted by measured animal activity. (Strategy 3)

Table 4. Correlation between calculated and measured ventilation rate, expressed by R^2

Trial and section	Strategy 1 (CO_2 only) (R^2)	Strategy 2 (CO_2 + dromed.) (R^2)	Strategy 3 (CO_2 + activity) (R^2)	Relative ventilation rate Calcul./measured
2/III	0.93	0.95	0,81	1.17
2/IV	0.63	0.80	0.86	1.10
3/III	0.96	0.96	0.96	1.02
3/IV	0.87	0.87	0.87	1.06

Table 4 shows that the agreement between ventilation rates measured by measuring fans and calculated on the basis of the measured carbon dioxide concentration is good, except for Trial 2, Section IV, where only 63 % of the diurnal variation in ventilation rate can be explained by variations in the carbon dioxide concentrations. In all other cases for strategies 1, 2 and 3 in Table 4, R^2 is 0.8 or above, which must be considered fairly good. In trial 2 section III, strategy 3, the correlation between measured and calculated ventilation rate is low, which can only be explained as some unknown malfunction of the activity measuring system in that specific case.
For climate control strategies with a high p-band, where the maximum ventilation capacity occurs at several degrees Celsius above the temperature setpoint, it can be shown that the ventilation rate will not vary so much, and the calculation of ventilation rate based on the carbon dioxide concentration can be fairly good. On the other hand, if the p-band is low (1 or 2°C), the ventilation rate will fluctuate very much. Therefore, the increased carbon dioxide concentration during the day will not necessarily result in a higher carbon dioxide concentration, but in an increased ventilation rate. Table 4 also shows that the calculated ventilation rate is from 2 to 17 % higher than that measured or in average 8 % higher, which is fairly good, taken into account that the error in ventilation rate measured by measuring fans can be up to 4 %, and that some errors in calculated pig body mass may also be expected.
The ventilation rate calculated from carbon dioxide concentration and measured for section IV, Trials 2 and 3, is shown in Figure 6.



(a) (b)

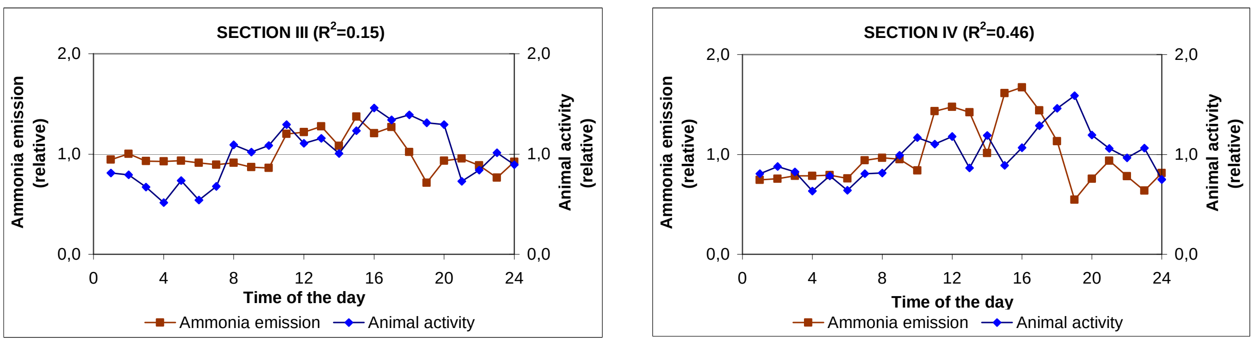
Figure 6. Ventilation rate, measured and based on CO_2, Trials 2 (a) and 3 (b), Section IV

Diurnal variation in ammonia emission

While there is physiological relation between animal activity and animal heat and carbon dioxide production, the relation between animal activity and ammonia emission is much more complex and influenced by e.g. urination behaviour, increased air movement over the floor due to active pigs and increased ventilation rate as a consequence of increased heat production. Also the fact that solid and slatted pens dry up during the night, due to low urination rate, will affect the diurnal variation in ammonia emission. Therefore a lower correlation between activity and ammonia emission, than between animal activity and heat and carbon dioxide production must be foreseen. Figure 7 shows the correlation between animal activity and ammonia emission based on ventilation rate, measured by measuring fans, for Trials 2 and 3.

The figures show that the ammonia emission has two maximums, one before noon and one after noon, reflecting the two middle feeding times at app.10.00 a.m. and 2.00 p.m. The two feeding

Trial 2



Trial 3

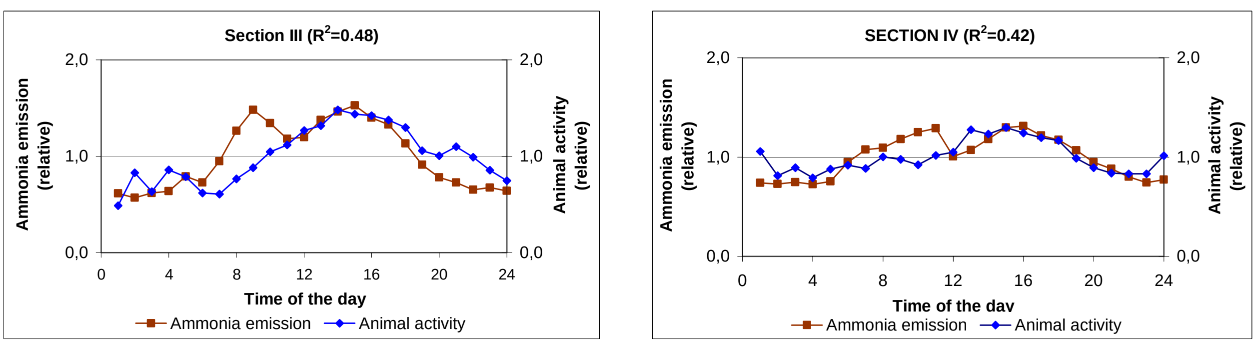


Figure 7. Correlation between ammonia emission and animal activity

times at app. 6.00 a.m. and 6.00 p.m. do not seem to result in a clear increase in the ammonia emission. The figures also show that that there is a low correlation between animal activity and ammonia emission (R^2 between 0.15 and 0.48), compared to the results from Trial 1 with a overall correlation coefficients of $R^2 = 0.56$, which might be explained by, e.g., seasonal differences in ventilation rate and pig behaviour.

CONCLUSION

On the basis of the experiments, the following conclusions can be made:

- The diurnal variation in animal activity can be approximated by use of a sinusoidal (dromedary) model, and a correlation of about $R^2 = 0.75$ was found.
- The ventilation rate based on measured carbon dioxide concentration and the calculated animal heat production, is a good approach for estimation of the ventilation rate as daily average. The deviation between measured and calculated ventilation rates was found to be between 2 % and 17 %.
- The ventilation rates based on carbon dioxide measurements can be improved by including a standard correction for animal activity (dromedary model), and a R^2 above 0.8 was found.
- The ammonia emission is correlated to the animal activity, and 15 to 56 % of the diurnal variation in ammonia emission can be explained by diurnal variations in the animal activity.

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