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Using Passive Flux Samplers to determine the ammonia emission from mechanically ventilated animal houses

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Abstract. *Ammonia emissions from animal houses are an important environmental issue in the Netherlands. The current technique in the Netherlands to measure ammonia emissions in mechanically ventilated animal houses is the chemiluminescence method (using a NO_x monitor after conversion of NH_3 to NO). During campaigns to measure emissions from animal houses, it became clear that management is an important factor in determining the emission level. Differences between animal houses of the same type and kind of animal may differ more than the variation in time and season within one animal house. These management related differences in emission factors point at the need to measure more animal houses during a shorter period. This stresses the need for development of flexible methods to be used in short term measurements, which allows monitoring the ammonia emission from a larger number of animal buildings per year. In this paper, a practical farm with different housing systems and two types of ventilation shafts (with and without a lid in the ventilation shaft to regulate the temperature inside the animal house) was selected to test the* *performance of passive flux samplers to measure the ammonia emission from mechanically ventilated animal houses. A statistical t-test shows that the differences between passive flux samplers and the reference method are not significant at the 95% significance level when combining all measurements. The use of a lid in the ventilation shaft improves the correlation between passive flux samplers and the reference method. As a result of these measurements, passive flux samplers are presented as an alternative to measure the ammonia emission from mechanically ventilated animal houses.*

Keywords. Passive flux samplers, ammonia emission, animal houses, forced ventilation

Introduction

Ammonia emission is a severe environmental problem in Europe. Atmospheric NH_3 readily reacts with atmospheric acids to form ammonium (NH_4^+), which is an important constituent in aerosols and precipitation (Erisman *et al.*, 1988). Deposition of NH_3 and NH_4^+ contribute to eutrophication and acidification of N-limited ecosystems (Heij and Schneider, 1991; Heij and Erisman, 1997). In the Netherlands, approximately 94% of the Dutch ammonia emissions (157 kton in the year 2000) originate from agricultural activities (RIVM and CBS, 2001). The aim of the Dutch government is to reduce in 2010 the total ammonia emission to approximately 70% (100 kton) compared with the year 2000 (Sliggers, 2001). Besides, the contribution from Dutch agriculture to the total ammonia emission should be reduced to 86% (86 kton) in 2010.

Ammonia emissions from animal houses (46% of total ammonia emissions from agriculture in 1997) are an important environmental issue in the Netherlands. Ammonia emission factors are used by the Dutch government as one of the tools to control agricultural ammonia emission. These factors are ammonia emissions of animal housing system categorised by species (Van der Hoek, 1994). When possible these factors are determined by measuring the ammonia emissions from a specific animal housing system over several months. Costs of these measurements on equipment, maintenance and labour are high. Due to these high costs the number of animal houses measured is relatively small. Due to the high variation observed between and within farms short-term measurements, which allows monitoring the ammonia emission from a larger number of animal buildings per year, are necessary.

To determine the ammonia emission from an animal house it is necessary to be able to establish the dynamics with time of the emission from the building. The surface under the emission curve will determine the total ammonia emission from the animal house. Two possible approaches can be considered:

1. At regular sampling time intervals, both the ventilation rate and the ammonia concentration in the outgoing air are determined. The emission numbers calculated in this way are average values for that particular sampling time interval. From these average emission values, an average emission for the animal building can be obtained. To have reliable results, short sampling time intervals, extended over a large period, should be considered.
2. From the air leaving the animal house through the ventilation shafts a proportional sample is taken. The amount of ammonia trapped in the sampler, together with the sampling time and a proportional constant factor (specific for the sampler), can be used to determine the ammonia emission from the building.

The current technique to measure ammonia emissions in mechanically ventilated animal houses is based on approach a). Because the frequency of measurements of ammonia concentrations and ventilation rates is usually high, the results obtained following this approach are usually precise and reliable. One advantage of using this method is that it is possible to follow the emission processes. One example for this kind of approach is the use of a NH_3 to NO converter and a NO_x analyser to measure ammonia concentrations, and a measuring fan (wheel-fan anemometer) in the shaft to estimate the ventilation rate (Groenestein, 1993; Groenestein *et al.*, 2001; Scholtens, 1993; Phillips *et al.*, 1998; Groot Koerkamp *et al.*, 1998; Demmers *et al.*, 1999).

For the second approach, one alternative is to use passive flux samplers. Passive flux samplers are mainly used in agriculture for the measurement of ammonia fluxes (mg m^{-2} s^{-1}) from non point sources such as field emissions after land spreading of manure and emissions from open manure silo's (Leuning *et al.*, 1985; Ferm, 1986; Ferm and Christensen, 1987; Ferm *et al.*, 1991; Schjoerring *et al.*, 1992; Klarenbeek *et al.*, 1993; Sommer *et al.*, 1996). Steen (1977) described a passive flux sampler for particles.

Leuning *et al.* (1985) reported the first form of passive flux sampler based on an internal (oxalic) acid coating to capture any ammonia in air flowing at a controlled rate through the sampler. This sampler was equipped with vanes and pivots to keep it pointing always upwind. This is an advantage when carrying out plot experiments, but makes the device less applicable to studies on manure stores or animal houses.

Ferm (1986) and Ferm *et al.* (1991) described a passive sampler for ammonia with a fixed orientation, showing a linear proportional relation between inside and outside air velocities, with a wind direction parallel to the orientation of the sampler. According to Ferm (1986) and Ferm *et al.* (1991), for other orientations (angle between the orientation of the sampler and the wind direction is $\alpha \neq 0$), there is a cosine dependency between the wind velocity outside and inside the sampler. However, Scholtens and Monteny (1999) showed instead a $\sqrt{\cos(\alpha)}$ dependency. The ammonia flux [$g.s^{-1}$] is calculated from the relation between inside and outside wind speed, the exposure time of the sampler and the amount of ammonia captured. As with Leuning's sampler, the principle was to capture ammonia from air flowing through the sampler, quantitatively, in an oxalic acid coating.

The aim of this paper is to assess the potential use of passive flux samplers for measurements of ammonia emissions from mechanically ventilated animal houses. As a starting point, the working principle of the passive flux sampler is presented. To test the performance of passive flux samplers in mechanically ventilated animal houses, a practical farm with different housing systems and two types of ventilation shafts (with and without a lid) has been used. Results of the comparison between passive flux samplers and a reference method, for each housing system and ventilation shaft type, are presented and discussed in detail.

Materials and Methods

Passive flux sampler theory

Scholtens (1996) describes a patented (patent number) modification of Ferm's design, consisting on moving the restriction (orifice) to the middle of the sampler (figure 1). This symmetrical design minimises the number of analysis while improving and simplifying validation procedures. For test purposes the sampler can be equipped with pressure points (radius pressure taps located at a distance from the orifice plate of approximately ½ D_o (orifice diameter)). As in Ferm's design, in the absorption chambers a specific gas or type of gases can be bound to a gas-absorbing agent.

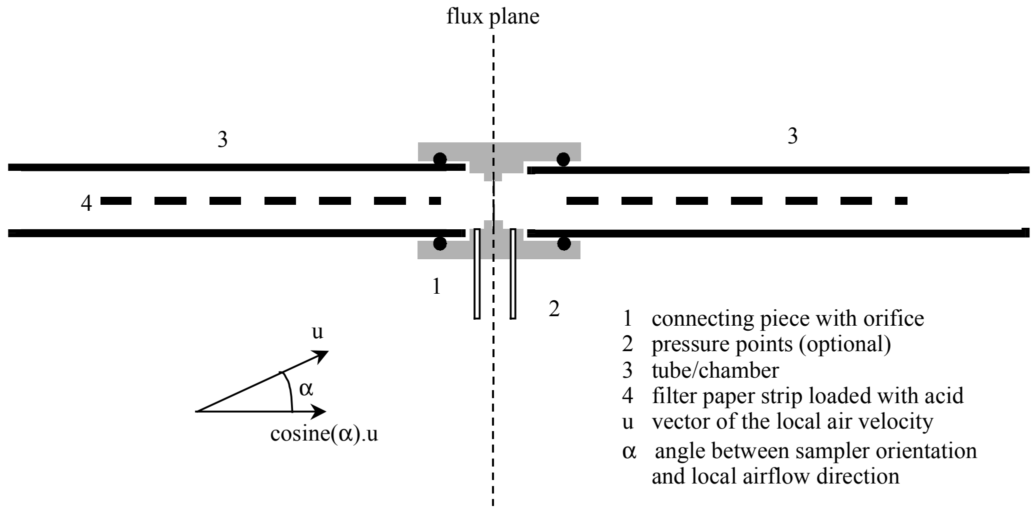

Figure 1. Schematic drawing of the improved sampler.

The working of a passive sampler is based on the following two basic principles. Firstly an airflow passing an object results in an under pressure downstream of this object. This under pressure can be described by the following equation (Perry *et al.*, 1985):

$$P_D = \frac{F_D}{A_p} = C_D \cdot \tfrac{1}{2} \rho \cdot v_m^2 \tag{1}$$

with: P_D under pressure downstream of object [Pa]

F_D drag force [N]

C_D drag coefficient [ ]

ρ air density [kg.m^{-3}]

v_m air velocity [m.s^{-1}]

A_p projected area of the object in the airflow [m^2]

Secondly, the airflow through an orifice meter depends on the pressure drop over the orifice meter, as shown in Perry *et al.* (1985).

$$P_O = \frac{(1 - B^4)}{YC^2} \cdot \tfrac{1}{2} \rho v_O^2 = C_O \cdot \tfrac{1}{2} \rho v_O^2 \tag{2}$$

with: P_O pressure drop over the orifice meter [Pa]

B ratio orifice diameter (D_O) to channel diameter (D_2)

C coefficient of discharge [ ]

Y expansion factor [ ]

v_O air velocity through orifice [m.s^{-1}]

C_O orifice meter constant [ ]

Both equations show a square root dependency between air velocity and pressure drop. In the first equation the pressure drop is caused by the air velocity, in the second equation the pressure drop induces an airflow through the orifice meter. Under normal atmospheric conditions both equations can be combined to the following equation (assuming P_D=P_O)

$$v_O = \sqrt{\frac{C_D}{C_O}} \cdot v_m = K_S \cdot v_m \tag{3}$$

with K_S the sampler constant. When this proportional relation exists, the amount of ammonia captured by the sampler can be described with equation (4). The wind direction is parallel to the sampler.

$$S_{NH3} = K_S \cdot A_O \int_{t1}^{t2} v(t) \cdot C_{NH3}(t)dt \tag{4}$$

with:

with:	Ao	surface area of hole in orifice [m^2]
	S_{NH3}	amount of ammonia captured [mg]
	C_{NH3}	ammonia concentration [$mg.m^{-3}$]
	t	time of day
	t_1	start of exposure
	t_2	end of exposure

The measured ammonia flux is then calculated from the amount of ammonia captured in the sampler:

$$F_{NH3} = \frac{S_{NH3}}{K_s \cdot A_o \cdot (t_2 - t_1)} \tag{5}$$

with:	F_{NH3}	ammonia flux [$mg.m^{-2}.s^{-1}$]
	t_2-t_1	exposure time [s]

And the emission through the ventilation shaft can be calculated as:

$$E_{NH3} = F_{NH3} \cdot A_{VS} \tag{6}$$

with:	E_{NH3}	ammonia emission [$mg.s^{-1}$]
	A_{vs}	surface area of the ventilation shaft [m^2]

The value of K_s is determined experimentally in a two-step process. In the first step, a value for the drag constant C_D is established using a wind tunnel or a ventilation shaft (both with $\cos(\alpha) = 1$). A range of air velocities is applied (0.5 -15 $m.s^{-1}$) and the pressure drop over the orifice meter in the sampler recorded. A linear regression on the results gives the C_D value for this sampler design. The relationship between air velocity through the orifice meter and the pressure drop over the orifice meter is measured using a soap bubble meter. A range of pressure drops (0-120 Pa) is applied and the airflow registered. The internal diameter of the orifice meter is used to calculate the air velocity. From the results a linear regression is used to calculate the orifice meter constant C_O. The sampler constant K_s is then calculated using equation (3).

Reference method

The reference method (Scholtens, 1990) is based on the measurement of ventilation rate by fan-wheel anemometers (Van Ouwekerk, 1993) and of ammonia concentration (in the ventilators that were running continuously) by using a NH_3-convertor and a NO_x-analyser (Thermo Environmental Instrument's Chemiluminescence NO-NO_2-NO_x analyser Model 42d; Van Ouwekerk, 1993). Ammonia emission is calculated as the product of the ammonia concentration measured with the NO_x monitor and the air leaving the building through the ventilator shafts.

Measurement location

Ammonia emission measurements took place in four different compartments (figure 2) in an animal house (calves for meat) during two production periods between April 1995 and May 1996. All the animals were of the same age. The compartments are connected through a walking area and swing doors perfectly closed. Three of them (C1, flushing system; C2, synthetic slatted floor; C3, reference) contained 60 animals in a collective accommodation, with cubicles (2.5m x 3 m) with space for 5 animals. The fourth one (C4, wooden slatted floor) had 44 animals in individual boxes (0.8 m x 1.8 m). The manure was collected in one canal at the end of the boxes. Each compartment had two rows of cubicles with a feeding area in the middle.

Each compartment was mechanically ventilated with two fans in the top of the building with a diameter of 45 cm (maximum capacity of 12000 $m^3.h^{-1}$), without interference or effects in the ventilation of the other compartments. One of the two fans was continuously working, while de other one was switched on when the animal house temperature was above 10 ^oC. When the second ventilator was not operating it was closed with a “butterfly lid”. The ventilation was changed depending on the outside temperature, the health and the age of the animals (Hol and Groenestein, 1997).

Ammonia emission measurements were performed beneath the ventilation shaft using passive flux samplers, and the results compared with the reference method (ammonia emissions measured with the reference method reported in Hol and Groenestein, 1997). Glass fibre paper inserts loaded with 5% sulphuric acid were placed in the samplers. After a sampling time of 1 week, the samplers were transported to the IMAG laboratory for analysis using spectrophotometry.

Results and discussion

The measurements during the first few weeks, without mechanical ventilation, in the veal calve sheds showed clearly that the open ventilation shaft was the main exhaust opening the doors were relatively unimportant. Figure 3 shows the ammonia emission measured with the passive flux samplers (PFS) and calculated with the reference method, for the four different animal housing systems studied. As the animals increase in size, an increase in ammonia emission is expected over time, which in fact is observed in all the different housing systems under consideration. The individual housing system seems to lead to smaller emissions when compared with the three group-housing systems. However, the number of animals in the individual housing system was also smaller than in the group-housing systems. In fact, when the emissions are normalised to emissions per animal, both the individual and the group-housing systems have a similar emission. For the synthetic group-housing system, the one with highest emissions, a break-through of ammonia was evident for some of the samplers. These measurements are also reported here, although they are not used for the final interpretation of the results.

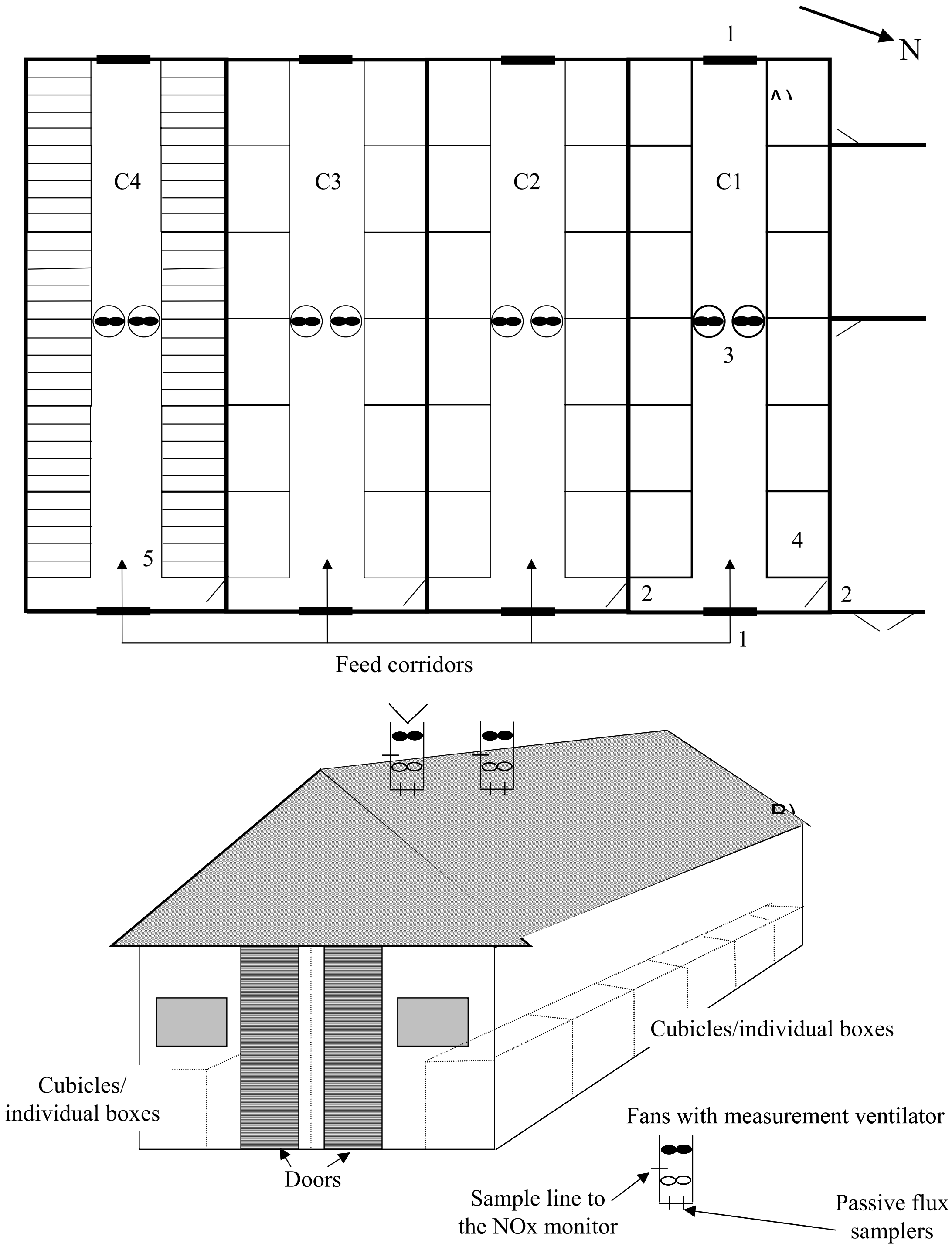

Figure 2. Overview of the measurement site in Kootwijkerbroek. A) Top view. The following notation has been used: C1, cubicles, flushing system; C2, cubicles, synthetic slatted floor; C3, cubicles, reference (traditional) house; C4, individual boxes, wooden slatted floor; 1, inlets; 2, connecting doors; 3, fans with a measurement ventilator; 4, cubicles for group accommodation; 5, boxes for individual accommodation; B) Front view of the animal house, showing the measurement set-up used for these measurements. Also shown the two ventilators, one with and one without a closing lid.

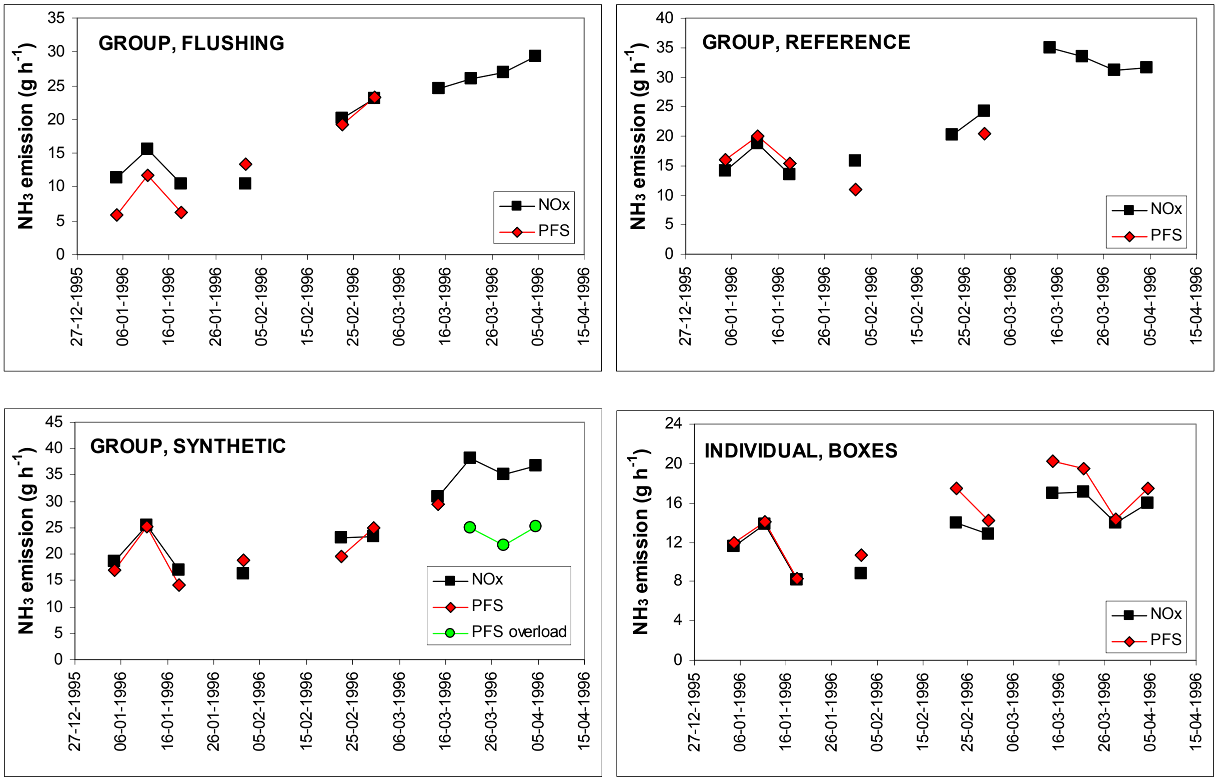

Figure 3. Ammonia emission pattern (g/h) as measured with passive flux samplers (PFS) beneath the ventilation shaft, and calculated with a reference method.

In general, a good agreement is observed for all the housing systems between the ammonia emission patterns calculated with the reference method and measured with the passive flux samplers (figure 4). This is reflected in an almost 1:1 line between both methods. However, a high dispersion in the data is also observed. For the group-housing system "synthetic", a break-through of ammonia was observed in some samplers. This data is also shown in the figure, but not used for the comparison of both measuring techniques. A statistical test (t-test) was performed in order to see whether or not the difference between the measurements obtained with both methods (reference and passive flux samplers) was significant. The results of this analysis, summarised in table 1, show that the differences between both methods are not significant (at the 95% significance level) for the three group-housing systems. In the individual-housing system, the correlation between both methods is good but the differences are significant.

Table 1. Statistical t-test (95% significance level) of the difference between the passive samplers and the reference system for each housing system.

Houses	Flushing	Synthetic	Reference	Boxes
Number of measurements	6	7	5	10
Average of |NOx|-|PFS|	1.98	0.78	0.71	-1.54
Standard deviation	3.15	2.24	3.32	1.26
|t|	1.54	0.92	0.48	3.87
t (95%)	2.57	2.45	2.78	2.26

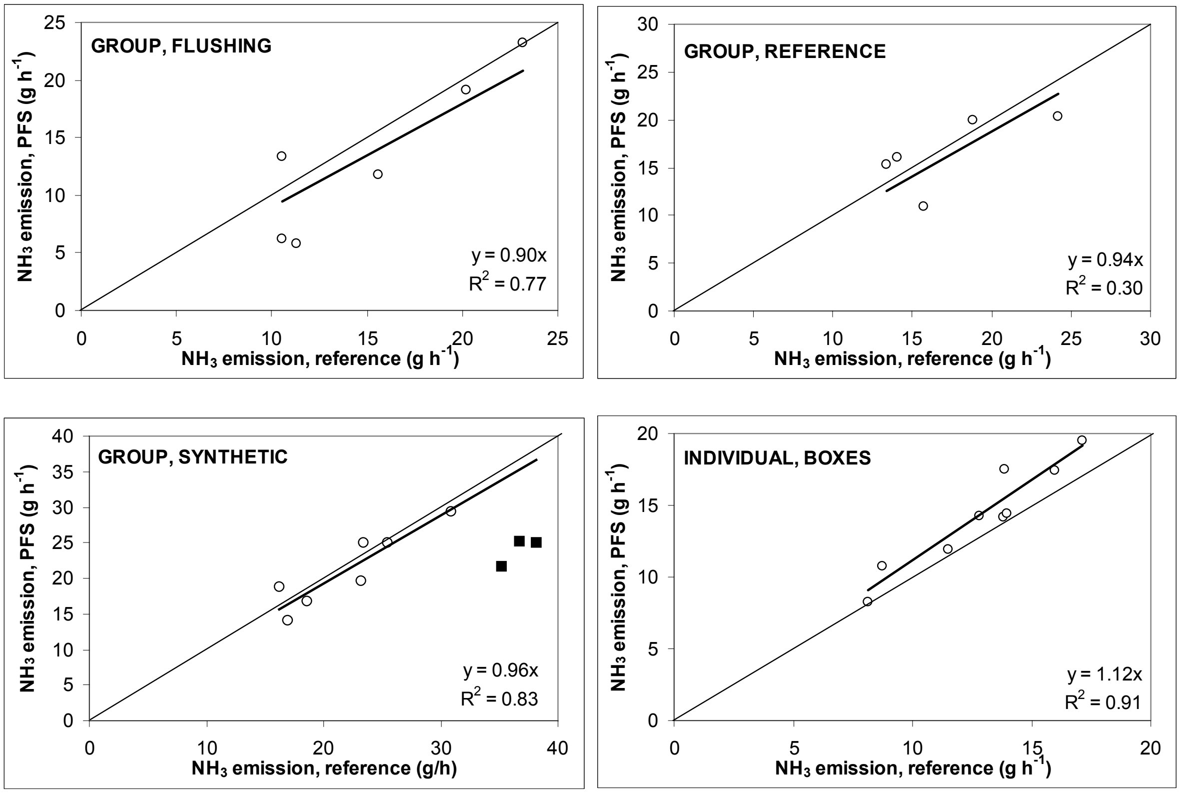

Figure 4. Correlation between the ammonia emission (g.h^{-1}) measured with passive flux samplers (PFS) beneath the ventilation shaft, and calculated with the reference method. The squares represent observed overload of the passive flux samplers.

Figure 5 shows the results of combining the measurements performed in all different animal houses, but differentiating between measurements in the ventilation shaft with and without lid. As in figure 4, results where the break-through of ammonia was observed, are presented in the figure but not used for further calculations. Both in the ventilation shaft with lid and in the ventilation shaft without lid, both measurement techniques compare well, but the data still shows a high dispersion. In this case, the statistical t-test (table 2) shows that the differences between both measurement techniques are not significant (95% significance level) for the ventilation shaft with lid. This is observed individually, for all the housing systems, and when we combine the data from all housing systems. For the ventilation shaft without lid, the combination of all data leads to the same results: no significant differences (95% significance level) between both measuring techniques. However, this is not the case for the group-housing system “synthetic”, and the individual (boxes) housing system.

Figure 6 shows the result of combining all measurements (i.e., for all housing systems, and both for the ventilation shaft with lid and without lid). Once again, the points showing the overload of the flux sampler with ammonia, are also presented in the figure, but are not used in the linear regression. The statistical t-test (table 3) shows that, when combining all measurements, the differences between both methods are not significant at the 95% significance level. In this way, passive flux samplers offer a new way of measuring the ammonia emission from mechanically ventilated animal houses.

Table 2. Statistical t-test (95% significance level) of the difference between the passive samplers and the reference system for the ventilation shafts with and without lid.

Shaft without lid	Flushing	Synthetic	Reference	Boxes	Total
Number of measurements	6	7	5	10	28
Average of |NOx|-|PFS|	1.51	1.43	-0.01	-0.89	0.36
Standard deviation	2.52	1.51	3.22	0.94	2.17
|t|	1.47	2.52	0.01	3.00	0.88
t (95%)	2.57	2.45	2.78	2.26	2.05

Shaft with lid	Flushing	Synthetic	Reference	Boxes	Total
Number of measurements	4	10	5	10	29
Average of |NOx|-|PFS|	-0.17	0.79	0.71	-0.65	0.15
Standard deviation	0.45	2.52	1.93	0.92	1.82
|t|	0.75	1.00	0.82	2.23	0.44
t (95%)	3.18	2.26	2.78	2.26	2.05

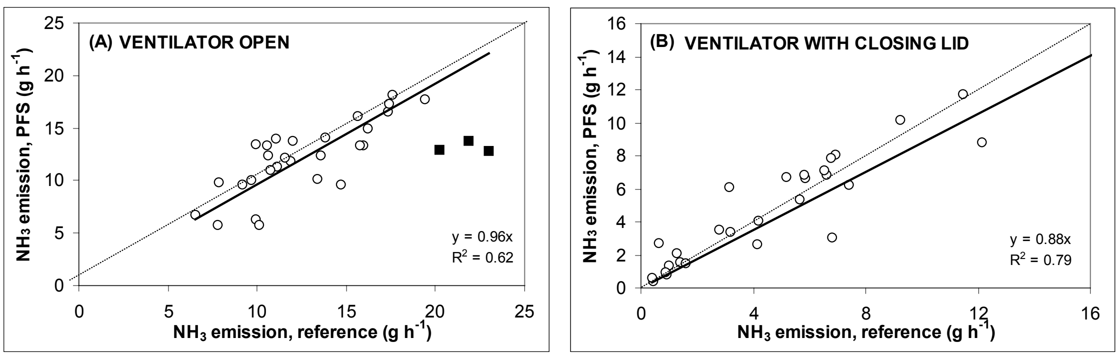

Figure 5. Comparison between the reference method and the PFS for the two different ventilators present in the animal house. The squares represent observed overload of the passive flux samplers.

Table 3. Statistical t-test (95% significance level) of the difference between the passive samplers and the reference system combining all measurements.

Houses	Total
Number of measurements	28
Average of |NOx|-|PFS|	0.20
Standard deviation	2.66
|t|	0.39
t (95%)	2.05

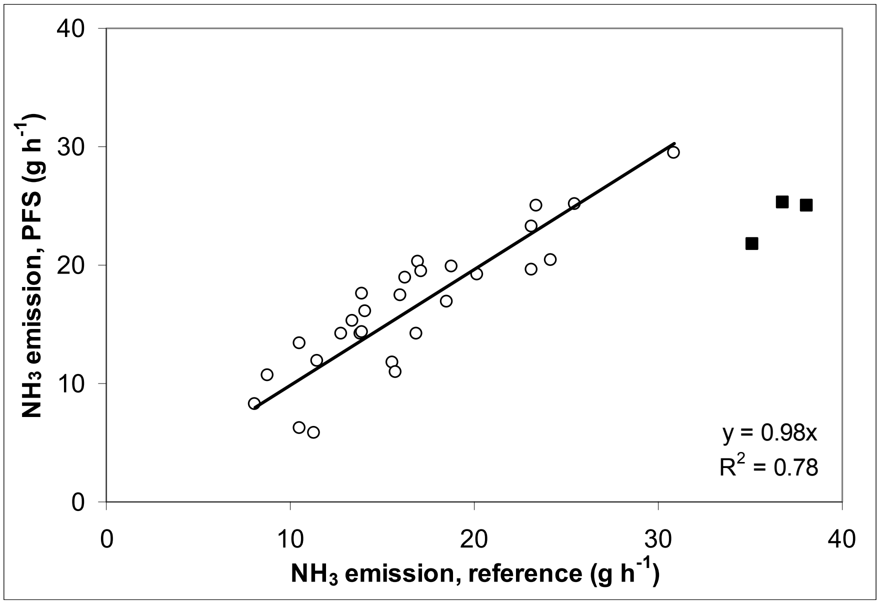

Figure 6. Comparison between reference method and the new concept for measuring ammonia emissions (g.h^{-1}) from mechanically ventilated buildings. The squares represent observed overload of the passive flux samplers.

Conclusions

In this paper, the potential use of passive flux samplers to measure the ammonia emission from mechanically ventilated animal houses has been presented as an alternative for the chemiluminescence method (NO_x monitor after conversion of NH_3 to NO). With the improved sampler it is simple to establish the sampler constant (K_s) under practical conditions for different sampler designs. It is not necessary to use an artificial ammonia source under field conditions or in a wind tunnel.

Passive flux samplers seem to underestimate the ammonia emission when compared to the reference method (NO_x chemiluminescence monitor, after conversion of NH_3 to NO). However, a statistical t-test shows that the differences between both measuring techniques are not significant at the 95% significance level when combining all measurements.

The use of a lid in the ventilation shaft to regulate the temperature inside the animal house improves the correlation between passive flux samplers and the reference method. The lid, when open, can force the airflow to be aligned with the samplers and, in this way, reduce the cosine dependency of the samplers. New measurements should be performed in order to see the influence of the lid in the constant factor K_s of the sampler.

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