Ammonia emission from organic pig houses determined with local parameters

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Abstract

The objective of this study was to determine the ammonia emissions from houses for growing-finishing pigs with an outside yard. While regular emission measurements are not possible in these open systems another approach was used. Local parameters were measured and used in an existing NH_3 emission model to calculate the ammonia emissions. The following local parameters were measured/determined: total urine fouled floor area, total manure area in the manure pit, surface temperature of fouled areas of floor and manure pit, air velocity above fouled floor areas. Parameters pH and NH_4-N content were measured by filter absorption of the urine puddles on the floor and the upper layer of the manure in the pit. These measurements were done in 3 pig houses with outside yard and in 2 regular houses, serving as reference. From the results of this study the following was concluded: 1) The floor emission is generally higher in houses with outside yard compared with regular houses, mainly caused by a larger fouled floor area. 2) The emission per m^2 pit surface area is significantly lower in houses with outside yard, especially as a result of the lower surface temperature of the manure in the pit. 3) The determination of ammonia emission in houses with outside yards using locally measured parameters provides a clear methodological perspective. Further validation of this method, however, is necessary. Particular attention should be given to what happens in the upper layer of the manure.

Keywords: pigs, outside yard, welfare friendly housing, ammonia emission, measuring method

Introduction

Providing an outside yard for pigs is generally regarded as an important way to improve the welfare of the animals. For this reason an outside yard is mandatory for organic and free-range pig farming. In regular pig farming in the Netherlands there is a desire as well to build pig houses with an outside yard. The question is whether ammonia emissions are not increasing when offering an outside yard. To meet societal requirements also houses with outside yards must reduce emissions as much as possible. Therefore the goal of this study was to determine ammonia emissions from pig houses with an outside yard. Furthermore, we would like to gain insight in the contribution of different sources of these emissions, i.e. emissions from the floor and emissions from the manure pit. Existing methods to determine ammonia emissions from mechanically ventilated houses are not suitable for determining emission levels from relatively open housing systems with an outside yard, as are used in organic pig production. Therefore a new method was developed, based on measuring local variables. These variables are used in an existing model to calculate emission levels from the manure pits and from the fouled floors. For comparison, besides organic pig houses with outside yards also regular houses without outside yard were involved in this study.

Material and methods

The study was conducted in four houses for growing-finishing pigs on commercial farms, including two regular farms and two organic farms. In addition, the study was conducted in the so-called Star+ house of Pig Innovation Center (PIC) Sterksel. In the organic pig houses and in the Star+ house the pigs had an outside yard. Hereafter, the different houses will be described in brief. In the layouts of the houses symbols are used for the different components. These symbols are explained in figure 1.

Regular house 1

The study was done in one of the rooms of the pig house. The room had 8 pens for 12 pigs each. In figure 2 the layout of a pen is given. The pen area was 12.0 m^2 (1.0 m^2/pig) and had a narrow concrete slatted floor at the front, a large convex concrete solid floor in the middle and a wide concrete slatted floor at the back of the pen. The depth of the manure pit was 1.25 m. The manure pit underneath the solid floor was not connected with the air inside the animal room. Air entered the room via an opening inside the door and was exhausted by two fans with a diameter of 45 cm. The maximum ventilation capacity was 12 000 m^3/h. Pigs were fed by a feed hopper with a drinking nipple inside.

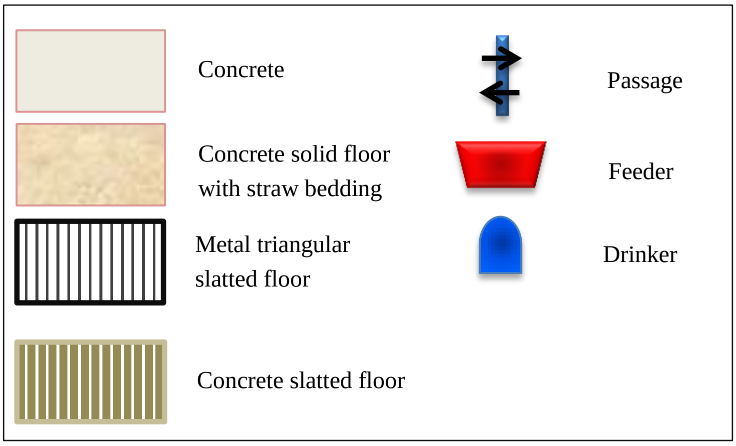

Figure 1 Symbols used in the different layouts of the pig houses

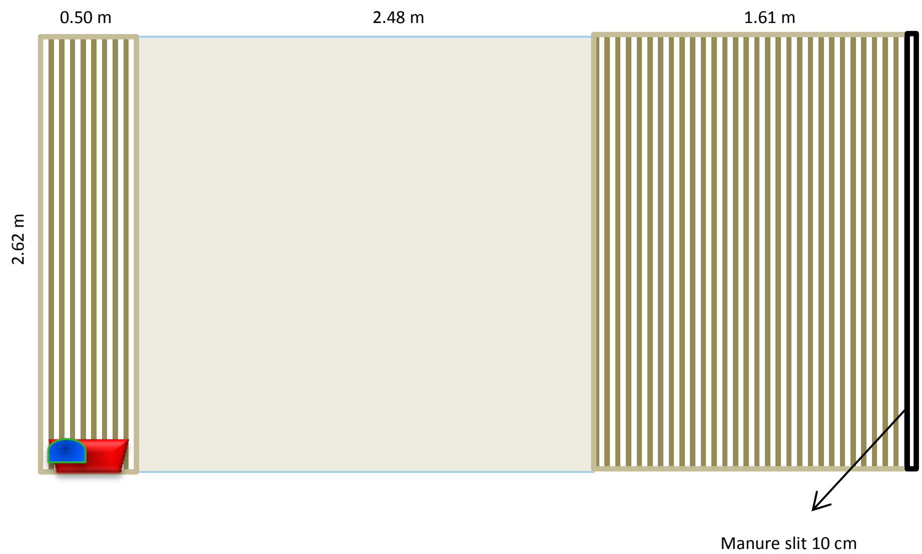

Figure 2. Layout of a pen in Regular house 1 (see Figure 1 for the symbol list)

Regular house 2

The study was done in one of the rooms of the pig house. The room had 6 pens for in total 53 pigs (5 pens with 9 and 1 pen with 8 pigs). In figure 3 the layout of a pen for 9 pigs is given. This pen had an area of 7.0 m^2 (0.78 m^2/pig) and had a narrow plastic slatted floor at the front, a large convex concrete solid floor in the middle and a wide metal triangular slatted floor at the back of the pen. The depth of the manure pit was 0.65 m. There was no manure storage beneath the solid floor. Air entered the room via an opening above the door and was exhausted by a fan with a diameter of 40 cm. The maximum ventilation capacity was 4 400 m^3/h. Pigs were fed by a feed hopper with a separate drinking bowl.

Organic house 1

The study was done in one of the rooms of the pig house. The room had 6 pens for 17 pigs each. In figure 4 the layout of a pen is given. The total pen area was 33.5 m^2 (1.12 m^2/pig inside and 0.85 m^2/pig outside). The concrete solid floor inside had some straw bedding. The slatted floors inside and outside were of concrete. The depth of the manure pits were 1.5 m. The house was natural ventilated through open windows and the passage to the outside yard. Pigs were fed by a trough with drinking nipples on top.

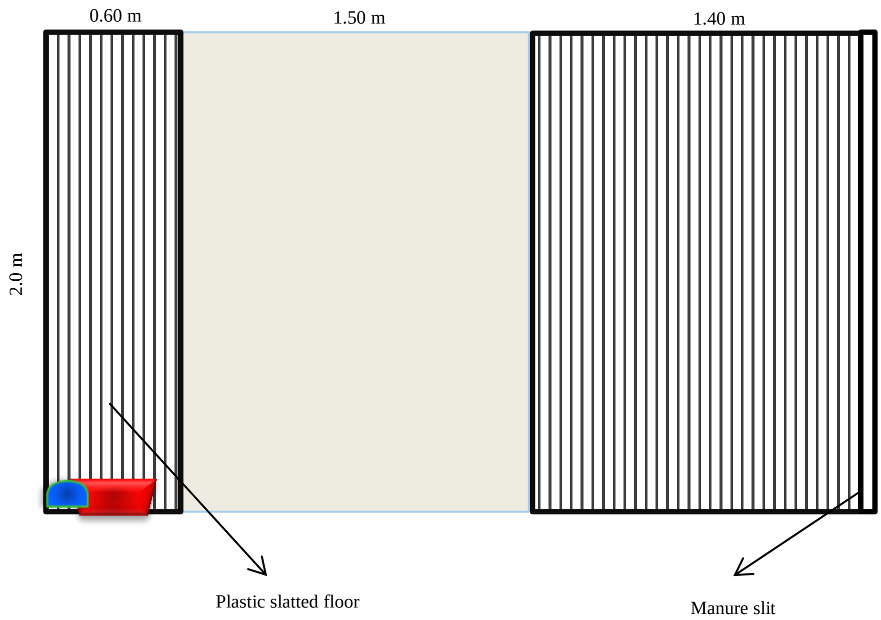

Figure 3. Layout of a pen in Regular house 2 (see Figure 1 for the symbol list)

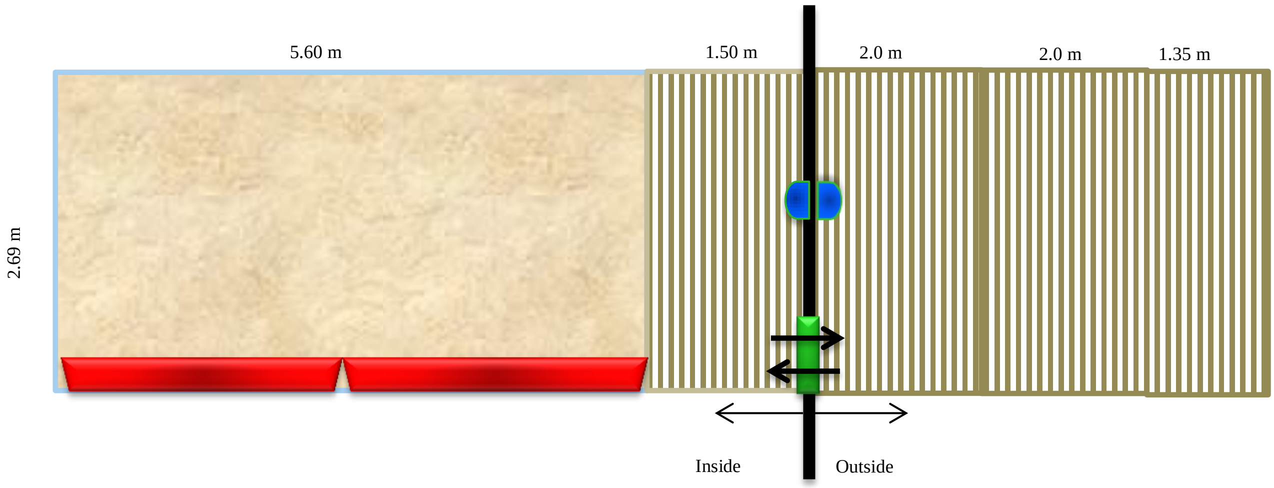

Figure 4. Layout of a pen in Organic house 1 (see Figure 1 for the symbol list)

Organic house 2

The study was done in one of the rooms of the pig house with one large pen for 50 pigs. In figure 5 the layout of the pen is given. The total pen area was 116 m^2 (0.97 m^2/pig inside and 1.33 m^2/pig outside). The concrete solid floor inside had straw bedding. The outside yard had a concrete slatted floor near the building and a metal slatted floor at the other side. In between there was a wide convex concrete solid floor. The house was mechanically ventilated. Pigs were fed by feed hoppers with drinking nipples inside.

Star+ house

The Star+ house had one room with 12 pens for 18 pigs each. In figure 6 the layout of one pen is given. The house was naturally ventilated. The outside yard was not open as in the commercial houses, but covered by a roof and surrounded by windbreak netting (see picture in figure 7). The total pen area was 21.9 m^2 (0.88 m^2/pig inside and 0.33 m^2/pig outside). The slatted floor inside was metal made and the slatted floor outside was for a small area metal and for a large part concrete based. Underneath the total slatted floor area a V-shaped manure belt was running. This belt directly separated urine and faeces. The urine continuously ran to a closed storage tank, while the faeces were removed 6 times a day by turning the belt.

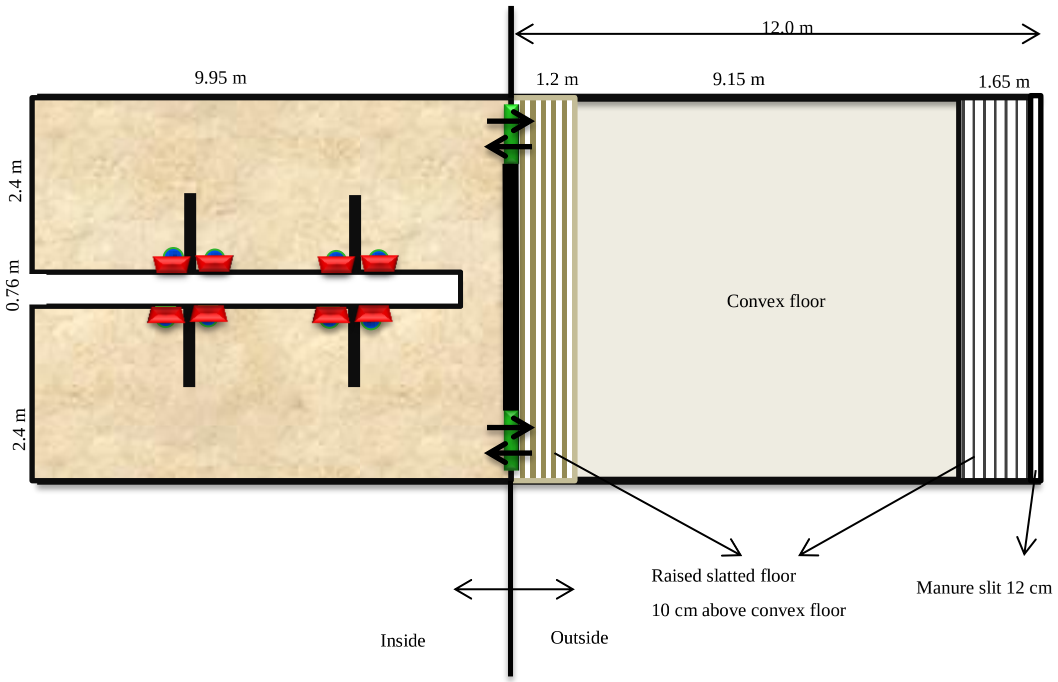

Figure 5. Layout of a pen in Organic house 2 (see Figure 1 for the symbol list)

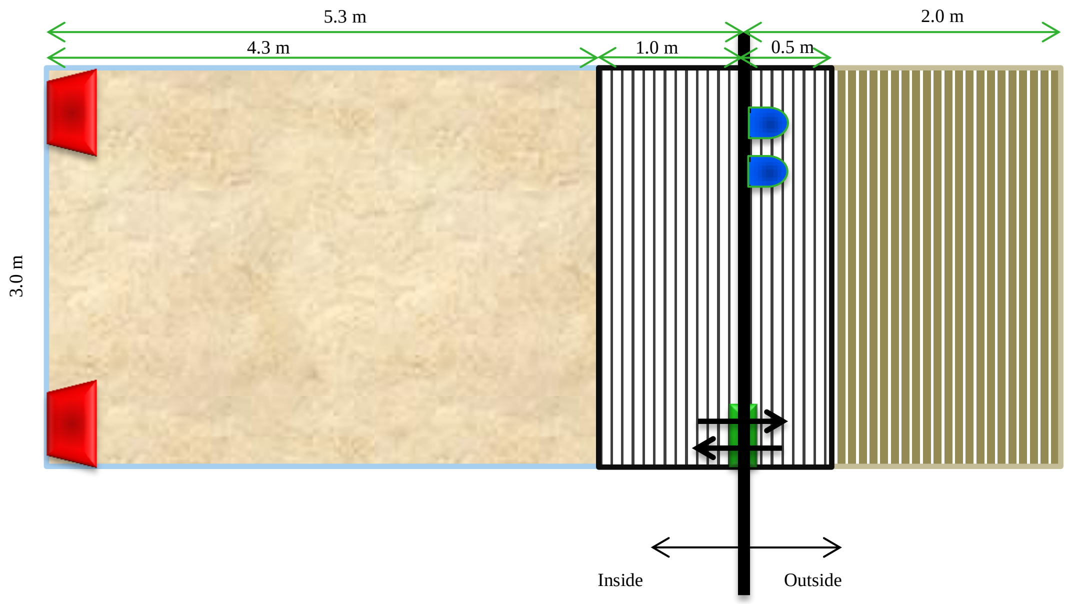

Figure 6. Layout of a pen the Star+ system (see Figure 1 for the symbol list)

Measurements and observations

The following observations were done in the commercial houses:

- The fouled floor area: once a week at 3 different moments during daytime the areas fouled with urine puddles were drawn on a grid drawing by the instructed farmer.
- Once every 6 weeks (in total 4 measuring days) the following samples were taken by a research assistant:
  - Aggregate samples in duplicate of urine puddles on the (solid and slatted) floor. Samples were taken by absorbing urine in glass fibre filters. For each duplicate sample, samples were taken at 10 different locations inside the room. On each sampling locations two filters were sucked up with urine. One filter was added to a pot with 10 ml acid (1% HCl), while the other filter was added to a pot with 10 ml water. The acid in the pot stopped the urease activity, preventing urea to be converted to ammonia during the transport and storage time. Thus we could determine which part

of the urea-N was converted into NH4-N. Within the pot with absorbed urine in water the pH was directly measured at the location. The pots, including filters, were weighed at the lab before and after sampling. In this way the amount of absorbed urine could be calculated. In this urine NH4-N and N-total were analysed. The concentrations were corrected for the amount of water / acid added to the pots. Inside the regular houses the number of urine fouled locations was often less than 20, due to little fouling of the floor. In these cases the maximum possible number of filter samples was taken.

    - Aggregate samples in duplicate of the surface layer of the manure in the pit. With more than one pen per room, samples were taken in 2 pens at 5 different locations in the manure pit per pen, otherwise at 10 locations. Samples were taken in the same way as for the urine puddles, but were only added to a pot with water, because it is expected that in the manure pit all the urea is already converted to ammonium.
- At the same days as the urine/manure sampling the following measurements were done:
    - Surface temperatures of fouled (slatted) floors on at least 10 locations (with the Rayngel ST ProPlus of Raytek, Santa Cruz, VS).
    - Surface temperatures of manure in the pit on at least 10 locations (with the Rayngel ST ProPlus of Raytek, Santa Cruz, VS).
    - Air velocity above urine fouled floor areas (hot wire air velocity sensor, Lambrecht meteo GmbH, Göttingen).

Figure 7. Pictures of the Star+ system. Left: the whole house with the outside yard (right side) covered by a roof and windbreak netting; Right: picture from inside with the passage to the outside yard. Between the outside yard and the inside of the house there is a valve inlet for air.

<u>Measurements Star+ house</u>

Within Star+ the same measurements according to the same procedures as in the commercial pig houses were done with one exception:

- Since the Star + house does not have a slurry storage underneath the slatted floor, but uses a manure belt for manure removal, duplicate samples were taken from urine wet spots on the manure belt. Here, the same procedure was used as for sampling the fouled floors in the commercial houses. In this way, we could determine which part of the urea in the urine on the manure belt had been converted into ammonium.

<u>Data analyses</u>

The measurements inside the commercial pig houses and the Star+ house were used to determine the ammonia emission with the following model (Aarnink & Elzing, 1998):

$$E_{NH3} = \frac{k \times A \times f \times [TAN]}{H} \quad (1)$$

Where:

E_{NH3} = ammonia emission (mole/s)
k = mass transfer coefficient (m/s)
A = area of the ammonia solution (m^2)
f = fraction of non-ionized ammonia in the solution (-)
[TAN] = total ammonia nitrogen concentration in the solution ($mole/m^3$)
H = constant of Henry (-)

The mass transfer coefficient is determined by the air velocity above the emitting surface and by the temperature of the emitting surface. The fraction non-ionized ammonia is determined by the pH and the temperature of the surface of the ammonia solution. The constant of Henry is determined by the surface temperature, as well. All these relationships are described in Aarnink and Elzing (1998). All input variables for these calculations were measured within this study, except for the air velocity above the manure surface in the pit. This was assumed to be 0.05 m/s for all the manure pits in this study, inside as well as outside. At the moment it is not exactly clear what chemical and physical processes take place in the boundary layer of urine puddles and of manure. Therefore we used a relationship between the measured pH in the upper layer of the manure (at approx. 5 mm depth) and the ammonia emission to correct for diet induced pH differences in the layer. Canh et al. (1998) found the following relationship between the pH measured at approx. 5 mm beneath the surface level and the ammonia emission relative to the control diet (with a pH of the upper layer of 9.95): Y = 0.34 X – 2.07 (R^2 = 0.96), where Y is the correction factor and X is the pH of the upper layer of the urine puddle or manure. Emission levels per m^2 emitting area in this study were corrected with this formula, relative to the emission level in a defined reference situation (Mosquera et al., 2011).

Results

In table 1 the mean T/RH of outside air and the mean temperatures of the different emitting areas are given. Furthermore, the air velocities above the emitting areas are given. This table shows that temperatures of the emitting solutions (urine puddles and manure) inside are higher in regular houses than in organic houses and Star+. This can only partly be explained by the higher outside temperatures during the measurements. Relationships between outside and inside temperatures show that in organic pig houses and Star+ the inside temperature is a lot stronger related to the outside temperature than in regular housing.

Table 1. Temperature (T) and relative humidity (RH) of the outside air during the measurements, the temperature of the urine puddles and manure surfaces, and air velocity (v) above fouled floors. (Standard deviations between brackets).

House	T_outside	RH_outside	T_floor_inside	T_manure_inside	T_floor_outside	T_manure_outside	v_floor_inside	v_floor_outside
	(°C)	(%)	(°C)	(°C)	(°C)	(°C)	(m/s)	(m/s)
Regular 1	13.7 (4.4)	73.9 (13.2)	24.3 (2.9)	21.9 (2.2)	n.a.	n.a.	0.09 (0.03)	n.a.
Regular 2	15.9 (10.7)	65.3 (16.4)	27.5 (3.0)	22.9 (4.0)	n.a.	n.a.	0.19 (0.09)	n.a.
Organic 1	11.9 (4.7)	78.4 (14.2)	21.7 (2.0)	15.7 (2.1)	13.8 (4.9)	12.2 (3.9)	0.09 (0.05)	0.25 (0.09)
Organic 2	11.1 (4.9)	72.8 (15.6)	15.7 (4.2)	n.a.	11.6 (5.4)	10.6 (5.9)	0.17 (0.11)	0.22 (0.11)
Star+	10.7 (6.8)	80.2 (9.9)	22.6 (5.1)	14.8 (6.1)	15.5 (6.7)	14.2 (6.7)	0.16 (0.012)	0.24 (0.17)

n.a. = not applicable

In table 2 the mean emitting floor and manure pit areas are given for the different pig houses during the whole period of the study. This table shows that large differences are observed in the emitting floor areas. Mean, with urine, fouled areas (inside + outside) were 0.117, 0.003, 0.248, 0.160, 0.247 m^2/pig for Regular 1, Regular 2, Organic 1, Organic 2 and Star+, respectively.

In table 3 the N-concentrations and the pH of urine puddles and the upper layer of the manure in the pit are given. This table shows that the mean percentage of urea in urine puddles that is converted to NH4-N is pretty comparable between the different houses (varying from 28 – 35%). The mean NH4-N concentration of the urine puddles on the floor varied between the different houses, ranging between 1.2 and 2.3 g/kg, and the mean pH of the urine puddles varied from 8.1 to 8.9, with the lowest values for the regular houses and the highest levels for organic houses. The NH4-N concentration of the upper layer of the manure in the pit did not differ much between regular and organic houses (measured range 3.2 – 4.3 g/kg). The NH4-N concentration in the Star+ house, however, was considerably lower (1.5 g/kg). As is shown in the same table only a part of urea-N was converted to NH4-N on the manure belt (30%). The pH of the upper layer of the manure was higher in organic houses (8.41) than in regular houses (7.96), and was highest in Star+ (8.96). The high pH in Star+ was probably caused by the fact that the urine on the belt was not mixed with the faeces. Faeces have a buffering effect on the pH of urine. The difference between organic and regular houses might have been caused by differences in diet composition.

Table 2. Mean emitting areas (in m^2 per pig) for the floor (slatted and solid) and manure pit, inside and outside the pig house during the course of the whole study in the different pig houses (standard deviation between brackets).

House	Floor_inside	Pit_inside	Floor_outside	Pit_outside
Regular 1	0.117 (0.021)	0.35 (-)	n.a.	n.a.
Regular 2	0.003 (0.001)	0.44 (-)	n.a.	n.a.
Organic 1	0.148 (0.103)	0.24 (-)	0.10 (0.044)	0.85 (-)
Organic 2	0.010 (0.009)	0.00 (-)	0.15 (0.075)	0.32 (-)
Star+	0.097 (0.003)	0.00 (-)	0.15 (0.054)	0.33 (-)

n.a. = not applicable

Table 3. Nitrogen concentrations and pH of (filter) samples from urine puddles and upper layer of manure in the pit (standard deviation between brackets).

	Urine puddles on floor				Upper layer of manure			
House	NH4-N_floor[1])	NH4-N_floor_max[2])	converted_urea_floor[3])	pH_floor	NH4-N_pit	NH4-N_pit_max[4])	converted_urea_belt	pH_pit
	(g/kg)	(g/kg)	(%)	(-)	(g/kg)	(g/kg)	(%)	(-)
Regular 1	1.31 (0.33)	3.90 (1.37)	35.3% (9.3%)	8.16 (0.33)	4.26 (0.62)	n.a.	n.a.	8.11 (0.16)
Regular 2	1.23 (0.48)	3.49 (1.37)	35.3% (-)	8.09 (0.17)	4.29 (0.67)	n.a.	n.a.	7.81 (0.09)
Organic 1	1.43 (0.60)	4.01 (0.80)	35.1% (12.5%)	8.43 (0.38)	3.23 (0.65)	n.a.	n.a.	8.20 (0.14)
Organic 2	2.32 (0.69)	8.22 (2.46)	28.3% (9.1%)	8.95 (0.14)	3.93 (0.31)	n.a.	n.a.	8.61 (0.33)
Star+	1.67 (0.66)	5.39 (0.55)	31.4% (13.4%)	8.58 (0.10)	1.50 (0.28)	5.08 (0.68)	30.3% (10.5%)	8.96 (0.07)

[1]) This value was determined by stopping the urea conversion by putting the 'urine-filters' in acid.
[2]) This value was determined by putting the 'urine-filters' in water, so the urea conversion could proceed until all the urea was converted.
[3]) This is the percentage of NH4-N in the urine puddles on the floor compared with the maximum value when all the urea is converted to ammonia.
[4]) This measurement was only done when using the belt system while it was assumed that in the manure pit all the urea is already converted to ammonia.
n.a. = not applicable

Table 4 shows that the estimated ammonia emission levels of both regular houses were quite comparable (3.29 and 3.47 kg/y per pig place). For Organic 1 the estimated ammonia emission was a bit higher than for the regular houses (3.74 kg/y per pig place), while it was considerably lower for Organic 2 (1.68 kg/y per pig place); for Star+ this was 2.70 kg/y per pig place. In Regular 2 there was almost no floor emission, mainly caused by the low floor fouling and the use of metal slats. In Regular 1 on average 25% emitted from the floor. In the organic houses this was 44 and 58%, while it was approx. 80% in Star+.

Table 4. Calculated ammonia emissions from the floor and from the manure pit, inside and outside the pig house (in kg/y per pig place), based on local measured parameters (standard deviations between brackets).

House	NH3_emission_floor_inside	NH3_emission_pit_inside	NH3_emission_floor_outside	NH3_emission_pit_outside	NH3_emission_inside	NH3_emission_outside	NH3_emission_total	NH3_emisision from floor
Regular 1	0.81 (0.59)	2.48 (0.78)	n.a.	n.a.	3.29 (1.19)	n.a.	3.29 (1.19)	25%
Regular 2	0.06 (0.06)	3.42 (1.74)	n.a.	n.a.	3.47 (1.76)	n.a.	3.47 (1.76)	2%
Organic 1	0.90 (0.87)	0.60 (0.15)	0.73 (0.74)	1.51 (0.78)	1.50 (0.93)	2.23 (1.46)	3.74 (2.31)	44%
Organic 2	0.05 (0.02)	n.a.	0.93 (0.68)	0.70 (0.46)	0.05 (0.02)	1.64 (1.12)	1.68 (1.11)	58%
Star+	1.14 (1.05)	0.00 (0.00)	1.03 (0.89)	0.53 (0.39)	1.14 (1.05)	1.57 (1.20)	2.70 (2.22)	80%

n.a. = not applicable

Conclusions

From this study the following main conclusions can be drawn:

- Despite the larger area for pigs within organic houses, the ammonia emission doesn't need to be higher than in regular houses.
- The emission per m^2 pit area is considerably lower in organic houses compared with regular houses caused by the lower temperatures of the upper layer of the manure.
- The floor emission is generally higher in (organic) houses with outside yard than in regular houses. This is mainly caused by a larger fouled floor area per pig in these pens.
- Determining the ammonia emission in open houses with outside yard by measuring local variables seems to have perspective. For determining absolute emission levels the model needs to be (further) validated. This approach, however, gives good insight in the relative contribution of the different ammonia sources and the relative emission levels of the different housing types. In future work attention should be given to the chemical and physical processes in the upper layer of the manure and of the urine puddles.

References

Aarnink, A.J.A., Elzing, A. 1998. Dynamic model for ammonia volatilization in housing with partially slatted floors, for fattening pigs. *Livest. Prod. Sci. 53: 153-169*.

Canh, T.T., Schrama, J.W., Aarnink, A.J.A., Verstegen, M.W.A., Klooster, C.E.v.t., Heetkamp, M.J.W. 1998. Effect of dietary fermentable fibre from pressed sugar-beet pulp silage on ammonia emission from slurry of growing-finishing pigs. *Animal Science 67: 583-590.*

Mosquera, J., Hol, J.M.G., Winkel, A., Lovink, E., Ogink, N.W.M., Aarnink, A.J.A. 2011. Fijnstofemissie uit stallen: vleesvarkens [Fine dust emission from livestock houses: growing-finishing pigs]. Livestock Research, Report 292, revised version.