

Effects of floor design and floor cleaning on ammonia emission from cubicle houses for dairy cows

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Received 7 October 1996; accepted 19 January 1997

Abstract

To obtain more detailed knowledge of low-emission floor systems for dairy cow houses an experiment was set up in which the traditional slatted floor and two different solid floor systems were compared:

a non-sloped (L) and a 3% one-sided sloped floor (S), both systems combined with a highly frequent (96 times per day) or normal (12 times per day) removal of manure by a scraper. For both the slatted and solid floor systems ammonia emissions were measured continuously over two separate two-week periods. On the solid floors also the development of urease activity was recorded. Urease activity was measured as the accumulation of ammoniacal nitrogen in a urea solution (10 g urea-N l⁻¹) in contact with the floor surface. Activity has been expressed as g NH₃ m⁻² h⁻¹.

The ammonia emission from the compartment with the L12 variant was almost equal to the emission from the compartment with a slatted floor. The S12 variant reduced ammonia emission by 21% compared to the slatted floor. Raising the scraping frequency from 12 to 96 times per day led to a 5 percentage point increase in ammonia emission reduction (L96: 5%; S96: 26%).

During the last testing period, just before removal of the cows, ammonia emission from the compartment with the S12 variant was 30–35 g NH₃ h⁻¹ (10 cows). After removal of the cows this level decreased to 3–17 g NH₃ h⁻¹ (average: 8.7 g NH₃ h⁻¹). This suggested incomplete suppression of ammonia emission from the slurry pit by the solid floor system. Covering the openings through which the slurry collected by the scraper system was dropped in the pit reduced emission to 4–10 g NH₃ h⁻¹ (average: 5.5 g NH₃ h⁻¹). However, covering only decreased ammonia emission when the inside temperature was higher than the outside temperature.

The rate of formation of urease activity differed considerably between the two-week periods, partly due to differences in temperature regime. At and below 10°C average daily temperature almost no formation of urease activity was observed, whereas at about 20°C the formation rate reached values up to about 0.04 g NH₃ m⁻²h⁻². Up to an urease activity of about 2 g NH₃ m⁻²h⁻¹, ammonia emission increased with increasing urease activity. At higher levels of urease activity either the amount of urea on the floor surface or the rate of volatilization of ammonia from a urine puddle or from the slurry pit to the inside air limited the ammonia emission.

Keywords: ammonia emission, cubicle houses, floors, urease activity

Introduction

The Dutch government aims at an ammonia emission reduction in the year 2000 and 2005 of respectively 50% and 70% relative to the year 1980 (Anonymous, 1995a). Total ammonia emission in The Netherlands was 254 kton in 1980. About 224 kton originated from agriculture, specially animal manure (Anonymous, 1995b). In 1986 total ammonia emission was 241 kton of which 86 kton originated from animal housing systems. Dairy cattle houses were the source of 42 kton of ammonia emitted (Oudendag & Wijnands, 1989). Total ammonia emission from agriculture was reduced to 208 kton in 1993, whereas emission from animal housing systems increased to 98 kton (Anonymous, 1995b). Research aims at the development of new animal housing systems which, according to governmental targets, should reduce ammonia emission (De Haan & Ogink, 1994).

For dairy cows, the traditional housing system in The Netherlands is the cubicle house with a slatted floor and a slurry storage underneath the floor. The faeces and urine excreted by the animals are collected in the slurry pit. Urinary nitrogen is the main source of ammonia emission, since ammonia is mainly formed by the breakdown of urea. This reaction is catalyzed by the enzyme urease, produced by bacteria present in the faeces and on surfaces that are frequently fouled with faeces (e.g. floors, Ketelaars & Rap, 1994). In traditional cubicle houses, urea can therefore be converted in ammonia at both the floor (top surface and side faces of the slats) and in the slurry pit. Roughly estimated, 60% of the total ammonia emission from a cubicle house provided with slats originates at the floor surface, whereas the remaining 40% is emitted from the slurry pit (Ogink & Kroodsma, 1996).

Many parameters, such as pH, temperature, urea content of the urine, slurry composition, area wetted with urine, fouling of the floor and air velocity, influence the ammonia emission (Aarnink *et al.*, 1996; Monteny *et al.*, 1996). The air velocity above the surface of slurry in the pit and the air exchange between the pit and the house play a key role in the ammonia emission from the pit. Both can be reduced by covering the slurry pit with a solid floor. In the case of perfect covering of the slurry pit, its contribution to ammonia emission from the building may be eliminated. Faeces and urine from solid floors are removed by a scraper. In case the manure is stored in an underfloor pit, the manure collected by the scraper is dropped into the pit through openings located at the floor ends. Due to these necessary floor openings, ammonia emission reduction is expected to be lower than in the case of perfect covering of the slurry pit, but no further information is present as to which extent.

Further, ammonia emission reduction is expected from fast removal of the urine on the floor. This might be achieved by both sloping the floor top surface and intensive scraping.

Differences in the rate of urea degradation which may arise from different urease activity on the top surface of the floor (Ketelaars & Rap, 1994) may also contribute to variations in ammonia emissions.

Previous experiments with V-shaped solid floors demonstrated an ammonia emission reduction of 50% compared to slatted floors (Swierstra *et al.*, 1995). These floors had a 3% double-sided slope towards a central urine gutter through which

freshly excreted urine is drained to the slurry pit. Knowledge of the exact causes of ammonia emission reductions obtained is incomplete since reductions may be caused partly by a lower ammonia emission from the floor and partly by a decrease of slurry pit emission. An experimental plan was set up to investigate the influence of solid floor slope, scraping frequency and build-up of urease activity at the floor on ammonia emission from the cow house and to investigate the impact of floor openings on slurry pit emission.

Materials and methods

Experimental accommodation and animals

The experiments were performed in an experimental cubicle house which is part of the IMAG-DLO research farm 'De Vijf Roeden'. A detailed description of this facility and its operation has been given by Ogink & Kroodsmma (1996) and Swierstra *et al.* (1995). Briefly, the cubicle house consists of three identical compartments each housing 10 non-lactating cows of the Holstein-Friesian breed. For the experiments reported here only two compartments were used, one having a slatted floor and serving as a reference (ref), the other (exp) having alternately two different solid floor systems, consisting of a solid floor covering the slurry pit.

The reference floor was made of 3 m long and 1.1 m wide slatted concrete elements. The slats were 120 mm wide and separated by 37 mm wide gaps. The solid floor consisted of 3 m long and 1 m wide concrete elements finished by a steel float trowel. Joints between the elements were filled with a plastic component. Three bolts were cast in at each of the two supported sides of the elements. By turning the bolts, the elements could be accurately placed in the required position, enabling both a slope of 0% (leveled) and a one-sided slope of 3% (3 m span). In case of a slope the urine was drained towards a recess near the cubicles in which a steel urine gutter was situated. The urine and faeces were removed by a 3 m wide slurry scraper with a rubber strip. At both floor ends the slurry was dropped in the pit through openings as wide as the span of the floor (3 m) and 0.25 m in length. The scraper also cleaned the urine gutter.

The slurry pit was situated underneath the passage area of 34.5 m². The slurry in the pit was mixed for half an hour two times per day, at 01:00 and 13:00 h. Slurry was sampled after mixing four times per experimental period and the contents of pH, dry matter (DM), total-N (N) and ammonia-N were determined in duplicate. Slurry height was 0.4 m at each start of a new period. Between start and end of each experimental period, slurry level increased only 10 centimeters due to addition of fresh slurry produced. For the purpose of another experiment ran simultaneously in the third compartment, slurry had to be changed two times during the experiment. As a result mean contents of DM, N and ammonia-N were higher during the first three periods (81, 4.8 and 2.6 g kg⁻¹) compared to the remaining periods (63, 3.8, 2.1 g kg⁻¹); pH (on average 7.9) was not affected.

Cows were given 30 kg cow⁻¹ day⁻¹ from a mixed ration of grass silage, beet pulp

and concentrates. Feed was sampled once a week and analyzed in duplicate. DM content in samples varied between 260 and 311 g kg⁻¹, N content between 22.5 and 26.9 g kg⁻¹ DM, and potassium (K) content between 13.4 and 19.7 g kg⁻¹ DM.

Experimental design

The experiment lasted 16 weeks in which the two solid floor systems were tested twice during separate two-week periods (a, b). Systems were coded with L (leveled floor) or S (sloped floor) followed by the number 12 or 96 indicating the scraping frequency. The order in which systems were tested was: L12a, L96a, S12a, S96a, L96b, L12b, S96b, S12b. For practical reasons (reduction of the number of times the floor slope had to be adjusted) L and S variants were tested in 4-week periods alternately. The experiment started March 14th 1995 and ended July 4th 1995.

At the start of each period urease activity on the floor surface of the experimental compartment was removed by cleaning with a high pressure hose, followed by rinsing with 2 N hydrochloric acid (1.4 l m⁻²), and cleaning once more with the high pressure hose after 30 minutes. Absence of urease activity was then checked.

At the end of the experiment animals were removed but ammonia emission was measured for another 13 days (till July 17th) to investigate whether ammonia emission still occurred. During three full days of this period (July 10, 12 and 13th) an attempt was made to eliminate the contribution of the slurry pit by completely covering all floor openings.

Ammonia emission

Each compartment in the cubicle house was mechanically ventilated, enabling easy sampling of the exhaust air in the ventilation shafts. Air samples were taken about ten times per hour and led to an ammonia converter outside the compartment. In the converter, the NH₃ in the air was oxidized to NO and the air was led to a NO_x analyser that measured the concentration of NO. Outside the house at a distance of about 50 m the ammonia concentration was also recorded, defining the concentration of the incoming air. Anemometers situated in the ventilation shafts recorded air flow. As for the ammonia concentration, ventilation data were stored about ten times per hour. By multiplication of the amount of outgoing air by the difference between the ammonia concentration in the outgoing and the incoming air, ammonia emission was calculated per compartment. The measuring system and its functioning are described in detail by Scholtens (1990).

Temperature

The temperature was measured by sensors both inside and outside the compartments. Inside, the measuring device was situated near the feeding fence, about 2 m above floor level. The outside temperature measurements took place at the same location as the ammonia concentration measurements, viz. 50 m from the experimental house at the outer wall of another building.

Urease activity

Urease activity on the floor was measured by incubating 50 ml of a urea solution (10 g urea-N l⁻¹) in PVC cylinders (diameter 83 mm) on top of the floor. Cylinders had been cast in concrete and provided with rubber rings to prevent leakage of the urea solution. After stirring the urea solution in the cylinders, samples were taken at t = 0 min, to correct for ammonium and ammonia already present on the floor. After 30 min. another sample was taken to measure ammoniacal nitrogen formation. Samples taken at t = 0 and t = 30 min were conserved by acidification with hydrochloric acid. Ammoniacal nitrogen was measured spectrophotometrically. Each time, urease activity was measured in 32 cylinders evenly distributed over two floor elements. Another 8 cylinders were filled with demineralised water to measure ammonium formation from the natural supply of nitrogenous compounds on the floor. Urease activity was measured at day 1, 2, 4, 8 and 11. At day 1 measurements were performed before and immediately after cleaning the floor with hydrochloric acid. From these data urease activities for days that no measurements were made were estimated by linear interpolation. With exception of day 1, measurements were performed after passage of the manure scraper. Urease activity was calculated from total ammoniacal nitrogen accumulation in the urea cylinders in 30 minutes and has been expressed as g NH₃ m⁻²h⁻¹.

Actual urease activity depended on the amount of enzyme and the temperature of the urea solution. The temperature of the urea solutions used equaled ambient indoor temperature. The original data were used to establish a relationship between urease activity and ammonia emission. To allow meaningful comparisons of enzyme accumulation actual measurements of activity were corrected to a standard temperature of 15°C. Temperature correction was derived from a separate experiment carried out in a cubicle house with an epoxy coated concrete floor. Urease activity on the floor was measured on eight fixed locations, first at a floor temperature of 19°C, after cooling the floor with water at a temperature of 11°C, and again after reequilibration at the ambient temperature of 19°C. Activity at 19°C appeared to be twice as high as at 11°C. From this information temperature dependency was estimated according to the Arrhenius equation (Avery, 1974) as:

$$ua_{(T=15^{\circ}\text{C})} = ua_{(T)} \cdot e^{-7091 / (15 + 273)} / e^{-7091 / (T + 273)} \quad (1)$$

ua = urease activity in g NH₃ m⁻² h⁻¹,
T = temperature of the urea solution in °C.

Statistical analyses

In most experimental periods, from the beginning the ammonia emission from the experimental compartment showed an increase after the preceding removal of urease activity. The ratio between mean daily ammonia emissions from the experimental compartment (exp; solid floor) and the reference compartment (ref; slatted floor) was described by an exponential curve for each experimental period separately:

$$E_{\text{exp}} / E_{\text{ref}} = a + b \cdot r^t \tag{2}$$

E_i = daily mean ammonia emission from compartment (i = exp, ref),
 t = day number (t = 1...14) within a period.

Parameter a is the constant level, whereas $b \cdot r^t$ ($r < 1$) describes the gradual course towards this level a. Parameters a, b and r were calculated by regression analysis. Emission data from the first day of each period were omitted because change-over related activities within this day disturbed the normal emission pattern during this day. In the case that curve (2) resulted in a ratio of at least 0.90a at the ninth day of a period, the results of day 9–14 were used to calculate ammonia emission reduction. In case a constant ratio was attained within a few days, curve (2) could not be used to describe the course of the ratio. Also then, ammonia emission results from day 9–14 of the testing period were used in the further analysis. In this analysis, variation in the ratio was explained by the following model:

$$\log (E_{\text{exp}} / E_{\text{ref}})(t) = c + h_{L,S}(t) + s_{12,96}(t) + v(t) \tag{3}$$

E_i = daily mean ammonia emission from compartment (i = exp, ref),
 c = the expected reduction in case of a non-sloped floor (L) and a scraping frequency of 12 times per day (12),
 $h_{L,S}(t)$ = the effect of a 3% slope (S) relative to 0% slope (L) at day t,
 $s_{12,96}(t)$ = the effect of a scraping frequency of 96 times per day (96) relative to 12 times per day (12) at day t,
 $v(t)$ = the stochastic contribution at day t,
 t = day number (t = 1...112) in experiment.

The relationship between the successive error components was described by a first order autoregressive model (Box & Jenkins, 1976):

$$v(t) = b \cdot v(t-1) + a(t) \tag{4}$$

b = autoregression coefficient,
 a(t) = independently distributed errors with mean zero.

The results of the first 8 days of each two-week testing period were not included in the analysis. Five ratio's were missing due to technical problems with either the measuring devices (three days) or the scraper in the experimental compartment (two subsequent days in L96a). The emission on the last day of S12a was not included because an exceptional peak in emission reduction was observed.

To describe ammonia emission from the floor and the slurry pit of the experimental compartment with the solid floor systems as a function of urease activity, exponential curves were fitted to the combined data sets of both replicates of each floor system:

$$E_{\text{exp}} = f (1 - e^{-k \cdot u^a}) + p \tag{5}$$

E_{exp} = daily mean ammonia emission from experimental compartment in $\text{g NH}_3 \text{ h}^{-1}$,

ua = urease activity in $\text{g NH}_3 \text{ m}^{-2} \text{ h}^{-1}$,
 f, k, p = regression constant.

The estimate of p in this model represents ammonia which does not originate from the floor as it is assumed that without urease activity no ammonia will be generated on the floor. Emission from sources like the slurry pit and lying area of the animals may contribute to p. The estimate of f is the contribution of the floor to total ammonia emission when urease activity no longer limits ammonia emission from the floor surface.

Results

Ammonia emission and ammonia emission reduction

Figure 1a presents the daily mean ammonia emission from the experimental and the reference compartment and the daily mean temperature in the experimental compartment. The temperature in the reference compartment was almost identical.

The ratio between ammonia emissions from both compartments could be described with Equation 2 for each of the variants L12a, L96a, S96a, L96b and L12b separately. In periods S12a, S96b and S12b the ratio could not be described with Equation 2 since already after a few days no systematic increase of the ratio was observed. However, ammonia emission results of day 9–14 were fairly constant and could be used in the statistical analysis. At the end of L12a the ratio between ammonia emissions from both compartments still tended to increase. Therefore, the results of this period were not used in the calculation of ammonia emission reduction.

Figure 1b presents the actual daily reduction in ammonia emission from the experimental compartment compared to the reference compartment. The calculated reductions (100% minus proportion according to (2), or minus average proportion during day 9–14) are also presented.

Table 1 shows the parameter estimates for Equation 3. The corresponding percentage of ammonia emission reduction (relative to the reference compartment) is presented in Table 2. The leveled floor with a scraping frequency of 12 times per day did not result in a significant ammonia emission reduction compared with the slatted floor. Reduction increased to 5% as the scraping frequency was raised to 96 times per day. For the sloped solid floor reductions were 21% and 26% at respectively normal and highly frequent scraping.

Table 1. Estimation of parameters used in Equation 3. c = the expected reduction in case of a non-sloped floor and a scraping frequency of 12 times per day; h = the effect of a 3% slope relative to 0% slope; s = the effect of a scraping frequency of 96 times per day relative to 12 times per day.

Model parameter	Estimated value (s.e.)
c	0.002 (0.02)
h	-0.24 (0.02)
s	-0.06 (0.02)

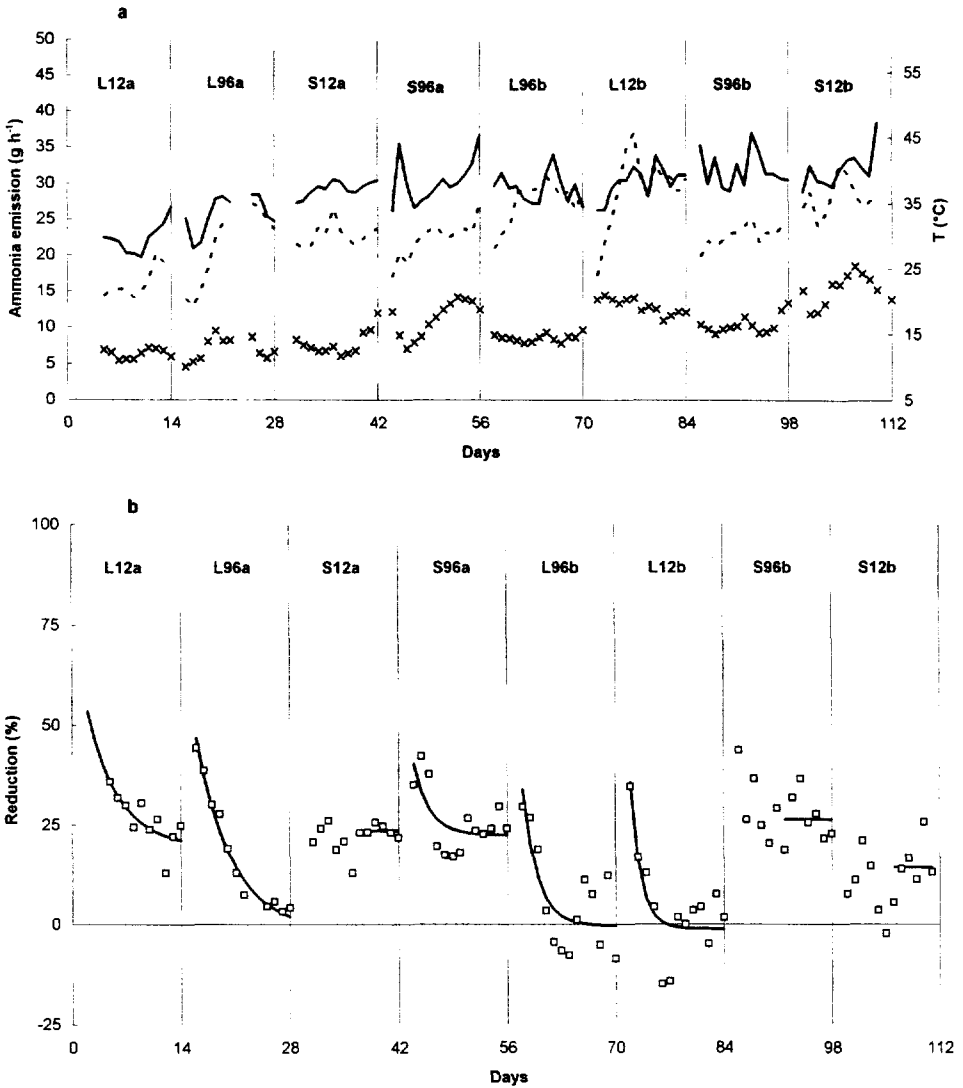


Figure 1a,b. Daily mean ammonia emission from the experimental (-----) and the reference compartment (—) and the daily mean temperature in the experimental compartment (x) (a) and actual daily reduction in ammonia emission from the experimental compartment compared to the reference compartment (□) and the calculated reduction (100% minus proportion according to (1), or minus average proportion at day 9–14) (—) (b).

Urease activity

Increase of urease activity on the solid floor systems is given in Figure 2a and b. Urease activity values at the start of each period (i.e. immediately after cleaning the

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Table 2. Model (3) estimates on arithmetic scale of ammonia emission reduction due to solid floor based systems (relative to compartment with slatted floor).

Slope (%)	Scraping frequency (day ⁻¹)	Emission reduction (%)
0	12	0
0	96	5
3	12	21
3	96	26

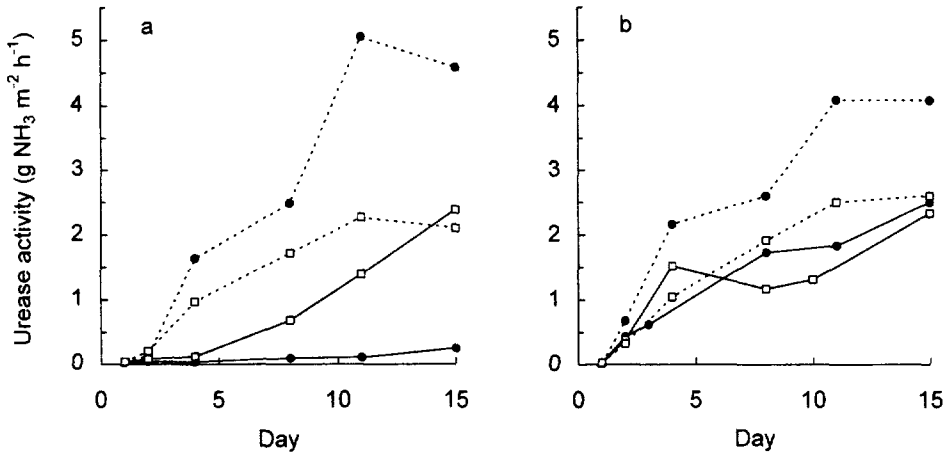


Figure 2a,b. Temperature standardized development of urease activity on the level solid floor (a) and on the solid floor with a 3% one-sided slope (b) with frequent (96 times per day, □) or normal (12 times per day, ●) manure removal (—= period a, ----- = period b). Individual data are mean values of 32 measurements corrected to a standard temperature of 15 °C.

floor with hydrochloric acid) were very low (between 0.02 and 0.04 g NH₃ m⁻² h⁻¹ at 15 °C) indicating successful removal of enzyme activity.

The relation between the temperature regime and the rate of urease activity build-up is presented in Figure 3. The increase of urease activity between two measurements was divided by the duration of the time interval (resp. 24, 48, 96 and 72 hours in Figure 3) and related to the average indoor air temperature during the same time interval.

Urease activity and ammonia emission

Only data from the level solid floor systems could be used to obtain reliable estimates for the parameter *p* in the model relating ammonia emission to urease activity (Equation 5, see Figure 4). For the sloped floor systems observations at low activity were not available as activity on day 2 already amounted several hundreds mg NH₃ m⁻² h⁻¹. For the leveled solid floor a value for *p* of 12.1 g NH₃ h⁻¹ was found with frequent scraping and a value of 13.9 g NH₃ h⁻¹ at normal scraping frequency. As these estimates were not significantly different from the mean of these two values, the

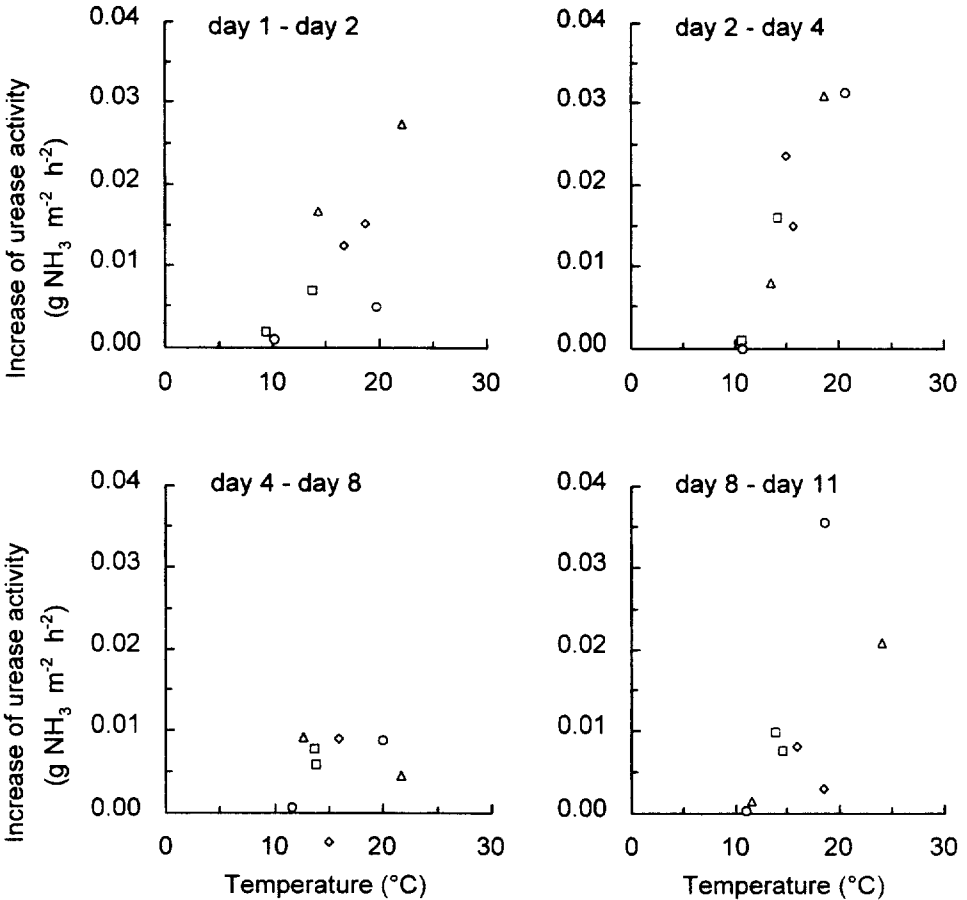


Figure 3. Increase of urease activity as a function of the average indoor temperature between subsequent measurements (○ = L12 variant, □ = L96 variant, △ = S12 variant, ◇ = S96 variant). Increase in activity was calculated from measurements corrected to a standard temperature of 15°C.

mean value (13 g NH₃ h⁻¹) was used to fit curves to the data of all (sloped as well as non-sloped) experimental solid floor systems. This yielded the estimates with s.e. as presented in Table 3. Since the total ammonia emission is the sum of parameters f

Table 3. Estimation of parameters, including s.e., for the model according to Equation 5 based on p = 13 g NH₃ h⁻¹.

System	f (g NH ₃ h ⁻¹)	k (m ² h (g NH ₃) ⁻¹)
Leveled solid floor with frequent scraping	15.5 (0.7)	1.95 (0.38)
Leveled solid floor with normal scraping	17.9 (1.1)	1.09 (0.40)
Sloped floor with frequent scraping	10.9 (0.5)	1.32 (0.28)
Sloped floor with normal scraping	15.2 (0.8)	0.80 (0.13)

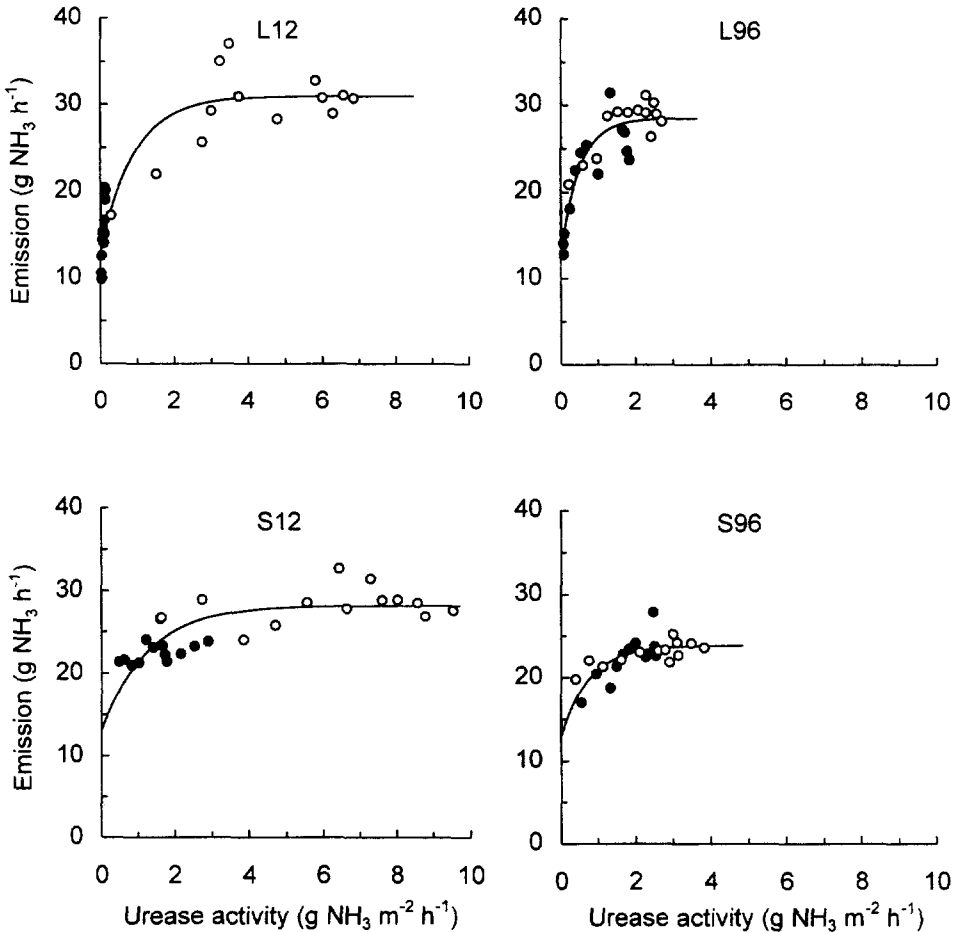


Figure 4. Relation between urease activity of the floor and average daily ammonia emission for four different solid floor systems (● = period a, ○ = period b).

and p, total ammonia emission was estimated at 29 and 31 g NH₃ h⁻¹ for the leveled solid floor and 24 and 28 g NH₃ h⁻¹ for the 3% one-sided sloped floor with frequent and normal manure removal, respectively.

Ammonia emission in the absence of animals

Figure 5 shows the daily course of ammonia emission, ventilation rate, inside temperature and the difference between inside and outside temperature in the absence of animals indoors. The average ammonia emission during this period varied between 3 and 17 (average: 8.7) g NH₃ h⁻¹. Figure 6 presents ammonia emission from Figure 5 in relation to the difference between the inside and outside temperature as well as the results when additionally the openings of the slurry pit were covered. During the lat-

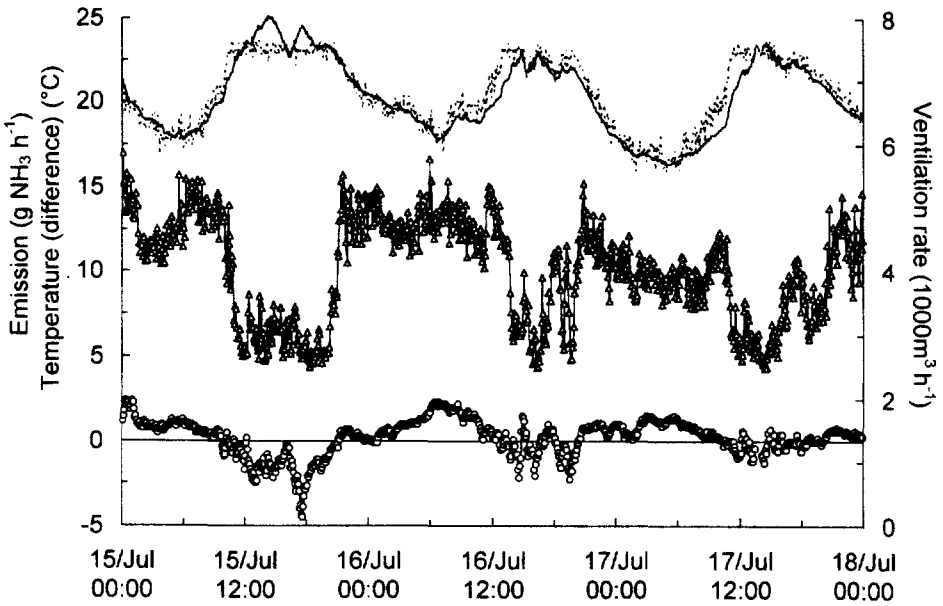


Figure 5. Course of ammonia emission ($-\Delta-$), ventilation rate (\cdots), inside temperature ($—$), and the difference between inside and outside temperature ($-\circ-$) in the absence of animals indoors; data from the period 15–17 July 1995, solid floor system with a 3% one-sided slope.

ter situation, average ammonia emission decreased to 4–10 g NH₃ h⁻¹ (average: 5.5 g NH₃ h⁻¹).

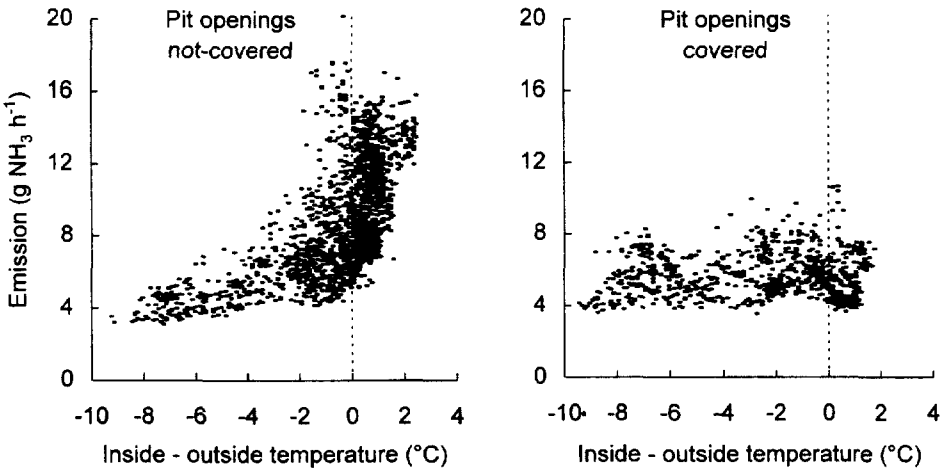


Figure 6. Ammonia emission in the absence of animals indoors in relation to the difference between inside and outside temperature, with slurry pit openings not-covered or covered; data from the period 9–17 July 1995, solid floor system with a 3% one-sided slope. Points are individual measurements taken with six minutes intervals.

Discussion

Ammonia emission and ammonia emission reductions

Statistical analyses demonstrated that the slope of the floor (0% or 3%) had more impact on ammonia emission reduction than the scraping frequency (12 or 96 times per day).

Ammonia emission from a floor increases as the thickness of a urine puddle and the floor area fouled by a urination increase (Aarnink *et al.* 1996; Monteny *et al.*, 1996). Sloping a floor might reduce the thickness of a urine puddle and as a consequence, reduce ammonia emission. However, due to the draining of the urine to a urine gutter, sloping a floor also increases the floor area fouled by a urination. The reduction of the thickness of a urine puddle had more impact than the increase of the surface area wetted by a urination since sloping the solid floor led to a 21 percentage point increase of ammonia emission reduction.

A scraper not only removes urine and faeces, thus enabling better draining of the urine, but also spreads urine over an area larger than the initial puddle. Frequent scraping thus influences ammonia emission reduction both somewhat positively and negatively. In these experiments the positive effect apparently dominated, since increasing the scraping frequency from 12 to 96 times per day increased ammonia emission reduction by 5 percentage point.

Compared to the $\pm 50\%$ reduction found in case of solid floors sloped towards the middle of the span (Swierstra *et al.*, 1995), relatively low reductions (S12: 21%; S96: 26%) were found in this experiment. This could be caused partly by the relatively large distance from a urination to the urine gutter, which is twice as large for the one-sided sloped floor.

Urease activity

Fresh faeces and urine normally do not contain much ammonia. Any ammonia which is emitted from a cubicle house must be produced from degradation of nitrogenous compounds by microbial enzyme activity. Enzyme activity developed on the floor surface over a period of days or weeks as a result of regular fouling with urine and faeces. This source of urease activity is proposed to be incorporated in a mineral salt deposit of urinary and faecal origin. These salts probably precipitate due to the increase in pH following urea degradation, resembling the formation of urease stones after bacterial infections of the urinary tract (McLean *et al.*, 1988). Dilute acid is an effective means to reduce urease activity which may be the result of removal of the 'urease stone' layer on the floor as demonstrated by the data in Figure 2.

Between periods large differences in rate of increase of urease activity were observed. As a consequence, final levels reached at the end of each period differed considerably. For instance, final urease activity for the leveled solid floor with normal manure removal amounted to only $0.25 \text{ g NH}_3 \text{ m}^{-2} \text{ h}^{-1}$ at the end of period L12a, whereas it reached a value of $4.58 \text{ g NH}_3 \text{ m}^{-2} \text{ h}^{-1}$ in period L96a.

Below 10°C enzyme activity did not seem to change; above 10°C rate of build-up

increased to maximal values of $0.04 \text{ g NH}_3 \text{ m}^{-2} \text{ h}^{-2}$ (see Figure 3), equivalent to a daily increase of $0.96 \text{ g NH}_3 \text{ m}^{-2} \text{ h}^{-1}$.

Differences between periods obscured any true differences in rate of build-up due to the floor system used. Data from most periods suggest that without repeated cleaning with acid, irrespective of the floor system, levels of urease activity ultimately would have exceeded $2 \text{ g NH}_3 \text{ m}^{-2} \text{ h}^{-1}$ (at a standard temperature of 15°C).

Urease activity and ammonia emission

Irrespective of the presence of a slope or the frequency of manure removal from the solid concrete floor most systems tested in this experiment build up urease activity to such an extent (i.e. $> 2 \text{ g NH}_3 \text{ m}^{-2} \text{ h}^{-1}$) that the rate of urea degradation no longer limited ammonia emission. Therefore, without measures taken to control urease activity, either the urea availability on the floor surface or the rate of ammonia volatilization at the boundary between the inside air and the urine puddle or slurry will determine the contribution of the tested solid floor to total ammonia emission. For the sloped floors the estimate of the contribution of the floor (the parameter f in Equation 5) roughly corresponded to estimates of the total amount of urinary urea which is retained on the floor (data to be published elsewhere), hence to urea availability. On the leveled floor emission was much lower than the estimated ammonia formation from retained urinary urea, indicating that volatilization was the limiting factor in ammonia emission.

Sources of ammonia emission

With the solid floor systems, urease activity at day 2 of L12a corresponded to a potential production rate of ammonia of $1\text{--}2 \text{ g NH}_3 \text{ h}^{-1}$ taking into account a floor surface of 34.5 m^2 . Actual ammonia emission rate on this day was $10\text{--}14 \text{ g NH}_3 \text{ h}^{-1}$. This difference indicates that apart from urea on the floor surface other sources or sites of ammonia production and emission must have existed. The slurry pit was probably one of these sites as covering of the pit openings showed a lower emission (Figure 6). Figure 6 further suggests that temperature differences are the driving force for the ammonia emission contribution of the slurry pit. In Figure 6 the temperature difference is inside minus outside temperature. In case of not-covered floor openings ammonia emission was highest when the temperature difference was positive and dropped sharply when the difference became negative. Probably, the exchange of air between pit and house caused by the relatively cold incoming air that entered the slurry pit forced emission of ammonia formed in the pit. The increase of ammonia emission at a positive temperature difference was not found when the openings of the pit were covered. The coverings prevented the relatively cold air from entering the pit and thus might have decreased air exchange and ammonia emission.

It must be noted that in this trial the effects of covering were observed under the rather extreme conditions of a hot summer in the absence of animals. The contribution of the slurry pit under more representative conditions remains to be investigated.

ed. The same holds for other sources and sites of ammonia emission, like the lying area.

Conclusions

From the results of this experiment it is concluded that for cubicle houses solid floors without a slope may not result in a lower ammonia emission than slatted floors. Even with a one-sided sloped solid floor ammonia emission reduction may be less than 25% compared to a slatted floor.

In the design of a sloped floor attention must be paid to parameters affecting the spread of urine on the floor surface (layer thickness and area wetted) to reduce ammonia emission. The distance from a urination to a urine gutter and the cleanness of the floor are two of these parameters.

Ammonia emission from the slurry pit is not eliminated by covering the pit with a solid floor provided with openings to drop the manure collected by a scraper.

Slurry pit construction, floor cleaning including control of urease activity and other unidentified factors may be critical to obtain a desired ammonia emission reduction of 50% or higher. Pit construction should minimize air exchange between pit and house. With regard to floor cleaning spraying or flushing with water or dilute acid might be promising measures.

To allow the effective design of low-ammonia emission solid floor systems more information is required on actual sites, sources and processes of ammonia production and volatilization.

Acknowledgements

Financial support was obtained from the Dutch Cement and Ready-mix Concrete industry (VNC, SPOB), the Ministry of Economic Affairs, FOMA ('Financierings-overleg Mest- en Ammoniakonderzoek') and the Ministry of Agriculture, Nature Management and Fisheries.

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