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INVESTIGATIONS OF FACTORS AFFECTING AIR POLLUTANTS IN ANIMAL HOUSES*

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Abstract: Investigations of the mass balance of dust in houses for pigs and chickens have shown that the generation of dust is related to the number and weight of animals, but is also affected by the activity in the buildings. Ventilation rate has a limited effect on the concentration of dust due to the importance of settling of the dust on different surfaces inside the buildings. Dust reducing measures such as electrostatic air cleaning, removal of dust with vacuum cleaners and ionization of the air have not realized any considerable reduction of the dust concentration. Automatic spraying of small droplets of water with two types of spraying nozzles has reduced the dust concentration. Spraying with a mixture of rape seed oil and water has also been effective with manual spraying as well as with an automatic spraying system. Investigations of ammonia in animal houses have shown that air leakage, location of air inlets and outlets, stocking rate of the animals, air flow rate and time intervals between manuring will affect the release and concentration of ammonia. Tracer gas measurements carried out in a calf stable have indicated that the location of a concentrated source of a pollutant but also the function and location of air inlets and outlets have strong influence on the spreading and concentration of pollutants in the air.

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INTRODUCTION

The presence of air pollutants in animal houses may create health problems among workers as well as depressed health status of the animals. For example, acute respiratory illness has been reported as common among swine confinement workers [6, 7, 29]. Frequent symptoms are cough, phlegm and sputum, itchy throat, runny nose, etc. Since measures to reduce the contamination of air in animal houses are urgent, there is a need to improve our knowledge of how different parameters affect the release and concentration of air pollutants in the buildings. An important objective for the climatization research at the Department of Agricultural Biosystems and Technology (JBT) has been to investigate in which ways different parameters affect the mass balance of different air pollutants in animal houses. The highest concentrations of air pollutants, such as dust and ammonia normally occur in buildings for pigs and poultry. For this reason, this report will mainly discuss pollutants in buildings for these animals. The report will deal only with technical and physical aspects of the release of the following air pollutants: dust, ammonia, hydrogen sulphide and carbon dioxide.

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Knowledge is also still poor about how ventilation technique affects the spreading and concentration of contagious matters which can be released and concentrated in (a) specific place(s) in a house. Therefore, one objective has been to simulate the concentrated release of a contagious matter with tracer gas technique and then determine how the concentration at different locations in a building is affected by the location of the source of the pollutant, and also by air inlets, air outlets, ventilation rate and mixing properties of the air.

Dust

Sizes of dust particles. An investigation of the number of dust particles of different sizes [21] in a building for growing finishing pigs have shown that about 20% of the total mass of dust is less than 5 μm in size. However, it should be noted that 90% of particles greater than 0.5 μm can be respired.

The role of activity. Several investigations [11, 15, 21, 22, 30] have shown that the activity in animal houses has a strong influence on the concentration of dust in the air. The concentration normally increases during periods when the activity is high, such as during feeding, weighing and transportation of animals.

It should further be mentioned that an international survey about air pollutants in buildings for laying hens [17] has shown large differences in dust concentrations between cage systems and different alternative housing systems. The concentration of dust is generally higher in alternative systems, probably due to increased activity [17].

Origin of dust. Nilsson [21] has shown that the type of foodstuff (dry or wet) had limited influence on the daily averages of total dust concentrations in buildings for growing-finishing pigs. Consequently, a considerable proportion of the dust seems to derive from the pigs themselves. However, in both cases (dry and wet foodstuffs), the dust concentrations increased during the feeding time due to increased activity. The influence of feeding technique on the activity of pigs may have an indirect effect on the dust concentration. Robertson [24] has shown significantly higher dust concentrations at restrictive feeding compared with *ad libitum* feeding.

Measures against dust. Danish investigations with ionization in pig houses [20] have resulted in a 20–30% decline in dust concentration.

It has earlier been proved [27] that the spraying of mixtures of oil and water in pig houses reduced dust concentration by 75–80%. However, it has not been verified whether the reduction of dust is due to less generation of dust from the pigs' skin surfaces or if the oil functions as a dust binding agent on different building surfaces.

Ammonia

Factors affecting the generation and concentration of ammonia. Ammonia is produced by decomposition of nitrogenous compounds in the manure. The release of ammonia is affected by several factors. The most important factors are [1, 2, 4, 8, 11, 14]:

- number and size of the animals;
- sizes of surfaces where faeces and urine are exposed;
- storage time of faeces and urine inside the buildings;
- ventilation rate;
- air movements around manure surfaces;
- ventilation techniques;
- air leakages through the manuring system;
- air and manure temperature;
- pH value of the manure;
- moisture content of the manure;
- carbon/nitrogen-ratio (C/N) of the manure;
- composition of the foodstuffs.

The role of sizes of exposed surfaces. The release of ammonia increases with increasing sizes of those surfaces that are covered by faeces and urine [2, 10]. Building planning that minimizes exposed surfaces may therefore be one way to abate ammonia release [28].

Manure handling. An international survey of air pollutants in buildings for laying hens [17] showed a wide range of concentrations (from 1 to 84 ppm) depending on the type of manure handling used. This survey indicated that the type of manure handling is the decisive factor for the release and concentration of ammonia. The lowest values for ammonia release have been found in systems using conveyors for manure removal and in particular in systems where manure is dried on the conveyors. Systems with bedding and deep pit manure storages gave the highest values in this survey.

Investigations of deep litter for cattle and pigs [18] have also verified that the release of ammonia increases when the amount of faeces and urine increases in the litter. These investigations also showed that the release of ammonia is considerably higher when deep litter is used compared with manure handling systems where the manure is removed regularly.

Airflow rates and air movements. Several investigations at JBT [2, 11] have proved that the release of ammonia will increase with increasing airflow rate. The reasons for this are:

- Pressure difference between ammonia in the manure and in the air increases, which enhances the force to evaporate ammonia from the manure.
- If air velocities increase around exposed surfaces with faeces and urine, then the mass transfer coefficient for ammonia from the surfaces will also increase.

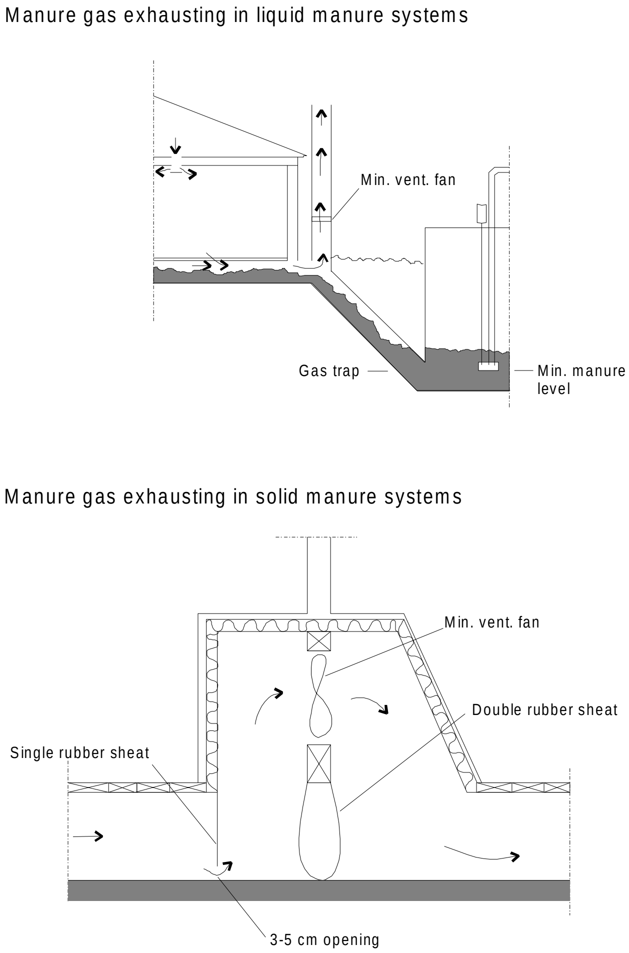

Figure 1. Methods of preventing gas leakage into the building when manure is handled in the liquid or solid state.

Temperature and pH-value of the manure. Several investigations have proved that increased air temperature increases the release of ammonia [1, 2, 3, 16]. Air temperatures above the animals lower temperature demand should therefore be avoided in the buildings.

Increasing pH- value of the manure also increases the release of ammonia [1, 8, 16, 19]. Investigations by Karlsson and Jeppsson [18] have also indicated that the use of peat in straw beddings can reduce the release of ammonia due to decreased pH-value of the manure.

Moisture content and C/N- ratio of the manure. The release of ammonia from strawbeddings for poultry is affected by the moisture content of the bedding [4]. The release decreases at decreasing moisture content. Investigations with chickens kept on litter have shown that the release of ammonia can be held on a low level if the moisture content of the litter is reduced with a floor heating system [11]. Field investigations reported by von Wachenfelt [31] have also shown that the release of ammonia in production of chickens in Sweden has decreased due to the use of improved water nipples with a low spillage of water into the litter.

The C/N- ratio of manure will also influence the release of ammonia from straw-rich manure. The C/N- ratio in straw-beddings should be higher than 30 for keeping the release of ammonia on a low level [9].

Other pollutants

Hydrogen sulfide is mainly produced in liquid manure at anaerobic conditions. This gas is not released continuously but mainly when the manure is agitated. High concentrations can occur when liquid manure is stirred or flushed out [26]. The gas can also be released by air leakages from outside manure storages and by high air velocities in manure channels [25]. The presence of hydrogen sulfide in animal houses is therefore mostly a question of management. It is recommended that there should be a gas trap between the building and storages located outside, see Figure 1. It is also recommended that the building should be ventilated at the highest possible capacity when the manure is flushed out.

The concentration of carbon dioxide in the outside atmosphere is approximately 340 ppm. This gas is present at elevated levels in all animal houses. Resulting from metabolic processes, most carbon dioxide is released via respiration. The amount of carbon dioxide released is related to the metabolic level of the animals. The concentration of carbon dioxide in animal houses provides information about the ventilation rate in relation to the metabolic processes of the animals [23] and thereby also some indication of the general hygienic quality of the air. It is recommended keeping the concentration of carbon dioxide below 3000 ppm [5].

MATERIALS AND METHODS

Most of the investigations presented here have been carried out in three research buildings at the Alnarp Södergård research station. One of the buildings is equipped as a climate chamber which provides the opportunity to control and simulate the outside climate, inside climate, ventilation rate, as well as the design and location of air inlets and outlets. The efficiency of different treatments to abate air pollutants have been investigated by analysing measurements at steady state conditions in the following mass balance equation for air pollutants:

$$m = q \times (C_e - C_o) + S + F$$

m – generation of an air pollutant, mg/h
q – ventilation rate, m^3/h
C_e – concentration in the exhaust air, mg/m^3
C_o – concentration in the outside air, mg/m^3
S – removal of an air pollutant by physical reactions in the air, mg/h
F – amount of an air pollutant removed by air cleaning devices, mg/h

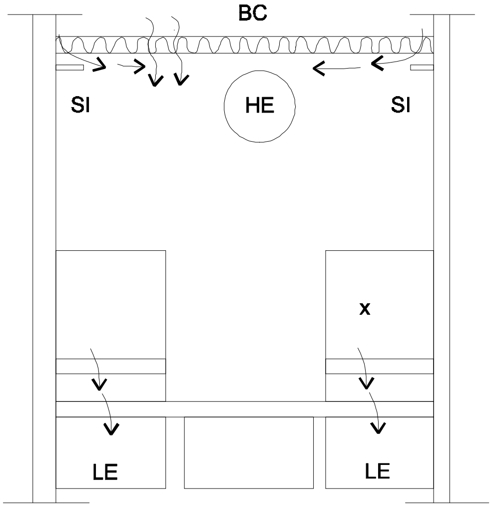

Figure 2. Design of the calf stable where tracer gas measurements took place. HE – high exhaustion; LE – low exhaustion; BC – breathing ceiling; SI – slotted inlet; x – measuring place.

Table 1. Combinations of air inlets and air outlets which have been investigated.

No.	Air inlet	Air outlet
1	Slotted inlet at ceiling	At ceiling (high exhaustion)
2	Slotted inlet at ceiling	Through manure channel (low exhaustion)
3	Breathing ceiling	At ceiling (high exhaustion)
4	Breathing ceiling	Through manure channel (low exhaustion)

Measurements and analysis

Dust. The effectiveness of different treatments has been analysed by:

- gravimetic measurements of the amount of total dust (mg/m^3) with 37 mm diameter Millipore filters at a flow rate of 1.9 l/min;
- gravimetic measurements of the amount of respirable dust (mg/m^3) with Millipore filters after separation of larger particles with a SKC cyclon;
- counting the number of particles of different sizes with a Rion optical particle counter;
- weighing the settled dust on 0.230 m^2 settling plates;
- measuring the ventilation rate with an Alnor hot wire anemometer in the exhaust air ducts.

Each measurement was carried out over a period of 3-4 days at a constant ventilation rate. Different treatments have been compared to reference values measured before and after the treatments.

Different measures to reduce the generation and concentration of dust have been analysed by using the following properties in the mass balance equation:

- total and respirable dust concentrations;
- settling rate of total dust;
- generation of dust.

Ammonia. Ammonia concentrations were measured with reaction tubes (Kitagawa) and with a Miran 104 infrared spectrophotometer in the following places:

- exhaust air;
- 1.7 m above the floor in the middle of the stable;
- 0.3 m above the floor in the middle of the stable;
- 0.3 m above slatted floor in the middle of the stable.

Ventilation rate was measured with an Alnor hot wire anemometer in the exhaust air ducts. The release of ammonia was calculated as the product of the concentration in the exhaust air and the ventilation rate.

Ventilation effectiveness. The tracer gas sulphur hexafluoride (SF_6) has also been used in a pilot study in order to determine how a pollutant from a concentrated source is spread in a calf stable (Fig. 2) depending on the location of the air outlet but also depending on whether the inlet air velocity is high (slotted inlet) or low (breathing ceiling). The combinations of air inlets and air outlets investigated are described in Table 1.

The tracer gas was injected 1.0 m above the floor in a calf pen. For each combination of air inlets and air outlets, the ventilation rate was varied at at least three different levels. The source of the pollutant was varied between two places, near or far from the air outlet respectively. The concentration of the tracer gas was determined in six different places (in pens without calves) by an infrared spectrophotometer (Miran 104) connected to an automatic air collecting system. Ventilation rate was measured with orifice plates in the exhaust air ducts.

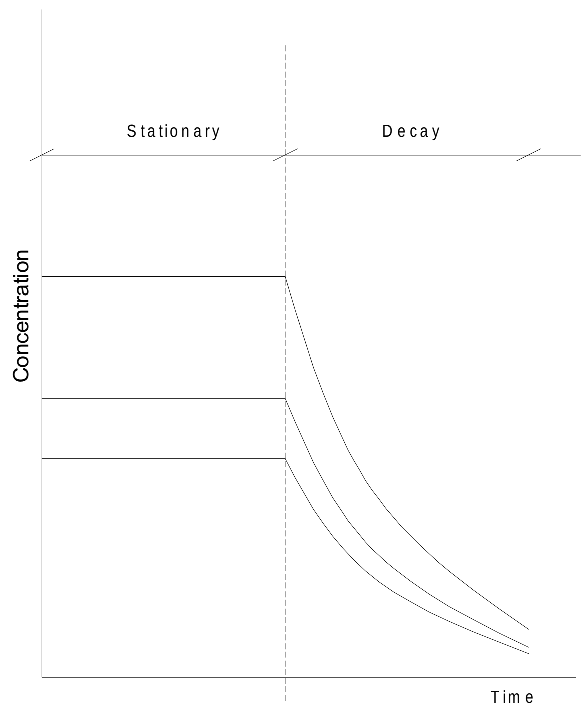

Figure 3. Example of tracer gas concentrations during a trial.

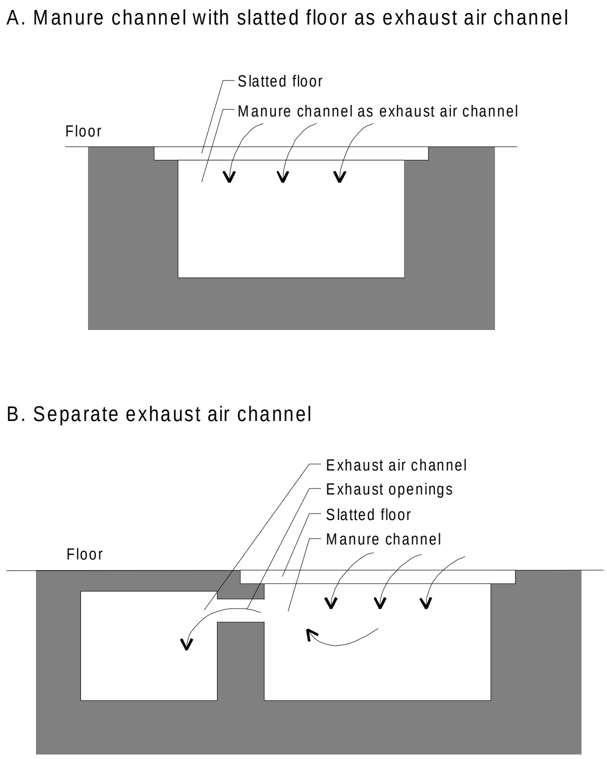

Figure 4. Two investigated principles for manure gas exhaustion.

The function of the ventilation was characterized by the following properties:

- total and local air exchange rates;
- distribution of the concentration along the stable;
- ventilation effectiveness, ε.

These properties have been determined by measuring the concentration of the tracer gas both at stationary conditions (constant release) as well as during the decay after the release of the gas was stopped, which is described in Figure 3. The ventilation effectiveness ε was determined as:

$$\varepsilon = \frac{C_e - C_o}{C_x - C_o}$$

C_e – concentration in the exhaust air
C_o – concentration in the inlet air
C_x – concentration in a specific place

Measures to reduce the concentration of dust

The following methods to reduce the generation and concentration of dust have been investigated in pig houses:

- increased ventilation rate;
- choice of ventilation technique with low mixing properties of the air;
- electrostatic air cleaning;
- ionization of the air;
- dust removal by vacuum cleaning;
- water showering on walking alleys;
- salt spread on walking alleys;
- humidification of the air with different spraying nozzles;
- oil treatment;
- change of housing system.

Ventilation technique. It has not earlier been clarified to what extent the mixing properties of ventilation systems influence the dust conditions. Two ventilation systems with different mixing properties of the air have therefore been investigated, namely:

- high speed air inlet (concentrated recirculating air inlet) in combination with high exhaustion outlet;
- breathing ceiling (low speed) in combination with low exhaustion outlet.

Oil treatment. In our investigations with oil treatment 10% rape seed oil in a water solution was used. The mixture has been applied in two different ways, namely:

- manually spraying directly on the pigs with a knap-sack sprayer;
- automatically, by a spraying system with full cone nozzles parallel to the feeding troughs.

In the first case, the oil mixture was applied once per day during feeding time. The automatic system for spraying oil consisted of two full cone nozzles per pen located parallel to the feeding troughs. The oil mixture was sprayed over the pig’s backs once per day during the feeding of the pigs.

Humidification with different spraying nozzles. Three types of spraying nozzles have been investigated in an automatic spraying system with water, namely:

- high pressure (ultra sound) nozzles;
- flat fan nozzles;
- full cone nozzles.

The nozzles were operated automatically in short sequences in a building with growing - finishing pigs. They were operated twice per hour from 8 a.m. until 6 p.m. and once per hour during the rest of the day.

Methods to reduce the concentration of ammonia

The following methods to reduce the generation and concentration of ammonia were investigated in pig and poultry houses:

- increasing ventilation rate;
- minimising the storage time of the manure inside buildings;
- prevention of air leakage into the building through manure channels;
- exhausting ventilation air through manure channels.

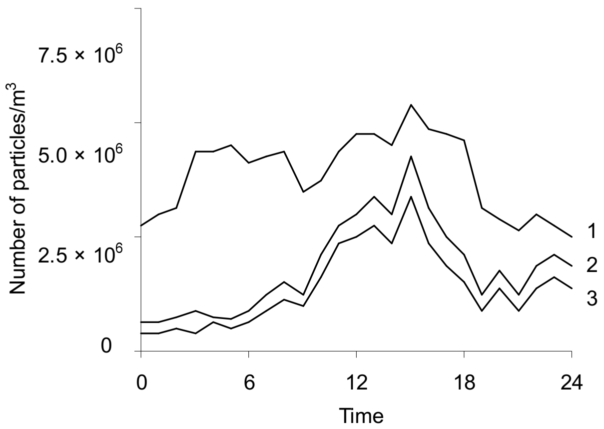

Figure 5. Daily variation in the number of dust particles at constant ventilation rate (75 m^3/pig, h) in a building for growing - finishing pigs. Line 1 – Particle size 0.5–1.0 µm; Line 2 – Particle size 1.0–2.0 µm; Line 3 – Particle size 2.0–5.0 µm.

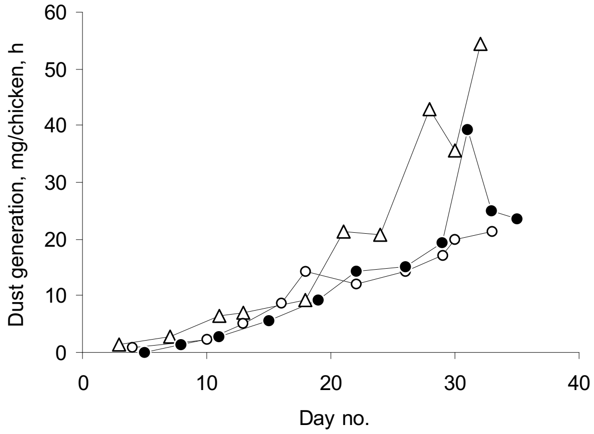

Figure 7. Generation of dust at different ages of chickens, determined during three production batches.

Location and design of air outlets. Three ways of exhaustion of the air were investigated in a pig house:

- high exhaustion (fans in the roof or in the walls);
- manure gas exhaustion through a manure channel covered with slatted floor;
- manure gas exhaustion through an exhaust air duct with openings into the manure channel.

The two investigated principles of manure gas exhaustion are described in Figure 4.

Manuring intervals. The influence of manure storage time on ammonia release has been studied both with laying hens and pigs by varying the manuring intervals.

RESULTS

Dust

Levels. Field studies in buildings for growing - finishing pigs performed in Sweden during the winter showed that the daily average of total dust concentration in the air varied between 1.3 and 6.3 mg/m^3 air.

During chicken production, the daily average has increased gradually during the growing period, with concentrations up to 9.9 mg/m^3 being observed during the last phase of the production period.

Activity. The variation in number of particles of different sizes during a day with constant ventilation rate in a building for growing - finishing pigs is presented in Figure 5. The figure clearly shows an increase in the number of dust particles in daytime when the activity is higher than at night. Similar situations have been observed when raising chickens.

Number and weight of the animals. Our investigations in pig houses have shown that the amount of dust released is proportional both to the number of animals and to their weights (Fig. 6). The release of dust also increases with increasing age of chickens (Fig. 7). This fact indicates that a considerable part of the dust can be generated from the animals themselves.

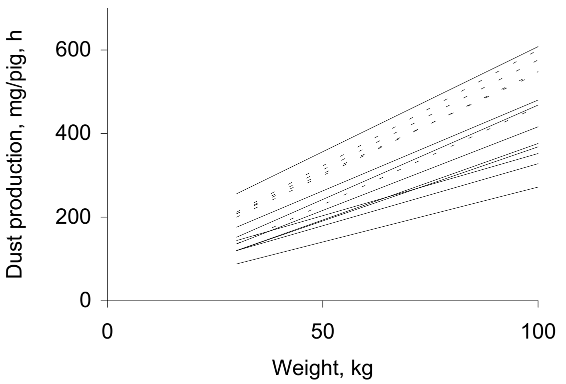

Figure 6. Relationships between the generation of dust and average body weight of growing-finishing pigs, determined by linear regression in 14 production batches.

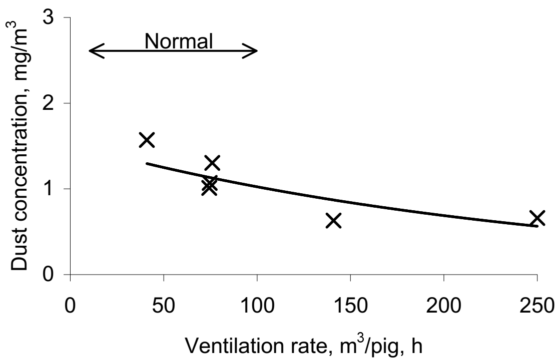

Figure 8. The influence of ventilation rate on total dust concentration in a building for growing-finishing pigs with an average body weight of 67.0 kg.

Settling of dust. Only a minor part of the generated dust is removed by the ventilation air. The major part of the dust settles on different surfaces inside the buildings. It has been found that the settling rate of the dust increases linearly with the concentration in the air both in buildings for pigs and for chickens. The settling rate of dust varies to a large extent between different locations inside the buildings. However, it has also been found that the variations of the settling rate follow the same pattern over entire production periods. This fact indicates that the airflow patterns inside the buildings may have an influence on the dust conditions.

Ventilation rate. Increased ventilation rate is often recommended as a method for reducing the concentration of air pollution in buildings. Unfortunately, the ventilation rate has a limited diluting effect on the total mass of dust at those ventilation rates recommended for insulated animal houses in temperate areas. The reason is that the settling of dust on different surfaces is a more important mechanism for removing large dust particles from the air than the ventilation rate. Figure 8 shows the effect of different ventilation rates on total dust concentration in a building for growing - finishing pigs. It should be noted that dilution of the dust by increased ventilation will increase the heating requirement in wintertime in temperate regions. Similar results have also been obtained for laying hens.

Measurements of the number of particles of different sizes in a pig house have indicated that increased ventilation rate mainly reduces the number of particles larger than 1.0 μm and had only a limited effect on the number of particles smaller than 1.0 μm.

Ventilation technique. Results presented in Table 2 show higher dust concentrations with an air inlet with high inlet air velocity (concentrated recirculating inlet) in combination with high exhaustion than with an inlet with low air velocity (breathing ceiling) in combination with low exhaustion. The results indicate that increased air movements from the air inlets may increase the dust concentration. The influence on the respirable fraction of the dust has been statistically significant.

Table 3. The influence of air cleaning on total dust concentration.

Trial no.	Total dust concentration			Airflow, air cleaner m^3/pig, h	Ventilation rate, m^3/pig, h
	Air cleaner mg/m^3	Reference mg/m^3	Difference %		
1	0.94	1.24	- 24	17.3	12.4
2	0.92	1.28	- 28	10.3	31.9
3	1.39	1.77	- 21	10.3	46.2
4	1.21	1.45	-17	17.2	46.2
5	1.60	1.74	-8	11.6	36.4
6	1.09	1.41	- 23	11.6	53.0

Air cleaning. The effectiveness of air cleaning devices on dust concentration is dependent not only on the airflow through the device but also on the ventilation rate in the building. The reduction in dust concentration has therefore been determined at different airflow rates through an electrostatic air cleaner and also at different ventilation rates in a pig house. The use of the air cleaner had minor influence (Tab. 3) on the dust concentration in the air although it was proved that the equipment removed a large fraction of the particles from the air which had passed through it. Considering the mass balance of the dust it is obvious that air cleaning equipments need large airflow capacities if the dust concentration in the air is to be affected (Tab. 3). The airflow through an air cleaner has the same influence on the dust concentration as an equally large increase in ventilation rate in the building.

Ionization of the air. Our investigations with ionization devices have not proved to have had any significant effect on the dust concentration (weight basis) in the air.

Removal of dust with vacuum cleaners. The use of a vacuum cleaner designed for industrial purposes, as well as a central vacuum cleaning system, were investigated in a pig house. Both devices were used to clean floor surfaces as well as other surfaces, such as pipes, etc. at different cleaning intervals. Although most surfaces

Table 2. The influence of ventilation techniques on dust generation and concentration.

Parameter	Concentrated recirculating inlet + high exhaustion			Breathing ceiling + low exhaustion			Difference	
	n	$\overline{x}$	S.D.	n	$\overline{x}$	S.D.	%	
Total dust concentration, mg/m^3	10	1.29	0.57	7	1.14	0.32	+13	NS
Respirable dust concentration, mg/m^3	6	0.26	0.095	4	0.15	0.061	+77	*
Dust generation mg/pig, h	11	253	104	6	322	116	-21	NS
Ratio of respirable dust, %	6	18.8	3.5	4	14.2	4.8	+32	NS
Exhausted dust, %	9	25.9	7.3	5	21.0	6.0	+23	NS

n – number of measurements; $\overline{x}$ – average; S.D. – standard deviation; N.S. – non-significant difference; * – significant difference $0.05 > p > 0.01$.

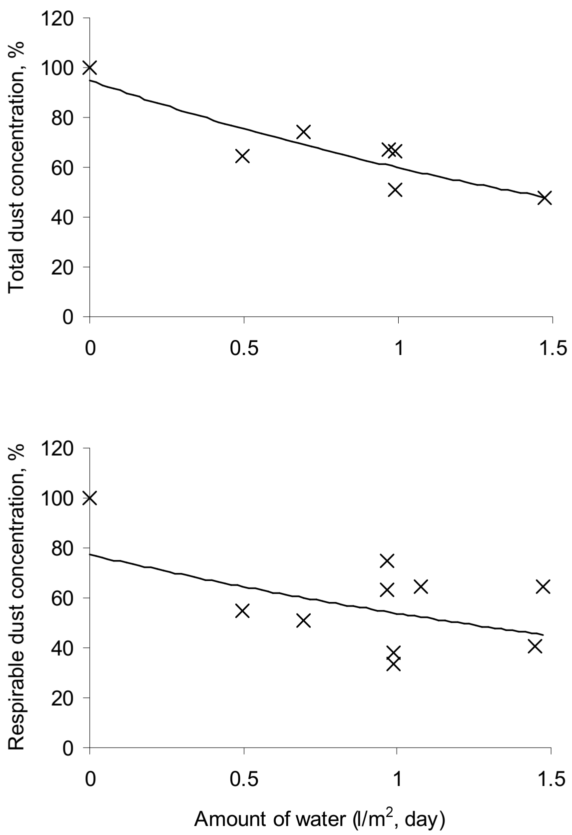

Figure 9. Relative levels of dust concentrations when flat fan nozzles were used (reference level is 100%).

looked cleaner after the treatments no significant effect could be measured regarding total and respirable dust concentrations, settling rate or generation of dust.

Water showering on walking alleys. Water showering of floor surfaces in walking alleys has resulted in minor reductions of the total dust concentration (on average 9% reduction) as well as of dust generation (9% reduction). However, it should be noted that these changes were not statistically significant.

Table 4. Relative levels (%) when a rape seed oil mixture was sprayed manually directly on the pigs compared to values received at no treatment (reference level which is set to 100%).

Trial no.	Total dust concentration	Respirable dust concentration	Settling rate	Dust generation
1	4	9	87	50
2	5	4	75	48
3	*	51	38	61

* Failure in measurements

Salt spread on walking alleys. Spraying a salt solution (KCl) on walking alleys did not result in any significant changes in dust conditions. However, in one trial, when a salt solution was sprayed in the air with spraying nozzles, the total dust concentration was reduced by 41%.

Humidification with water droplets. Spraying water droplets gave different results depending on the type of nozzles used. The use of high pressure nozzles (ultrasound nozzles) which created droplets in the size range of 5–10 μm resulted in a significant increase of both total and respirable dust concentrations during nine comparative trials. The reason for the increased dust concentrations was probably an ultrasound (frequency 30 kHz) created by the nozzles. This sound was not heard by humans. However, observations of the pigs clearly showed that the pigs reacted in an abnormal way the first times the nozzles were in operation. The increased dust concentrations may only be explained by an increased activity of the pigs due to the ultrasound.

The use of flat fan nozzles operated at a pressure of 0.35 MPa resulted in a reduction in both total and

Table 5. Results from trials with different housing systems.

Property	Trial	Conventional housing system			Housing system with strawbedding			Δ
		n	$\bar{x}$	S.D.	n	$\bar{x}$	S.D.	
Total dust concentration mg/m^3	1	10	1.26	0.57	15	0.19	0.06	-75***
	2	17	1.91	0.82	11	0.91	0.22	-52***
	3	14	1.00	0.40	14	0.39	0.10	-61***
	4	17	0.787	0.35	7	0.62	0.41	-21 NS
	5	23	1.37	0.59	23	0.45	0.15	-67***
Respirable concentration mg/m^3	2	5	0.30	0.23	10	0.096	0.087	-68*
	3	11	0.09	0.05	13	0.034	0.036	-62**
	4	16	0.14	0.07	6	0.215	0.146	+53 NS
	5	23	0.15	0.06	7	0.059	0.015	-61***

n – number of measurements; $\bar{x}$ – average; S.D. – standard deviation; Δ – difference (%); NS – non-significant difference; *–*** – significant difference: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

respirable dust concentrations, see Figure 9. In these trials, each pen was equipped with four (horizontal spraying direction) flat fan nozzles in combination with a full cone nozzle (orientated downwards).

The use of full cone nozzles operated at 0.3 MPa pressure also reduced both total and respirable dust concentrations. The settling rate and the generation of dust were also affected, see Figure 10. The effectiveness was improved with increasing length of the spraying periods.

Oil treatment. The effectiveness of manual spraying of a mixture of rape seed oil and water on pigs is presented in Table 4. The manual treatment affected all the parameters measured.

In order to see if the oil affected the release of dust from the skin, one treatment was carried out outside the building so that no oil should cover any building surfaces. In this treatment the total dust concentration was reduced to 84% of the reference level. The treatment caused a significant reduction of settling rate (63% of the reference level) and generation of dust (72% of the reference level). It can be concluded that the treatment with oil reduces to some extent the generation of dust from the skin and also functions as a dust binding agent on surfaces in the building.

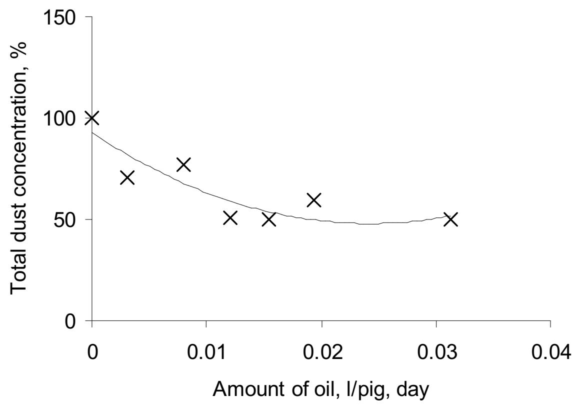

Figure 11. Relative changes in dust concentration when an automatic oil spraying system has been used.

The reduction in total dust concentration with automatic spraying of different amounts of oil and water is presented in Figure 11. The treatments resulted in a considerable reduction in total dust concentration.

Choice of housing system. Five comparative trials between a conventional housing system and a housing

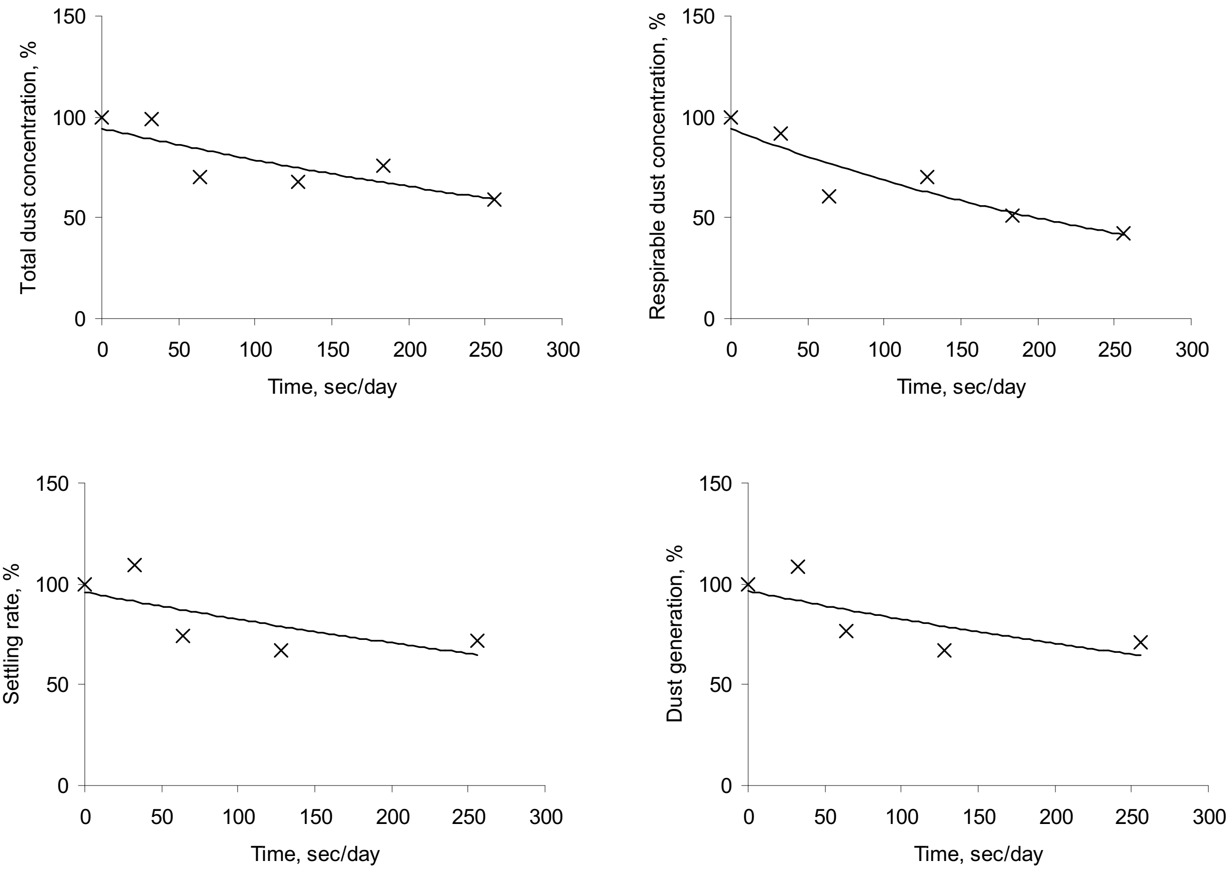

Figure 10. Influence of humidification on total and respirable dust concentrations, settling rate and generation of dust as a function of the spraying period when full cone nozzles were used (reference level is 100%).

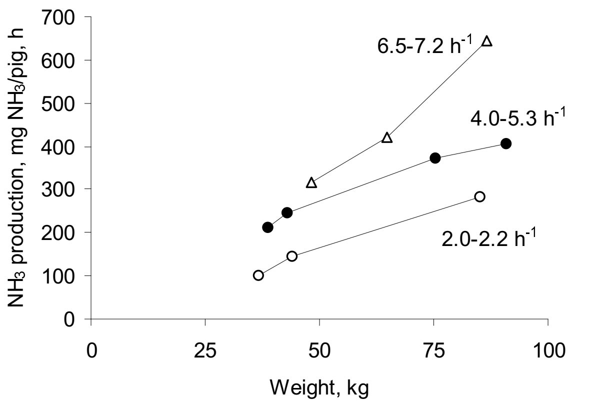

Figure 12. Release of ammonia in a house for 64 growing-finishing pigs in relation to pig weight and air exchange rate after 24 hours manure storage.

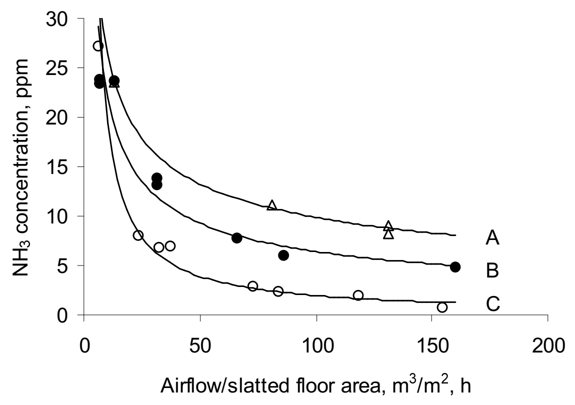

Figure 13. Ammonia concentrations according to airflow rate when the air is exhausted with a fan in the wall (A), exhausted through a separate exhaust air duct (B), and exhausted through the manure channel (C) in a house for growing-finishing pigs.

system with strawbedding for growing-finishing pigs showed that the latter system, in spite of containing much straw, in general creates lower dust concentrations (Tab. 5). An explanation for this may be that the bedding contains much moisture.

Ammonia

Levels. The concentration of ammonia in livestock buildings is normally highest during winter conditions. This is due to the low ventilation rates which normally occur in winter time because of increased heat losses from the buildings. Field studies carried out in houses for growing-finishing pigs in the northern part of Sweden when outside temperature varied between -18 and -1°C showed that the ammonia concentration ranged between 10 and 45 ppm at 1.5 m above the floor. In farrowing houses the concentration ranged between 5 and 25 ppm. Significantly higher concentrations were observed at the level of manure surfaces.

In chicken production, the ammonia concentration in the indoor air at the end of the growing period varied between 14 and 69 ppm. The concentration of ammonia generally remained low during the first two weeks of the growing period, but thereafter increased rapidly.

Number and size of animals. It has been observed in our investigations that the amount of ammonia released into the air in pig houses will increase with the body weight and number of the pigs (Fig. 12). The reason is probably an increasing amount and exposure of manure in the building with the increasing number and weight of pigs.

Ventilation rate. Investigations with different ventilation rates for growing-finishing pigs also showed that the generation of ammonia increased with increasing ventilation rate (Fig. 12).

Prevention of air leakages in manure channels. Unfortunately, air leakages through manure channels into livestock buildings are all too common in buildings with exhaust ventilation systems (under pressure). Any opening in the building envelope will function as an air inlet. Our field investigations in pig houses in northern Sweden showed that air leaked in the manure channels between compartments in buildings and in channels leading to the outside storages. Such leaks were found in 54% of the pig houses studied. Elevated ammonia concentrations were observed when leakages occurred in manure channels. For this reason, prevention of air leakages in manure channels is the first requirement if high ammonia concentrations are to be avoided. Effective sealing mechanisms in the manure channels are necessary.

Design and location of air inlets. Our investigations have also shown that the design and location of air inlets can affect air velocities around surfaces exposed to faeces and urine and thereby will also affect the release of ammonia. Air inlets should therefore be designed and located in such a way that they minimise air velocities on these surfaces.

Design and location of air outlets. The concentration of ammonia 0.3 m above the slatted floor in a house for growing-finishing pigs is presented in Figure 13 for three investigated outlets (Fig. 4) at different airflow rates in the building. The high exhaustion outlet created the highest concentrations of ammonia. The lowest concentrations were found when exhaustion of the air was directly through the manure channel. This result is somewhat surprising as the best result was expected from the exhaust air duct connected to the manure channel. The probable explanation is that the manure channel in this investigation was short (13.8 m) and fairly deep (1.2 m) which made it function well. For longer and more shallow channels, a separate exhaust air duct should give the best result.

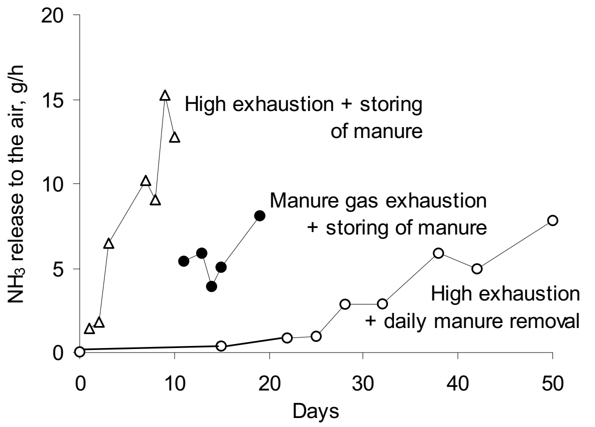

Figure 14. The influence of manure storage time on conveyors on ammonia release in an aviary system for laying hens when ventilation air is exhausted at roof level (high exhaustion) and when the air is exhausted through an air duct close to manure conveyors (manure gas exhaustion).

Exposed surfaces and manure storage time. Investigations in a pig building with a slatted floor showed that ammonia concentration increases only when the length of time between removals of manure was longer than 24 hours. In our investigations, shorter manuring intervals did not result in any further improvement. Even if the amount of manure in the building is kept to a minimum, there will still be a release of ammonia from urine and faeces on the floor. Consequently, manure removal once or twice per day seems to be sufficient to prevent increases in the concentration and release of ammonia in pig houses.

Our investigations on the production of chickens kept on litter have also shown that release of ammonia increases at increasing amount of manure stored in the litter.

Our studies carried out with an aviary system for laying hens at JBT showed a strong influence of the amount of manure stored on conveyors (manure belts) on ammonia release (Fig. 14). It is therefore recommended that manure collected on conveyors should be removed every day.

Ventilation effectiveness. Tracer gas (sulphur hexafluoride) measurements carried out in a calf stable (Fig. 2) indicated that the location of a concentrated source of a pollutant, and also the function and location of air inlets and outlets (Tab. 1), have a strong influence on the spreading and concentration of the pollutant in the air.

The local air exchange rates in different locations differed less than 20% from the average of the total air exchange rate in the stable, independent of ventilation rate and type of air inlets. Exhaustion through manure channels resulted in lower local air exchange rates in the pens compared to high exhaustion for both types of air inlets. Supply of inlet air at low speed through a breathing ceiling resulted in local air exchange rates as high as when inlet air was supplied with high speed air inlets (slotted air inlets).

Exhaustion of outlet air through manure channels decreased the concentration of the tracer gas remarkably. This led to a high ventilation effectiveness in the entire part of the stable (Fig. 15), particularly when the inlet air was supplied with a breathing ceiling.

The location of the source of the pollutant also has a strong influence on both concentration and ventilation effectiveness. The highest ventilation effectiveness was reached when the gas was released near the air outlet.

DISCUSSION AND CONCLUSIONS

Investigations of the mass balance of dust have shown that the generation of dust is proportional to the number of animals, but is also affected by the weight of pigs and chickens. Another factor which has a strong influence on the concentration of dust is the activity in the buildings [15, 21, 22]. Dust concentrations are higher during the day than at night. A major part of the generated dust settles on different surfaces inside the buildings. An increased ventilation rate has a limited effect on the concentration of dust due to the importance of the settling of the dust.

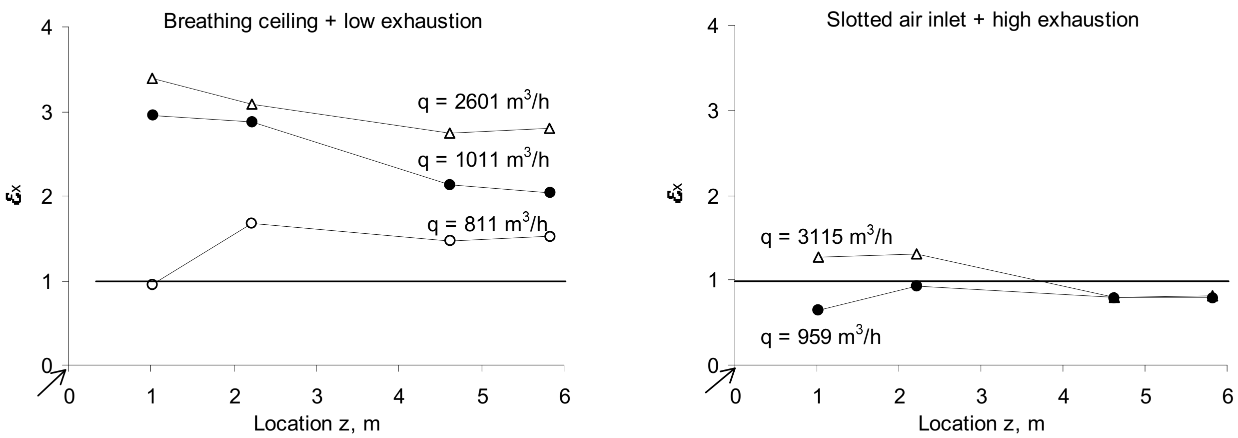

Figure 15. Ventilation effectiveness (ε_x) at different distances from the injection point of an air pollutant (z, m) at two combinations of air inlets and air outlets. The pollutant is released at the arrow. q = ventilation rate, m^3/h.

Dust reducing measures such as electrostatic air cleaning, removal of dust with vacuum cleaners, and ionization of the air, have not resulted in any considerable reduction of the dust concentration. Automatic spraying of small droplets of water has reduced the dust concentration with two types of spraying nozzles. With another type of nozzle the generation of dust in a pig house was increased due to an emitted ultrasound which enhanced an activity of pigs. Spraying with a mixture of rape seed oil has been effective both with manual and automatic system. The oil seems to have a decreasing effect on the generation of dust from the skin of pigs, and also to function as an agent binding settled dust.

Investigations of ammonia in livestock buildings have verified that air leakage, location of air inlets and outlets, stocking rate of the animals, airflow rate and time intervals between manuring will affect the release and concentration of ammonia. The easiest way to reduce the concentration of ammonia in livestock buildings is to prevent air leakage through manure channels and to exhaust as much air as possible through the manure channels. Depending on the type of manure system, air leakages may be eliminated by using tight-fitting hatches, a water trap or evacuation fans in the manure channels (Fig. 1). Where there are separate urine drains, they should also be provided with water locks or evacuation fans.

In the case of manure gas exhaustion through slatted floors, the concentration of ammonia in the building will depend on the possibility of preventing air from penetrating up through the floors. The suction stability is strongly affected by the airflow through the floor. The slots were 20% of the slatted floor area in our study. The investigations showed that a steady pressure drop through the slots is necessary if the air is to be exhausted evenly all over the slatted floor. This pressure drop depends on the air velocity through the slots. Airflows higher than 65 m^3/m^2, h through the slatted floor created a steady suction effect through the slots when the manure channel was used as an air duct. This airflow corresponds to a theoretical air velocity of 0.09 m/s through the slots. Earlier Swedish investigations [25] have suggested a minimum air velocity of 0.2 m/s through the slots for a steady suction effect. The difference can be explained by manure choking the slots in our investigations. Pressure measurements showed an increase in pressure drop in the slots which corresponded to a 50% decrease of air space in the slots.

It should also be stressed that a significant difference in ammonia concentration between high exhaustion and manure gas exhaustion was measured at lower airflow rates, 29 m^3/m^2 h.

Although the concentration of ammonia in the air will decrease with manure gas exhaustion it will increase the emission to the outside because of increased air changes and air movements in the manure channels. To avoid an increase of the emission to the outside atmosphere it is necessary to restrict the maximum airflow through the channels. Measurements at JBT have shown that it is possible to exhaust 30–40% of the maximum ventilation requirement through the manure channels in pig houses without any increase in ammonia emission compared with high exhaustion.

If possible, manure should be removed from livestock buildings at least once per day in solid manure systems.

Tracer gas measurements carried out in a calf stable have indicated that the location of a concentrated source of a pollutant, and also the function and location of air inlets and outlets, have strong influence on the spreading and concentration of pollutants in the air.

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